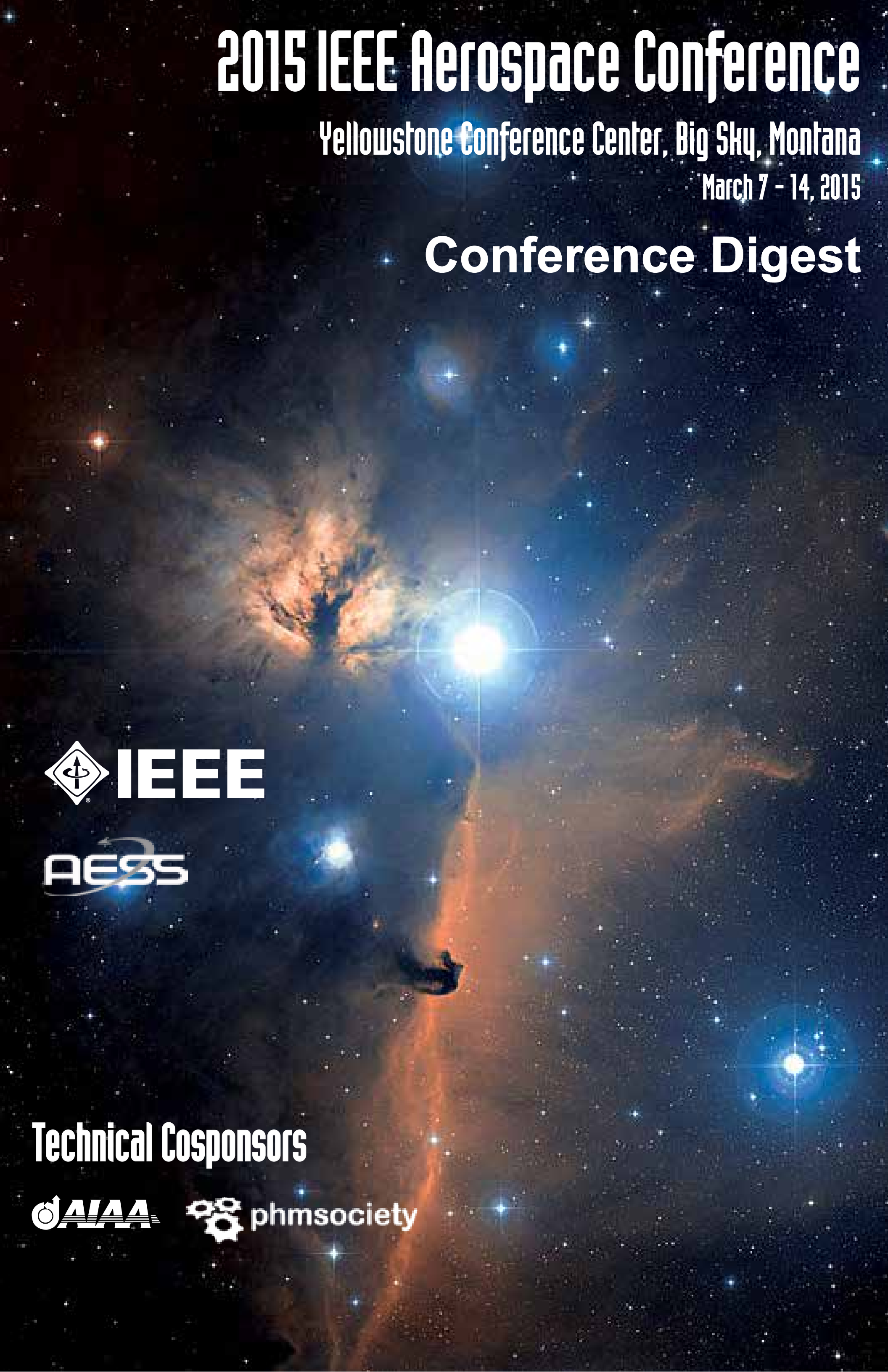

2015 IEEE Aerospace Conference

Yellowstone Conference Center, Big Sky, Montana

March 7 - 14, 2015

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2.0101 ICON: Where Earth's Weather Meets Space Weather

Kodi Rider (University of California, Berkeley), Thomas Immel (University of California Berkeley), William Craig (University of California Space Sciences Laboratory), Ellen Taylor (DesignNet Engineering),

Presentation: Kodi Rider, Sunday, March 8th, 04:30 PM, Gallatin

ICON is a NASA Heliophysics Explorer Mission designed to study the ionosphere, the boundary between Earth and space. This region, where ionized plasma and neutral gas collide and react, exhibits dramatic variability that affects space-based technological systems like GPS. The ionosphere has long been known to respond to space weather drivers from the sun, but recent NASA missions have shown this variability often occurs in concert with weather on our planet. The overall mission design and architecture of ICON, system design trades that have occurred through phase B of development, and challenges unique to the ICON mission are discussed. Set to launch in June 2017, ICON will perform a two-year mission to observe conditions in both the thermosphere and ionosphere. ICON's science objectives are to: 1) understand the source of strong ionospheric variability, 2) the transfer of energy and momentum from our atmosphere into space, and 3) how solar wind and magnetospheric effects modify the internally-driven atmosphere-space system. ICON will accomplish these 3 science objectives using a suite of 4 instruments mounted to a composite deck aboard an Orbital Sciences Corporation LEOstar-2 spacecraft bus.

2.0102 Incorporation of Secondary Payloads onto the Green Propellant Infusion Mission (GPIM)

William Deininger (Ball Aerospace), Victoria Moler (Ball Aerospace & Technologies Corp.), Christopher Mclean (Ball Aerospace),

Presentation: William Deininger, Sunday, March 8th, 04:55 PM, Gallatin

The Green Propellant Infusion Mission (GPIM) Project is sponsored by the NASA Space Technology Mission Directorate (STMD) as part of the work conducted by the Technology Demonstration Mission (TDM) Office. The goal of GPIM is to advance the technology readiness level (TRL) of a green propulsion technology based on the monopropellant AF-M315E via flight demonstration. As the Project lead, Ball is coordinating contributions from industry, NASA, and the U.S. Air Force to execute the GPIM project. In May 2014, the GPIM Project was authorized to integrate three Air Force Science Experiments Review Board (SERB) secondary pay-loads onto the GPIM space vehicle: iMESA-R, SWATS and SOS. This paper summarizes the flexibility of the BCP-100 spacecraft and describes the work to accommodate the three Air Force SERB payloads. The GPIM space vehicle consists of a GPPS Module mounted on a BCP-100 bus module with the three SERB payloads mounted to a bus side panel.

2.0103 NI-SAR S/C Concept Overview: Design Challenges for a Proposed Flagship Dual-frequency SAR Mission

Peter Xaypraseuth (Jet Propulsion Laboratory), Satish Ramanna (ISRO Satellite Centre), Alok Chatterjee (JPL/Caltech),

Presentation: Peter Xaypraseuth, Sunday, March 8th, 09:00 PM, Gallatin

NISAR will be the inaugural, large-scale collaboration between NASA and ISRO on an Earth Science mission and features a dual-frequency (L- and S-band) radar payload. The presentation will describe some of the challenges with the design of the spacecraft subsystems, the JPL/NASA-provided engineering payload (which includes a Solid-state Recorder, GPS Payload, Payload Communication Subsystem, Power Distribution Unit and Payload Data Subsystem), and launch vehicle to meet the requirements of the NISAR mission.

2.0104 Europa Clipper Mission: The Habitability of an Icy Moon

Todd Bayer (NASA Jet Propulsion Lab), Karen Kirby (JHU-APL), Brian Cooke (Jet Propulsion Laboratory),

Presentation: Todd Bayer, Sunday, March 8th, 05:20 PM, Gallatin

Europa, the fourth largest moon of Jupiter, is believed to be one of the best places in the solar system to look for extant life beyond Earth. “Because of this ocean’s potential suitability for life, Europa is one of the most important targets in all of planetary science” (2011 Planetary Decadal Survey). The proposed Europa Clipper mission would investigate Europa's habitability by characterizing the three “ingredients” for life as we know it: liquid water, chemistry, and energy. Europa Clipper would consist of a spacecraft equipped with a payload of NASA-selected scientific instruments, to execute numerous flybys of Europa while in Jupiter orbit. A key challenge is that the flight system must survive and operate in the intense Jovian radiation environment, which is especially harsh at Europa. The innovative design of this multiple-flyby tour is an enabling feature of this mission: by minimizing the time spent in the radiation environment the spacecraft complexity and cost has been significantly reduced compared to previous mission concepts. The spacecraft would launch from Kennedy Space Center (KSC), on a NASA supplied launch vehicle, no earlier than 2022. The proposed mission would be formulated and implemented by a joint Jet Propulsion Laboratory (JPL) and Applied Physics Laboratory (APL) Project team.

2.0105 The Juno Mission to Jupiter: Lessons from Cruise and Plans for Orbital Operations and Science Return

Stuart Stephens (Jet Propulsion Laboratory),

Presentation: Stuart Stephens, Sunday, March 8th, 09:25 PM, Gallatin

Juno is a NASA New Frontiers mission to Jupiter. It will enter a polar orbit in July 2016 with 9 instruments to study Jupiter’s atmospheric composition and structure, magnetic and gravity fields, and polar magnetosphere. Juno's goal is to understand the origin and evolution of Jupiter, thereby shedding light on the formation of the Earth and other planets. Its science objectives are satisfied with 30 orbits, a spin-stabilized solar powered spacecraft with radiation shielding, and a unique payload including microwave receivers, X- and Ka-band gravity science hardware, magnetometers, low- and high-energy particle detectors, and UV and IR spectroscopic imagers. Observations are made in two primary orientations, one for gravity science (main antenna pointing to Earth), and the other for microwave atmospheric sounding (nadir pointing in spin plane). Primary science data are collected within 3 hours of closest approach, although calibrations, occasional remote sensing, and magnetospheric observations are planned throughout the orbits. Since launch in August 2011, Juno has exercised its instruments with occasional checkouts, periodic maintenance, compatibility tests, and an Earth Flyby in October 2013. This paper discusses lessons learned from using the instruments and from challenges faced due to anomalies, with an emphasis on applications to orbital operations. It also focuses on mission plan details for the science orbits as well as on key work and remaining decisions, including recent evaluation of trajectory alternatives for the initial

large capture orbit and primary science orbits, and preliminary development of a tactical playbook to facilitate contingency response during the orbital mission.

2.0106 New Horizons Hibernation Operations: It Takes a Lot of Work to Sleep

Sarah Hamilton ,
Presentation: Sarah Hamilton, Sunday, March 8th, 09:50 PM, Gallatin

The New Horizons Mission was launched in January 2006 towards a flyby of Pluto in July 2015 and possible extended mission to fly by a yet-to-be-identified Kuiper Belt Object. Following a gravity assist flyby of Jupiter in early 2007, the eight year cruise phase operations baseline was defined to include long periods of hibernation, punctuated by Annual Check Outs for the subsystems and payload. Interspersed between these checkouts were precession periods needed to maintain communications with the spacecraft. As the final Annual Check Out prior to the flyby comes to a close in August 2014, hibernations operations have reached maturity. This paper briefly describes the current conduct of New Horizons hibernation operations from the perspective of Mission Planning and Scheduling: setting the hibernation period; computing the spin axis orientation during hibernation to maintain communications; specification of the spacecraft hibernation state; hibernation entry activities; activities during hibernation, including beacon and telemetry communications; and hibernation exit activities. The paper concludes with examples of the hibernation challenges met so far and some that are anticipated as the New Horizons Mission continues beyond Pluto.

2.0107 Ensuring Cassini's End-of-Mission Propellant Margins

Erick Sturm (Jet Propulsion Laboratory), Todd Barber , Duane Roth (Jet Propulsion Laboratory),
Presentation: Erick Sturm, Monday, March 9th, 08:30 AM, Gallatin

The Cassini spacecraft is in its final years. On September 15, 2017, Cassini will plunge deep into Saturn's atmosphere never to reemerge; thus concluding its second extended mission and 13 years in orbit around the ringed planet. As of October 2014, the spacecraft is four years in to its seven-year, second extended mission, the Cassini Solstice Mission (CSM). With three years left and only 2.5% of its loaded bipropellant and 37% of its loaded monopropellant remaining, the Cassini project actively manages the predicted end-of-mission propellant margins to maintain a high confidence in the spacecraft's ability to complete the CSM as designed. Accurate spacecraft navigation, rigorous remaining-propellant estimation, and frequent future propellant consumption prediction have resulted in efficient propellant use and a probability of sufficient propellant margin greater than 99%.

2.0108 The First Earth Venture Mission: How CYGNSS Is Using Engineering Models to Validate the Design

James Wells (NASA - Langley Research Center), John Scherrer (Southwest Research Institute),
Presentation: James Wells, Monday, March 9th, 08:55 AM, Gallatin

The first orbital mission chosen for the competitively selected, cost and schedule constrained, Principal Investigator-led Earth Venture opportunity is the CYclone Global Navigation Satellite System (CYGNSS). The CYGNSS mission is comprised of eight Low Earth Observing microsatellites that use GPS bi-static scatterometry to measure ocean surface winds. As specified in the selecting Announcement of Opportunity, the Principal Investigator for CYGNSS is held responsible for successfully achieving the science objectives of the selected mission and the management approach that he chooses to obtain those results has a significant amount of freedom as long as it meets the intent of key NASA guidance. One foundational tenant of the Class D approach chosen by CYGNSS was to maximize the use of off-the-shelf components and then offset this higher mission risk posture by early and thorough testing of multiple Engineering

Models. This not only tested hardware and software but it allowed for exercising of Assembly, Integration, and Test (AI&T) processes and procedures before ever building the flight units. The CYGNSS team is currently in Phase C of the Project Life Cycle. Testing of the Engineering Model (EM), the Structural Thermal Model (STM), and the Radio Frequency Model (RFM) has commenced and a discussion on the purpose and progress made to date of each of these engineering models as well as some associated lessons learned will be presented.

2.0109 The OSIRIS-REx Asteroid Sample Return Mission

Edward Beshore (University of Arizona), Dante Lauretta (University of Arizona), William Boynton (University of Arizona), David Everett (NASA - Goddard Space Flight Center), Ronald Mink (NASA Goddard Space Flight Center), Michael Moreau (NASA GSFC), Christopher Shinohara (University of Arizona), Jason Dworkin (NASA - Goddard Space Flight Center), Brian Sutter (Lockheed Martin Astronautics),

Presentation: Edward Beshore, Monday, March 9th, 09:20 AM, Gallatin

In September of 2016, the OSIRIS-REx (Origins, Spectral Interpretation, Resource Identification, Security, REgolith eXplorer) spacecraft will depart for asteroid (101955) Bennu. After arriving in the vicinity of the asteroid in the fall of 2018, it will undertake a program of observations designed to select a site suitable for retrieving a sample that will be returned to the Earth in 2023. The third mission in NASA's New Frontiers program, OSIRIS-REx will obtain a minimum of 60 grams of Bennu's surface, the largest sample of extra-terrestrial material returned to the Earth since the end of the Apollo lunar missions. The scientific rationale and mission plan will be presented, along with a description of the spacecraft and instruments, the ground system for processing observations, and some of the technological developments needed to to help ensure mission success.

2.0110 The CYGNSS Flight Segment; Mainstream Science on a Micro-Budget

Randall Rose (Southwest Research Institute), Christopher Ruf (University of Michigan), John Scherrer (Southwest Research Institute), James Wells (NASA - Langley Research Center),

Presentation: John Scherrer, Monday, March 9th, 09:45 AM, Gallatin

NASA's most recently awarded Earth science mission, the NASA EVM-1 Cyclone Global Navigation Satellite System (CYGNSS) mission is designed to provide data that will enable the study the relationship between ocean surface properties, moist atmospheric thermodynamics, radiation and convective dynamics. These relationships are postulated to be intrinsic to the genesis and intensification of tropic storms. Key information about the ocean surface under and around a tropic storm is hidden from existing space borne observatories because of the frequency band in which they operate. Using GNSS-based bi-static scatterometry performed by a constellation of micro-satellites offers remote sensing of ocean wave and wind with unprecedented temporal resolution and spatial coverage across the full dynamic range of ocean wind speeds in all precipitating conditions. A better understanding of these relationships and their effects will advance tropical storm intensity and storm surge forecast skill. Investigation of these properties has not been previously possible due to technology and cost limitations. Modeling techniques developed over the past 20 years combined with recent developments in nano-satellite technology and an increased risk posture allowed by NASA has enabled the CYGNSS mission. CYGNSS consists of 8 GPS bi-static radar receivers to be deployed on 8 separate micro-satellites in October 2016. The mission is cost capped at $150M inclusive of launch vehicle. It is being developed as a Category 3 mission with Class D payloads. This paper will present an overview of the CYGNSS flight segment implementation and how our Class D approach allows the development to meet cost constraints.

2.02 Future Space and Earth Science Missions

Session Organizer: Robert Gershman (Jet Propulsion Laboratory), Michael Amato (NASA GSFC), Patricia Beauchamp (Jet Propulsion Laboratory),

2.0201 Detection and Geo-Location of Sferics Onboard Lightning Nano-Satellite (LiNSAT)

Ghulam Jaffer (Institute of Space Technology (IST)),

Presentation: Ghulam Jaffer, Monday, March 9th, 10:35 AM, Gallatin

This paper presents architecture of a lightning detector onboard Lightning Nano-Satellite (LiNSAT) in low earth-orbit (LEO) and results of two terrestrial measurement campaigns to geo-locate and discriminate lightning types in the presence of noise sources. The LiNSAT will be launched with a three-satellite constellation to utilize a Time-of-Arrival technique. Our main scientific objective is to discriminate the discharges of lightning events evaluated by the inherent features and to differentiate cloud discharges from ground discharges that can be used to predict convective storm development. We conducted two measurement campaigns; one for artificial lightning produced in high voltage chambers and the second for natural lightning recorded at urban environments. We focused mainly on the received time series including noisy features and narrowband carriers to extract characteristic parameters. One of the major challenges of using a nano-satellite for such a scientific payload is to integrate the lightning experiment antenna, receiver and data acquisition unit into the small nanosatellite structure. The optimization in this mission is to use one of the lightning antennae integrated into the gravity gradient boom that increases the sensitivity and directional capability of the satellite toward the nadir direction. The lightning detector onboard has to perform tasks like determination of pulse-width, pulse-count, pulse rise/ fall time etc. The model will work in experimental modes for the detection of lightning events by employing preset criteria. After successful detection of lightning transients, the dumped data will be post-processed on the ground to whiten, de-chirp and classify signals in time and frequency domains.

2.0202 Monitoring Earth's Shortwave Reflectance: LEO and GEO System Architectures

Michael Mercury , Brian Drouin (Jet Propulsion Laboratory), Emily Brageot (Jet Propulsion Laboratory), Richard Beatty (Jet Propulsion Laboratory), Robert Green (Jet Propulsion Laboratory), Riley Duren (Jet Propulsion Laboratory),

Presentation: Michael Mercury, Monday, March 9th, 11:00 AM, Gallatin

Monitoring the Earth’s shortwave reflectance with persistent, sub-diurnal, cloud-resolved sampling would improve understanding of key climate system processes and track geo-engineering efforts. Current measurement systems do not provide the spatial, spectral or temporal sampling to distinguish between natural variability and anthropogenic modification, so this paper presents Low Earth Orbit (LEO) and Geosynchronous Earth Orbit (GEO) system architectures that would provide these monitoring capabilities. The LEO system concept would be a constellation of sixteen microsatellites in four orbit planes with a miniature push-broom Dyson spectrometer providing a 709 km swath. The satellite would be a Boeing microsat that builds on heritage of recent Boeing Space Environmental NanoSat Experiment (SENSE) mission. The GEO system concept would be a scanning Offner spectrometer on a constellation of six satellites launched from a single EELV class launch vehicle. Both systems would provide a two hour revisit, globally, at 1 km spatial resolution and 10 nm spectral resolution between 380 nm and 2510 nm.

2.0203 The Earth Photosynthesis Imaging Constellation: Measuring Photosynthesis with a CubeSat Platform

Adam Greenbaum (The Charles Stark Draper Laboratory), Stefan Slagowski (The Charles Stark Draper Laboratory), Lars Dyrud (Johns Hopkins University/Applied Physics Laboratory),

Presentation: Adam Greenbaum, Monday, March 9th, 11:25 AM, Gallatin

In response to NASA's Earth Venture Instrument-2 call, we proposed the Earth Photosynthesis Imaging Constellation (EPIC) mission. With EPIC, we will, for the first time, be able to provide the scientific community with global, spatially, and temporally explicit estimates of Gross Primary Production (GPP) directly from satellite observations. Understanding the significance of terrestrial GPP for the global carbon, water, and energy balance, as well as its spatiotemporal dynamics is one of the key goals of Earth system science. Our proposed method is based on first principles of plant physiology and radiative transfer theory and has been demonstrated by the science team members in theoretical and experimental research. We expect EPIC to fundamentally change and improve our understanding of global photosynthesis and provide entirely new avenues for modeling and predicting Earth system behavior globally. The EPIC mission consists of four, 3-axis stabilized 6U CubeSats flown in pairs to enable multi-angle measurements. Each EPIC spacecraft hosts an Integrated Vegetation Interferometer Spectrometer (IVIS) instrument. The highly compact IVIS consists of two primary sensors with separate, co-aligned optics: a spatial-heterodyne-spectrometer (IVIS/SHS) and hyperspectral imager (IVIS/HSI). This paper will provide a description of the EPIC mission and science goals, details of the EPIC team, details of the science techniques to be implemented, and demonstrate how the design of the proposed EPIC CubeSat spacecraft and integrated IVIS instrument enable the proposed science at a fraction of the cost of larger systems.

2.0204 COSMIC-2 / FORMOSAT-7: The Future of Global Weather Monitoring and Prediction

Kendra Cook (C2 International, LLC),

Presentation: Kendra Cook, Monday, March 9th, 10:10 AM, Gallatin

COSMIC-2/FORMOSAT-7 is a satellite program designed to deliver next-generation global navigation satellite system (GNSS) radio occultation (RO) data to users around the world. This program is the follow-on to the FORMOSAT-3/COSMIC mission, which was a joint US-Taiwan 6-satellite constellation demonstration mission launched in April 2006. The COSMIC mission was the world's first operational GPS radio occultation (GPS-RO) mission for global weather forecast; climate monitoring; atmospheric, ionospheric, and geodetic research. The GPS-RO data from COSMIC has been extremely valuable to the climate, meteorology, and space weather communities, including real-time forecasting users as well as U.S. and international research communities. This paper provides a brief overview of the COSMIC-2/FORMOSAT-7 Program including the program goals and objectives. It also discusses the status of the various segments of the program including the current satellite design, planned ground system architecture required to meet data latency requirements, launch vehicle development status, and payload development status.

2.03 System and Technologies for Landing on Planets, the Moon, Earth and Small Bodies

Session Organizer: Ian Clark (Jet Propulsion Laboratory),

2.0301 Nano-ADEPT: ADEPT for Secondary Payloads and Nanosat Re-Entry

Brandon Smith (NASA Ames Research Center), Ethiraj Venkatapathy (Space Technology Division, NASA ARC),

Presentation: Brandon Smith, Monday, March 9th, 04:30 PM, Gallatin

This paper describes Nano-ADEPT, a mechanically deployable entry system for small, secondary payloads. Nano-ADEPT uses a mechanical skeleton to deploy a revolutionary carbon fabric system that serves as both heat shield and primary structure during atmospheric entry. This paper explores the application of a Nano-ADEPT entry system for delivery of very small payloads (< 5 kg) to locations of interest in an effort to leverage low-cost platforms to rapidly mature the technology while simultaneously delivering high- value science. It is shown that secondary payload missions to Mars as well as entry from low Earth orbit are feasible. Secondary payload missions to Venus at small scale present a greater challenge and may only be feasible if the system can be designed with exceptionally low mass. The technology maturation strategy for Nano-ADEPT is described. Four test campaigns underway at the time of writing are discussed in detail, including deployment testing, wind tunnel testing, system-level arc jet testing, and a sounding rocket flight test. To conclude, a mission opportunity is described to demonstrate Nano-ADEPT from the International Space Station.

2.0302 Shadow-Based Matching for Precise and Robust Absolute Self-Localization during Lunar Landings

Hannah Kaufmann (German Aerospace Center (DLR)), Martin Lingenauber (German Aerospace Center - DLR),

Presentation: Hannah Kaufmann, Monday, March 9th, 04:55 PM, Gallatin

We present the use of shadows as predictable landmarks for accurate and robust absolute self-localization during lunar landing. Due to the lack of an atmosphere, shadows on the moon are not diffused, which enables easy pre-computation of their appearance. By matching descent images from a landers camera with reference images, rendered from available Digital Elevation Models (DEM), and the known sun position during the landing, we perform an estimation of the position. We first segment the shadows from the image content with adaptive binary thresholding, resulting in a binary shadow image. We have developed an enhanced shadow descriptor to depict a shadow's neighborhood by mapping the constellation of adjacent shadow centroids to a multilayer binary grid. This allows a time efficient and robust matching. Further we present the experiments conducted to test our method with the perturbations expected during the final phase of an actual lunar mission, particularly time and position deviation from the planned trajectory, and their results. With a maximum drift in position and time and at distances to the surface between 4km and 1km, more than 90% of the shadows were matched correctly at shadow abundant landing sites. At a landing site poor in shadows at least 40% correct matches were found at distances to the surface between 36km and 12km. We achieved for both altitude ranges an accuracy of the position estimate about 1% of the distance to surface or better.

2.0303 Resource Prospector Lander: Architecture and Trade Studies

Kristina Rojdev (NASA), Joshua Moore , Greg Chavers (NASA / MSFC), Sharada Vitalpur (NASA - Johnson Space Center),

Presentation: Kristina Rojdev, Monday, March 9th, 05:20 PM, Gallatin

NASA’s Resource Prospector (RP) is a multi-center and multi-institution collaborative project to investigate the polar regions of the Moon in search of volatiles. These volatiles can lead to production of oxygen and propellants, further enabling human exploration, and is a key step in NASA’s roadmap toward the exploration of Mars. The mission is rated Class D and is approximately 10 days. The RP vehicle comprises three elements: the Lander, the Rover, and the Payload. The Payload is housed on the Rover and the Rover is on top of the Lander. The focus of this talk is on a Lander element for the RP vehicle. The design of the Lander was requirements driven and focused on a low-cost approach. To arrive at the final configuration, several trade studies were conducted. Of those trade studies, there were six primary trade studies that were instrumental in determining the final design. These studies were on the following subsystems: the primary structure, communications, power, thermal, propulsion, and avionics. In each of the trade studies, the cost and the mass were primary figures of merit, along with other

figures of merit specific to the trade. This talk will discuss each of these trades in further detail and show how these trades led to the final architecture of the RP Lander.

2.0304 OSIRIS-REx, Returning the Asteroid Sample

Tom Ajluni , David Everett (NASA - Goddard Space Flight Center), Timothy Linn (Lockheed Martin Space Systems Company), Ronald Mink (NASA Goddard Space Flight Center), Joshua Wood (Lockheed Martin),

Presentation: Tom Ajluni, Monday, March 9th, 09:00 PM, Gallatin

This paper addresses the technical aspects of the sample return system for the upcoming Origins, Spectral Interpretation, Resource Identification, and Security-Regolith Explorer (OSIRIS-REx) asteroid sample return mission. The overall mission design and current implementation are presented as an overview to establish a context for the technical description of the reentry and landing segment of the mission. The prime objective of the OSIRIS-REx mission is to sample a primitive, carbonaceous asteroid and to return that sample to Earth in pristine condition for detailed laboratory analysis. Targeting the near-Earth asteroid Bennu, the mission launches in September 2016 with an Earth reentry date of September 24, 2023. OSIRIS-REx will thoroughly characterize asteroid Bennu providing knowledge of the nature of near-Earth asteroids that is fundamental to understanding planet formation and the origin of life. The return to Earth of pristine samples with known geologic context will enable precise analyses that cannot be duplicated by spacecraft-based instruments, revolutionizing our understanding of the early Solar System. Bennu is both the most accessible carbonaceous asteroid and one of the most potentially Earth-hazardous asteroids known. Study of Bennu addresses multiple NASA objectives to understand the origin of the Solar System and the origin of life and will provide a greater understanding of both the hazards and resources in near-Earth space, serving as a precursor to future human missions to asteroids. This paper focuses on the technical aspects of the Sample Return Capsule (SRC) design and concept of operations, including trajectory design and reentry retrieval.

2.0305 Numerical Study of Heat Flux Developed on an Aero-spike Structure in Hypersonic Flow

Navaneeth Soori ,

Presentation: Navaneeth Soori, Monday, March 9th, 09:25 PM, Gallatin

This study has been carried out to understand the flow properties over the aero-spike in detail and to arrive at the best possible configuration that could be put to practical use for missiles and re-entry vehicles. Initial studies were carried out on a blunted cone-flare in hypersonic flow to clearly grasp the flow physics at high Mach numbers. A test model based on Apollo re-entry capsule was designed, with a cylindrical aero-spike attached to its front. Computational analysis was done for this configuration, with the commercially available Fluent CFD software. The initial results found good similarity with the past studies, showing a drag reduction of more than 60% when the aero-spike is attached to the capsule. The dimensions of the aero-spike cylinder were varied uniformly as a function of the radius of the capsule. This showed some interesting results, with the drag decreasing gradually up to a minimum value as the spike radius is increased. The maximum heat flux is developed at the front blunt body of the spike and then varies along the surface of the spike. By adjusting the spike geometry, it is possible to predict the exact heat flux that is developed at different locations on the spike as well as the re-entry capsule. And by knowing the locations at which thermal load is maximum, suitable heat resistant systems can be installed at the critical locations exclusively, leading to a reduction in the over-all operational cost and better safety margins.

2.0306 LDSD Supersonic Flight Dynamics Test 1: Post-flight Reconstruction

Eric Blood (Jet Propulsion Laboratory), Prasad Kutty , Chris Karlgaard (Analytical Mechanics Associates, Inc.), Soumyo Dutta (EASI),

Presentation: Eric Blood, Monday, March 9th, 09:50 PM, Gallatin

The Low Density Supersonic Decelerator project's first Supersonic Flight Dynamics Test (SFDT) occurred on June 28, 2014, off the west coast of Kauai, Hawaii, over the Pacific Ocean. The test vehicle traveled to speeds above Mach 4 and to an altitude of over 200,000 feet. This flight, although classified as a test architecture shake-out flight, tested two technologies: a robotic class Supersonic Inflatable Aerodynamic Decelerator and a Supersonic Disksail Parachute. The reconstruction team was tasked with collecting all relevant pre-flight and flight data to accurately reconstruct the trajectory and technology performance during the science phase of the flight. Furthermore, the reconstruction team has been involved with reconstructing and exploring all aerodynamic and test vehicle properties that affected the entire flight phase. This reconstruction provided insight into the technology performance, which is a key deliverable for the LDSD project, as well as provided insight into lessons learned for subsequent SFDT flights, in the fields of data recovery, reconstruction, and pre-flight trajectory simulations.

2.04 Access to Space and Emerging Mission Capabilities

Session Organizer: David Callen (Scitor Corp), Eleni Sims (Aerospace Corporation),

2.0401 Launch Systems to Support Booming Nanosatellite Industry

Kaitlyn Kelley ,

Presentation: Kaitlyn Kelley, Tuesday, March 10th, 08:30 AM, Gallatin

While the high cost of launch remains an obstacle to space access, particularly for small satellites, clever integration of multiple systems enables launching thirty or more satellites on one vehicle. Spaceflight assists launch vehicle providers by purchasing excess space and leveraging proven technologies to maximize the number of satellites deployed. With new technologies from Innovative Solutions in Space (ISIS) and the design power of Andrews Space, Spaceflight has developed the capacity to launch thirty-five (35) 12U CubeSats into space using one ESPA Grande-derived Spacecraft. This paper presents some of the design trades completed in order to develop the QuadPack plate. With this technology, the era of launching small satellite constellations is here.

2.0402 Implementation of the First Orbital/Sub-orbital Program-3 Mission

Matthew Kanter (Aerospace Corporation), Oba Vincent , Daniel Morgan (TASC),

Presentation: Matthew Kanter, Tuesday, March 10th, 08:55 AM, Gallatin

The Orbital/Suborbital Program (OSP) is in the third manifestation of its contract form known as OSP-3. The OSP-3 contract is managed by the Rocket Systems Launch Program, which is part of the Air Force Space and Missile Systems Center (SMC) and is operated out of Kirtland Air Force Base, New Mexico. OSP-3 is an expansion from OSP- 2 in that it not only continues to utilize excess ICBM motors, but also includes potential Evolved Expendable Launch Vehicle new entrant launch vehicles. The first Task Order awarded on the OSP-3 contract was issued 4 December 2012 for the launch of the Deep Space Climate Observatory (DSCOVR) mission. DSCOVR is a joint effort between NOAA and NASA to provide real-time monitoring and advanced warning of space weather events along with providing earth-sensing data and imagery for environmental research. The DSCOVR mission launched in early February 2015 on an earth escape trajectory to Sun-Earth Lagrange point one (L1). NOAA funded NASA Goddard Spaceflight Center to refurbish the DSCOVR satellite (formally known as Triana) and NOAA will operate the spacecraft once checkouts are complete at the destination. This paper discusses some of the challenges, lessons, and successes encountered during the implementation of the OSP-3 contract for the DSCOVR mission.

2.0403 ULA Rideshare Capabilities for Providing Low-Cost Access to Space

Keith Karuntzos (United Launch Alliance),

Presentation: Keith Karuntzos, Tuesday, March 10th, 11:25 AM, Gallatin

United Launch Alliance (ULA) has a long history of providing launch services to high-value payloads for a variety of customers. The majority of these spacecraft has been launched as primary payloads, and used the full capability of the launch vehicle; yet there is a lower-cost alternative for achieving similar mission objectives: rideshare. Rideshare is the approach of sharing available launch vehicle performance and volume margins with two or more spacecraft that would otherwise go underutilized by the spacecraft community. This allows spacecraft customers the opportunity to get their spacecraft to orbit and beyond in an inexpensive and reliable manner. The ULA family of launch vehicles - the Atlas V, the Delta II, and the Delta IV - all have rideshare capabilities that can be used by the community to launch payloads to orbit for a much lower price than a dedicated single-manifest mission. These capabilities support a wide range of spacecraft sizes, from the smallest Cubesats, to the largest dual-manifest payloads. This presentation will provide a technical overview of current and future rideshare capabilities available, including Delta II P-POD dispensers, the C-Adapter Platform (CAP), the Atlas V Aft Bulkhead Carrier (ABC), the EELV Secondary Payload Adapter (ESPA), the AQUILA, the eXternal Payload Carrier (XPC), and the Dual Spacecraft Systems (DSS-4 and DSS-5). Additionally, programmatic considerations for designing, manifesting, and integrating rideshare missions will be discussed.

2.0404 Secondary Spacecraft in 2015: Analyzing Success and Failure

Michael Swartwout (Saint Louis University),

Presentation: Michael Swartwout, Tuesday, March 10th, 09:45 AM, Gallatin

The recent history of secondary spacecraft will be reviewed, with a particular emphasis on CubeSats. The launch logs will be studied to identify trends in size, mission performance, launch opportunities and mission success. The relative risk of on-orbit collision posed by CubeSats will be reviewed.

2.0405 Mission Case Studies Using the Rideshare Enabling Orbital Maneuvering Vehicle

Marissa Stender (Moog, Inc.), Joseph Maly (Moog CSA), Christopher Loghry (Moog Inc), Chris Pearson (Moog),

Presentation: Marissa Stender, Tuesday, March 10th, 10:10 AM, Gallatin

As rideshare launches become more available within the U.S., secondary payloads are still challenged by the limited choice of orbits and risk-adverse nature of primary payloads to allow for flexibility in the deployment sequence. The result is that a secondary payload’s final orbit is limited by its host and the propulsion capability of the individual spacecraft. Many of these challenges can be met through the use of a propulsive rideshare adapter. The Lunar Crater Observation and Sensing Satellite (LCROSS) mission demonstrated the use of a propulsive EELV Secondary Payload Adapter (ESPA) ring to expand and enhance an existing mission by utilizing the mass margin on a lunar launch. Similar propulsive ESPA technologies can be used as a baseline to provide orbit flexibility and optimization that was previously unattainable for secondary payloads. Multiple case studies were undertaken to demonstrate the utility, value and flexibility of the propulsive ESPA as a mission enabling technology. In each of the scenarios identified, the particular use of a propulsive ESPA ring gives rise to a number of shared launch opportunities that would not have previously been considered and improves the overall access to space for rideshare passengers. Further extrapolating these results shows how a single launch vehicle could be used to deliver three disparate payloads to varying orbits without sacrificing any missions' objectives.

2.0406 Disaggregated Space System Optimization Stochastic Analysis Techniques

Robert Thompson (US Air Force),

Presentation: Robert Thompson, Tuesday, March 10th, 10:35 AM, Gallatin

A methodology for the optimization of disaggregated space systems dubbed Disaggregated Integral System Concept Optimization (DISCO) has previously been proposed. The DISCO methodology was applied to multi-orbit and multi-function/multi-orbit disaggregation problems. The cost risk associated with these architectures is dependent upon stochastic variables such as satellite failure rates, and launch vehicle failure rates. This paper introduces techniques for assessing the impacts of these stochastic variables and parameters on optimized space system conceptual designs. Previous analysis was performed identifying cost effective Disaggregated Weather System Follow-on (DWSF) conceptual architectures. The analysis techniques introduced in this paper are applied to this DWSF space system optimization problem. Conceptual design considerations gleamed from the applied stochastic analysis techniques are then discussed along with the broader implications on small satellite constellation designs and small satellite access to space.

2.0407 Analysis of a 'Turn-Key' No Hardware Space Mission Using the Orbital Services Model

Jeremy Straub (University of North Dakota),

Presentation: Jeremy Straub, Tuesday, March 10th, 11:00 AM, Gallatin

This paper considers the value of a 'turn-key' style space mission. Under this approach, the mission's operator does not require any particular orbital or terrestrial assets. Instead it can procure the use of these assets on an as-needed basis. The orbital services model (OSM) provides a prospective solution to this challenge: a framework for the collaboration between multiple spacecraft. It includes defined mechanisms to define, locate and contract for services that are required. It also can be utilized to coordinate between multiple orbital craft and/or between orbital craft and ground facilities / service providers. This paper explores this concept from several directions. First, it considers what types of missions could be reasonably conducted using this approach. The cost (both in terms of development/fabrication and launch) for various types of sensors, compared to their value, is considered. Second, the economics of being a service provider are considered. Specific consideration is paid to service pricing relative to utilization levels. This is compared to similar ratios for terrestrial service industries. Third, a prospective mission concept for one OSM 'turn-key' mission is presented. The value proposition of this mission is assessed and the hardware and other capabilities required for it are discussed. This is then assessed relative to the provider's cost basis and profit expectations. Forth, a discussion of the economics for orbital service providers is presented, using the prospective mission as an illustrative example. Finally, prospective pathways to OSM 'turn-key' missions becoming a reality are discussed, before concluding.

2.05 Robotic Mobility and Sample Acquisition Systems

Session Organizer: Richard Volpe (Jet Propulsion Laboratory),

2.0502 Layer-Jamming Scales with Hardening Capability

Jessie Santiago (Clemson), Isuru Godage (Clemson University), Ian Walker (Clemson University),

Presentation: Ian Walker, Wednesday, March 11th, 04:30 PM, Madison

Continuum robots, which have continuous mechanical structures comparable to the flexibility in elephant trunks and octopus arms, have been primarily geared toward the medical and defense communities. In space, however, NASA projects these robots to have a place in irregular inspection routines. The inherent compliance and bending of these continuum arms are especially suitable for inspection in obstructed spaces to ensure proper equipment functionality. In this paper, we propose a new solution that improves on the functionality of previous continuum robots, via a novel mechanical scaly layer-jamming design. Layer-jamming assisted continuum arms have previously required pneumatic sources for actuation, which limit their portability and usage in aerospace applications. This paper combines the compliance of continuum arms and stiffness modulation of the layer jamming mechanism to design a new hybrid layer jamming continuum arm. The novel design uses an electromechanical actuation which eliminates the pneumatic actuation therefore making it compact and portable.

2.0503 Development of Simulation System for Multi-pair Crawlered and Transforming Explorer

Akihiko Honda (Tokyo Institute of Technology), Hiroki Kato , Toshimichi Tsumaki ,
Presentation: Akihiko Honda, Wednesday, March 11th, 04:55 PM, Madison

This paper describes a proposition of new rover targeting lunar and planetary exploration and development of simulation system using verification of multi-crawlered and transforming explorers. Firstly, we propose a new type of explorer capable of transforming its configuration and with a multiple pair of crawler mechanisms to improve mobility in extra-rough terrain. Extra-rough terrain is a word express conditions of surface where future exploration missions are requiring to investigate. For example, exploration at lunar lava tube needs a capable of higher climbing performance. Secondly, modeling equations for a multiple pair of crawlers connected to transformable legs are formulated. The application of the model to a conceptual examination and transforming pattern to facilitate mobility over extra-rough terrain is discussed, whereupon physical parameters for a conceptual design model are identified. The results were used by designing a proto type model because proposed mechanisms have a large design freedom. After the discussion, a proto type model of proposed rover was developed. This paper contains properties of the rover which are obtained by initial verification experiment. Finally, the hill-climbing performance was evaluated to assess the effectivity of the proposed explorer and validate the proposed simulation method. An experimental slope which has a capable of changing angle and controlled surface condition was build. Verification was conducted with 30-45[deg] slope and evaluate with simulation results. Simulation results were matched with experimental one and proposed crawler prove its possibility to climb over 45deg hill.

2.0504 Risk-aware Planetary Rover Operation Tool with Autonomous Terrain Classifier and Path Planner

Masahiro Ono (JPL), Thomas Fuchs (Jet Propulsion Laboratory), Mark Maimone (Jet Propulsion Laboratory), Jeng Yen (Jet Propulsion Laboratory),
Presentation: Masahiro Ono, Wednesday, March 11th, 09:00 PM, Madison

Identifying and avoiding terrain hazards (e.g., soft soil and pointy embedded rocks) are crucial for the safety of planetary rovers. This paper presents a newly developed ground-based Mars rover operation tool that mitigates risks from terrain by automatically identifying hazards on the terrain, evaluating their risks, and suggesting operators safe paths options that avoids potential risks while achieving specified goals. The tool will bring benefits to rover operations by reducing operation cost, by reducing cognitive load of rover operators, by preventing human errors, and most importantly, by significantly reducing the risk of the loss of rovers. The risk-aware rover operation tool is built upon two technologies. The first technology is a machine learning-based terrain classification that is capable of identifying potential hazards, such as pointy rocks and soft terrains, from images. The second technology is a risk-aware path planner based on rapidly-exploring random graph (RRG) and A* algorithms, which is capable of avoiding hazards identified by the terrain classifier with explicitly considering wheel placement. We demonstrate the integrated capability of the proposed risk-aware rover operation tool by using the images taken by the Curiosity rover.

2.0505 Realization of Vision-Based Navigation and Object Recognition Algorithms for the SRR Challenge

Velin Dimitrov (Worcester Polytechnic Institute), Mitchell Wills , Taskin Padir ,
Presentation: Velin Dimitrov, Wednesday, March 11th, 09:25 PM, Madison

In this paper we present our work towards more robust and reliable autonomous operation for sample return rovers, with the intent to intelligently integrate the human operator input and intent in future iterations. The work was guided by the 2014 NASA Sample Return Robot Centennial Challenge, and focused on the integration of vision-based navigation and object recognition algorithms into the previously developed Autonomous Exploration Rover (AERO). New training procedures for the cascaded classifiers led to significantly improved detection and tracking performance. In addition, modifications were made to the previous software architecture to speed-up detection and therefore enable detection in situations where the rover is moving. A GPU based implementation was also developed with significant improvements in detection rates in specific situations. AERO also saw improvements in navigation performance, with a completely redesigned navigation architecture based on the best practices suggested in the new ROS control framework. A new high level state machine significantly improved in handling conditions that previously caused navigation faults, and tighter integration between the subsystems in the navigation architecture led to better accuracy. A new method to integrate global information for virtual reality tags was developed and led to improvements in docking back at the starting location. We discuss all of these improvements in detail, and provide insight into our experiences with the algorithms and how they need to be further modified and improved.

2.06 Future Missions & Enabling Technologies for In Situ Exploration, Sample Returns

Session Organizer: Ying Lin (Jet Propulsion Laboratory), Patricia Beauchamp (Jet Propulsion Laboratory),

2.0601 Convex Programming Approach to Real-time Trajectory Optimization for Mars Aerocapture

Sean Swei (NASA Ames Research Center), Jing Zhang , Behcet Acikmese (University of Texas at Austin), Dinesh Prabhu (ERC Inc.),
Presentation: Behcet Acikmese, Tuesday, March 10th, 08:30 AM, Lake/Canyon

This paper is to develop a robust guidance and control (G&C) system and corresponding real-time algorithms for ADEPT (Adaptable Deployable Entry & Placement Technology) planetary entry vehicle for Mars aerocapture mission with large payloads. The convex optimization based guidance approach is proposed that enables the real-time implementation of the algorithm and increases the predictability and robustness of the closed-loop system. The objective of this study is to utilize ADEPT aeroshell as a controllable G&C effector through active bank angle and angle of attack modulation and convex optimization based control methods for planetary entry maneuvers. A Mars aerocapture case study is simulated to demonstrate the feasibility and efficacy of the proposed guidance concept.

2.0602 Integrated System Modelling of Lunar In-Situ Resource Utilization

Samuel Schreiner (Massachusetts Institute of Technology), Jeffrey Hoffman (Massachusetts Institute of Technology), Gerald Sanders (NASA/JSC), Kristopher Lee ,

Presentation: Samuel Schreiner, Tuesday, March 10th, 08:55 AM, Lake/Canyon

The production of oxygen from lunar regolith, a form of In-Situ Resource Utilization (ISRU), is a mission-enabling technology that can break the supply logistics chain from Earth to support sustained, affordable space exploration. We present the development of an integrated ISRU system model to study and optimize the system mass and power requirements, a critical development in understanding the proper application of ISRU systems. The integrated model includes subsystem models for a Molten Regolith Electrolysis (MRE) reactor, an excavator, a hopper and feed system, the power system, and an oxygen liquefaction and storage system. A hybrid genetic-algorithm/gradient-based optimization scheme is implemented to optimize the ISRU system design across a range of production levels. Lower oxygen production levels (<1500 kg/yr) are best managed with a single reactor operating at a traditional temperature of 1900K and a batch time of 2-3 hrs. Larger oxygen production levels are best met with multiple reactors that each produce 2500 kg/yr, operate at 2200K, and have a batch time around 1 hr. It is found that an MRE reactor can generate the entire ISRU system's mass worth of oxygen in as little as 52 days at a rate of 7 kg of oxygen annually per kilogram system mass.

2.0603 Defining the Requirements for the Micro Electric Propulsion Systems for Small Spacecraft Missions

Sara Spangelo (University of Michigan), Thomas Randolph (Jet Propulsion Laboratory), Damon Landau , Shawn Johnson ,

Presentation: Sara Spangelo, Tuesday, March 10th, 09:20 AM, Lake/Canyon

Recent technology advancements in Micro Electric Propulsion (MEP) will enable the next generation of small spacecraft to perform trajectory and attitude maneuvers with significant Delta-□V requirements, provide thrust over long mission durations, and replace reaction wheels for attitude control. These advancements will open up the class of mission architectures achievable by small spacecraft to include formation flying, proximity operations, and precision pointing missions in both LEO and interplanetary destinations. The goal of this study is to establish the optimal performance parameters for future MEP technology that are applicable to a broad range of flight demonstration platforms (e.g. dedicated 3-12U CubeSats to ESPA-class spacecraft), for a variety of applications, including LEO and Earth escape orbit transfers, travel to interplanetary destinations, hover and drag make-up missions, and performing reaction wheel-free attitude control. An integrated systems-level model for propulsion, spacecraft (power, data, telecommunication, thermal management), and orbit and attitude maneuvers is developed to support solution space exploration. MEP system performance parameters are derived that maximize the performance capability subject to realistic system-level constraints in the context of upcoming mission opportunities where MEP is enabling or advantageous relative to other technologies.

2.0604 A Simple Analytic Model for Estimating Mars Ascent Vehicle Mass and Performance

Ryan Woolley (Jet Propulsion Laboratory),

Presentation: Ryan Woolley, Tuesday, March 10th, 09:45 AM, Lake/Canyon

The Mars Ascent Vehicle (MAV) is a crucial component in any sample return campaign. In this paper we present a universal model for a two-stage MAV along with the analytic equations and simple parametric relationships necessary to quickly estimate MAV mass and performance. Ascent trajectories can be modeled as two-burn transfers from the

surface with appropriate loss estimations for finite burns, steering, and drag. Minimizing lift-off mass is achieved by balancing optimized staging and an optimized path-to-orbit. This model allows designers to quickly find optimized solutions and to see the effects of design choices.

2.0605 Thumper and Shotgun: Impactors to Estimate Asteroid Strength for NASA's Asteroid Redirect Mission

Kris Zacny (Honeybee Robotics Spacecraft Mechanisms Corporation), Bryan Yaggi (Honeybee Robotics Spacecraft Mechanisms Corporation), Philip Chu (Honeybee Robotics), Jerome Johnson (University of Alaska), Anton Kulchitsky (University of Alaska Fairbanks), Magnus Hedlund (Honeybee Robotics), Kiel Davis (Honeybee Robotics Spacecraft Mechanisms Corporatio), Brendan Hermalyn (NASA Ames Research Center), Gale Paulsen (Honeybee Robotics), John Abrashkin ,

Presentation: Kris Zacny, Tuesday, March 10th, 10:10 AM, Lake/Canyon

NASA's Asteroid Redirect Mission (ARM) aims to capture and bring back either an entire asteroid (Option A) or a large boulder from the surface of an asteroid (Option B) to a cis-lunar orbit. Options A and B have a range of risks; one of them relates to the unknown strength of the asteroid or boulder. This paper describes methods of estimating asteroid regolith strength and density, and the strength of boulders, using kinetic impactors: Thumpers and Shotgun.

2.0606 High Frequency Vibration and High Gravity Force Shock Testing for Potential Mars Sample Return

Katherine Acord (University of California, Davis),

Presentation: Katherine Acord, Tuesday, March 10th, 10:35 AM, Lake/Canyon

The current concept for a potential Mars Sample Return (MSR) campaign includes a series of missions that could drill, package, and return Mars rock cores to Earth through four sequential flight missions. A combination of structural stability, migration, force, hardware testing and analysis were employed to determine elements within the potential MSR campaign that could alter the mechanical integrity of Mars rock cores during transport to Earth. Therefore, Mars simulant rock cores, such as Bishop Tuff and China Ranch Massive Gypsum, were drilled to create samples for survivability tests to simulate the high frequency vibrations of a Mars Ascent Vehicle (MAV) and high gravity force shock of the Earth Entry Vehicle (EEV) that would be expected during MSR. This research addresses elements such as core orientation, amount of ullage (headspace), and clamshell position to better understand the causes and amount of fracturing throughout these flight-like environments.

2.0607 Autonomous Exploration of Planetary Lava Tubes Using a Multi-rover Framework

Wolfgang Fink (University of Arizona), Victor Baker (University of Arizona), Dirk Schulze Makuch , Christopher Hamilton (University of Arizona), Mark Tarbell (California Institute of Technology),

Presentation: Wolfgang Fink, Tuesday, March 10th, 11:00 AM, Lake/Canyon

Orbital photographic and remote sensing surveys of the Moon and Mars show extensive evidence of lava tube formation. Lava tube caves, including collapsed tubes with skylights, are of enormous importance to geology and astrobiology because they (1) allow direct examination of pristine bedrock, potentially including materials brought up from depths that are inaccessible from the surface; (2) provide good protection from solar proton event radiations; and (3) by analogy to Earth, might provide access to a rich biosphere hidden from the surface, specifically adapted to life in that extreme environment. While previous mission paradigms have prevented exploration of lava tube caves on Mars, new robotic exploration technologies and paradigms can now make this possible. To that effect a paradigm shift in autonomous robotic space exploration, termed "Tier-Scalable Reconnaissance" using a multi-rover approach can be employed: The introduction of in-situ operational autonomy, redundant mobile robotic surface probes coupled with a base rover, and multi-tiered science reconnaissance permit robotic traversal of risky, science-rich environments in a way that the loss of one or more robotic probes need not jeopardize the entire mission. As a prelude to actual planetary exploration, there are ready analog environments on Earth where such a multi-rover framework could be pre-deployed, tested, and evaluated.

2.07 In Situ Instruments for Landed Surface Exploration, Orbiters and Flybys

Session Organizer: Daniel Winterhalter (NASA Jet Propulsion Laboratory, California Institute of Technology), Stephanie Getty (NASA - Goddard Space Flight Center),

2.0701 Mass Analyzer for Real-time Investigation of Neutrals at Europa (MARINE)

Murray Darrach (Jet Propulsion Laboratory), Dragan Nikolic (Jet Propulsion Laboratory), Stojan Madzunkov (Jet Propulsion Laboratory), Evan Neidholdt ,

Presentation: Luther Beegle, Wednesday, March 11th, 08:30 AM, Gallatin

Presented herein is the progress on developing a new mass analyzer for analysis of the exospheres of planets, moons, and primitive bodies, such as found at Europa or Enceladus. The Mass Analyzer for Real-time Investigation of Neutrals at Europa (MARINE) is capable of measuring the abundances of neutral particle species in a planetary exosphere with very high sensitivity and determining their number density profiles at per-second sampling rates as a function of altitude above the planet or moon's surface.

2.0702 The Atmospheric Characterization for Exploration and Science (ACES) Instrument Suite for Mars

Scot Rafkin (Southwest Research Institute),

Presentation: Scot Rafkin, Wednesday, March 11th, 08:55 AM, Gallatin

The Atmospheric Characterization for Exploration and Science (ACES) instrument suite was designed to address the highest priority lower atmosphere goals and investigations identified by the Mars Exploration Program[1], and to address both exploration technology Strategic Knowledge Gaps (SKGs) and science goals identified for the Mars 2020 mission[2][3]. The ACES Mars surface in situ instrument suite measures atmospheric dust properties, fundamental atmospheric parameters, and the energy inputs that drive the atmosphere in ways that far exceed previous landed experiments. In addition to temperature, pressure, and relative humidity, ACES measures for the first time airborne particle concentration and size distribution, 3D wind components, and infrared and visible radiative fluxes. By combining the unique capabilities of ACES to determine turbulent eddy momentum fluxes and dust characteristics, ACES also measures the wind stress that lifts sand and dust.

2.0703 Design and Demonstration of the Mars Organic Molecule Analyzer (MOMA) on the ExoMars 2018 Rover

Ricardo Arevalo (NASA GSFC), William Brinckerhoff (NASA - Goddard Space Flight Center), Veronica Pinnick (NASA Goddard Space Flight Center), Xiang Li (University of Maryland, Baltimore County), Stephanie Getty (NASA - Goddard Space Flight Center), Paul Mahaffy (NASA Goddard),

Presentation: Ricardo Arevalo, Wednesday, March 11th, 09:20 AM, Gallatin

The Mars Organic Molecule Analyzer (MOMA) investigation is a key astrobiology experiment scheduled to launch on the joint ESA-Roscosmos ExoMars 2018 rover mission. MOMA will examine the chemical composition of geological samples acquired from depths of up to two meters below the martian surface, where fragile organic molecules may be protected from destructive cosmic radiation and/or oxidative chemical reactions.

The heart of the MOMA mass spectrometer subsystem (i.e., MOMA-MS) is a miniaturized linear ion trap (LIT) that supports two distinct modes of operation to detect: i) volatile and semi-volatile, low-to-moderate mass organics (≤500 Da) via pyrolysis coupled with gas chromatography mass spectrometry (pyr/GCMS); and, ii) more refractory, moderate-to-high mass compounds (up to 1000 Da) via laser desorption (LDMS) at ambient Mars pressures. Additionally, the LIT mass analyzer enables selective ion trapping via multi-frequency waveform ion excitation (e.g., stored waveform inverse Fourier transform, or SWIFT), and structural characterization of complex molecules using tandem mass spectrometry (MS/MS). A high-fidelity Engineering Test Unit (ETU) of MOMA-MS has been built and tested at NASA GSFC under relevant operational conditions (pressure, temperature, etc.). Spaceflight qualifications of individual hardware components and integrated subassemblies have been validated through vibration, shock, thermal, lifetime, and performance evaluations. The ETU, which is shown here to meet or exceed all functional requirements, serves as a pathfinder for the buildup, integration and test of the flight model that will be delivered to MPS in late 2015.

2.0704 Hyperdust : An Advanced In-situ Detection and Chemical Analysis of Microparticles in Space

Zoltan Sternovsky (LASP, Univ. of Colorado), Eberhard Gruen (LASP, Univ. of Colorado),
Presentation: Zoltan Sternovsky, Wednesday, March 11th, 09:45 AM, Gallatin

By determining the dust particles' source and their elemental and chemical composition, we can learn about the environments, where they were formed and processed. A long series of previous dust instruments lead to novel in-situ instrumentation suitable for implementing the goals of dust astronomy: determining the origin of dust particles and their elemental composition by the Hyperdust instruments. The Hyperdust instrument is a combination of a Dust Trajectory Sensor (DTS) together with an analyzer for the chemical composition of dust particles in space. The Hyperdust instrument is currently being developed to TRL 6 funded by NASA’s MatISSE program to be a low-mass, high performance instrument for future in-situ exploration.

2.0705 Analysis of Aqueous Environments by Laser Desorption/ionization Time-of-flight Mass Spectrometry

Xiang Li (University of Maryland, Baltimore County), Stephanie Getty (NASA - Goddard Space Flight Center), William Brinckerhoff (NASA - Goddard Space Flight Center), Kyle Uckert (New Mexico State University), Nancy Chanover (New Mexico State University),
Presentation: Xiang Li, Wednesday, March 11th, 10:10 AM, Gallatin

Laser desorption/ionization time-of-flight mass spectrometry (LD-TOF-MS) has been developed and used to characterize different groups of hydrous minerals. We have advanced the technique by including reversed polarity, precision ion gating, and a curved field reflectron mass analyzer. Reversed polarity provides capabilities in achieving complementary compositional information of the materials, and ion gating enhances the selectivity and sensitivity in specific mass ranges. Representative reference minerals including sulfates, clays, serpentine, and naturally collected complex samples have been analyzed by LD-TOF-MS as well as infrared (IR) spectroscopy, to provide supporting information. We demonstrate that mass spectrometry can identify water in mineral species, and reveal the presence of aqueous environments. Miniaturized LD-TOF-MS is a valuable instrument technique for the in situ characterization and analysis of samples as part of future landed planetary missions and astrobiology explorations.

2.0706 The Lunar Dust Experiment (LDEX)

Mihaly Horanyi (University of Colorado, Boulder),
Presentation: Mihaly Horanyi, Wednesday, March 11th, 10:35 AM, Gallatin

The Lunar Dust Experiment (LDEX) onboard the Lunar Atmosphere and Dust Environment Explorer (LADEE) mission discovered a permanently present dust cloud engulfing the Moon. The size, velocity, and density distributions of the dust particles are consistent with ejecta clouds generated from the continual bombardment of the lunar surface by sporadic interplanetary dust particles. Intermittent density enhancements were observed during several of the annual meteoroid streams, especially during the Geminids. In addition to the mass and speed of the impacting particles, in a significant fraction of the events, LDEX also recorded the electrostatic charge of the dust grains before their impact. Here we report on the initial analysis of the LDEX dust charge measurements.

2.0707 High Resolution, Texture-specific Rock Chemistry Measurement with PIXL micro-XRF

Abigail Allwood (Jet Propulsion Laboratory), William Elam , Joel Hurowitz (Stony Brook University), David Thompson ,

Presentation: Abigail Allwood, Wednesday, March 11th, 11:00 AM, Gallatin

2.0708 SHERLOC: Scanning Habitable Environments with Raman & Luminescence for Organics & Chemicals

Luther Beegle (Jet Propulsion Laboratory),

Presentation: Luther Beegle, Wednesday, March 11th, 11:25 AM, Gallatin

SHELOC is an arm-mounted Fluorescence and Raman spectrometer that was recently selected to be part of the payload for the next proposed NASA rover mission to Mars, scheduled for launch in 2020. SHERLOC enables non-contact, spatially resolved, high sensitivity detection and characterization of organics and minerals on the Martian surface. The investigation goals are to assess past aqueous history, detect the presence and preservation potential of biosignatures and to support the selection of samples for caching and potential return to Earth.

2.0709 Demonstration of a Portable AOTF IR Spectrometer for in Situ Exploration of Planetary Surfaces

Kyle Uckert (New Mexico State University), Nancy Chanover (New Mexico State University), David Voelz (New Mexico State University), Xifeng Xiao (New Mexico State University), Penelope Boston (New Mexico Inst. Mining & Technology),

Presentation: Kyle Uckert, Wednesday, March 11th, 11:50 AM, Gallatin

Characterizing the mineralogy of a planetary surface is essential to understanding its geologic and chemical evolution, which can be used to infer the past habitability of a region. Spectral signatures consistent with several important mineralogical and biogeochemical absorption features are located in the near infrared (NIR) spectral region, and thus offer a convenient wavelength range to probe for astrobiological investigations. The 1.6 - 3.6 μm range contains spectral signatures useful in identifying many of the basic organic compounds essential to life on Earth, several common minerals relevant to terrestrial planetary surfaces, including silicates, carbonates, sulfates, basalts, clay minerals, and iron oxides, which are ubiquitous on the Martian surface, as well as the fundamental stretching and bending modes of ices and volatiles relevant to icy Solar System bodies. We developed a portable NIR reflectance point spectrometer based on acousto-optic tunable filter (AOTF) technology for future in situ investigations of these spectral features on other planetary surfaces. We have demonstrated the efficacy of this technique in extreme subterranean environments using the Portable AOTF Spectrometer for Astrobiology (PASA) to detect spectral biosignatures consistent with microbial alteration of geologic samples. PASA measures the IR reflectance spectrum of geologic samples in the 1.6 - 3.6 μm range with a resolution of $\lambda / \Delta\lambda \approx 200 - 400$. We present the development and specifications of PASA, results from these expeditions, and discuss potential applications of a portable NIR point spectrometer based on AOTF technology for future landed or roving missions to other Solar System bodies.

2.08 Q/V Band and Beyond Satellite Missions

Session Organizer: Giorgia Parca (), Tommaso Rossi (University of Rome Tor Vergata), Elisa Ricci (University of Rome Tor Vergata), Giuseppe Codispoti (ASI, Italian Space Agency),

2.0801 The Alphasat Aldo Paraboni Experiment: Fade Mitigation Techniques in Q/V-Band Satellite Channels

Johannes Ebert , Michael Schmidt (Joanneum Research), Harald Schlemmer (Joanneum Research), Eral Türkyilmaz (JOANNEUM Research), Sabine Kastner Puschl , Juan Rivera Castro (European Space Agency),

Presentation: Johannes Ebert, Wednesday, March 11th, 08:30 AM, Lamar/Gibbon

The Alphasat Aldo Paraboni Payload incorporates two Q/V-band satellite transponders, which covers three spot beams over Europe placed towards Italy and towards Graz/ Austria. JOANNEUM RESEARCH developed and installed the ground station in Graz and operates communication experiments since beginning of 2014. The goal is to optimize the usage of the Q/V-band channel especially with respect to its high rain fades. In the first period of operation, particularly adaptive coding and modulation has been used as fade mitigation technique. In this paper, we present the architecture of the ground station, the setup and configuration of the experiments, as well as the results from the first nine months of operation. This includes a first estimate of the trade-off between the achievable spectral efficiency vs. the residual frame error rate with respect to the properties of the corresponding Q/V-band satellite link.

2.0802 Q/V-band Satellite Communication Experiments on Channel Estimation with Alphasat Aldo Paraboni P/L

Tommaso Rossi (University of Rome Tor Vergata), Mauro De Sanctis (Universití di Roma Tor Vergata, Dip. Ing. Elet.), Marina Ruggieri (University of Roma Tor Vergata), Giuseppe Codispoti (ASI, Italian Space Agency),

Presentation: Giorgia Parca, Wednesday, March 11th, 08:55 AM, Lamar/Gibbon

The Alphasat Aldo Paraboni communication experimental campaign is based on a transparent Q/V band transponder hosted as a piggy-back on a GEO satellite. Together with the transparent payload, two beacons having European coverage, one in Ka-band and one in Q/V-band, are used to perform propagation experiments. The transparent payload has three spot beams, two over Italy and one over Austria. The University of Rome Tor Vergata-CTIF Italy is the Principal Investigator for the communication experiments and is in charge of operating the payload and the Italian ground stations. The Alphasat Aldo Paraboni experiment is an important step toward the development of future High Throughput Satellite (HTS) systems, able to support hundreds of gigabit/s or terabit/s connectivity. These systems will require: a) use of frequency bands beyond Ka (i.e. Q, V and W bands); b) enhanced frequency reuse; c) use of Propagation Impairments Mitigation Techniques (PIMT). Alphasat Aldo Paraboni payload allows us to perform, for the first time, communication experiments over a Q/V band satellite link with adaptive PIMT, testing: Channel Estimation, Adaptive Coding and Modulation (ACM), up-link power control (ULPC) and space diversity. This paper presents the first results of the communication experiments campaign.

2.0803 Performance of the NASA Beacon Receiver for the Alphasat Aldo Paraboni TDP5 Propagation Experiment

James Nessel (NASA Glenn Research Center),

Presentation: James Nessel, Wednesday, March 11th, 09:20 AM, Lamar/Gibbon

2.0804 Optimization of ACM Algorithms over Q/V-band Satellite Channels with the Alphasat Aldo Paraboni P/L

Mauro De Sanctis (Universití di Roma Tor Vergata, Dip. Ing. Elet.), Tommaso Rossi (University of Rome Tor Vergata), Marina Ruggieri (University of Roma Tor Vergata), Giuseppe Codispoti (ASI, Italian Space Agency),

Presentation: Elisa Ricci, Wednesday, March 11th, 09:45 AM, Lamar/Gibbon

Future satellite communication systems providing broadband access to Internet require high throughput connectivity in the order of hundreds of Gbps or Tbps. Radical changes in technologies are needed to support these demanding requirements. One of the most important changes is the use of Q/V band frequencies which offer larger bandwidths with respect to the Ka band. However, Q/V band communication suffers from highly variable propagation losses and the use of Propagation Impairment Mitigation Techniques (PIMTs) is mandatory for an efficient use of radio resources such as power and bandwidth. In this paper we describe the first Q/V band satellite communication experiments that have been performed through the Alphasat “Aldo Paraboni” hosted payload. In particular, experimental results on ACM optimization will be presented.

2.09 Mission Design for Spacecraft Formations

Session Organizer: Giovanni Palmerini (Sapienza Universita' di Roma),

2.0901 Trajectory Design for Rendezvous in Lunar Distant Retrograde Orbit

Naomi Murakami (Japan Aerospace Exploration Agency), Koji Yamanaka (JAXA),

Presentation: Naomi Murakami, Thursday, March 12th, 04:30 PM, Gallatin

In out presentation, a strategy for Lunar Distant Retrograde Orbit (DRO) rendezvous, which is obtained with reasonable delta-v, flight time, and operation constraint, will be presented. First, we examine total delta-v and flight time required for a transfer from an LEO to various points in a DRO and illustrated their characteristics. Here, the basic transfer trajectories from LEOs to DROs are designed with three impulsive maneuvers at LEO departure points, lunar flyby points, and DRO insertion points. The results show how a certain region where the delta-v cost is low exists, and the flight time varies considerably according to the rendezvous point. In order to minimize total delta-v, it is important to select appropriate orbit plane of the the visiting spacecraft in an LEO. Thus, the launch timing is constrained. We propose an applicable launch window with these features in mind. We also conduct a case study to evaluate delta-v and flight time required for rendezvous after the visiting vehicle is inserted into the DRO at a certain distance from the station. The result shows the potential to widen the option to rendezvous.

2.0902 Attitude Coordination Strategies in Satellite Constellations and Formation Flying

Leonard Felicetti (University of Rome La Sapienza), Giovanni Palmerini (Sapienza Universita' di Roma),

Presentation: Giovanni Palmerini, Thursday, March 12th, 04:55 PM, Gallatin

The coordination of the attitude among different spacecraft belonging to a multiple platform system is a basic requirement in several missions, mainly the ones involving sensors like radars or optical interferometers. Different approaches are possible to define and chase such a coordinated attitude. The classic control strategy is the so-called leader-follower architecture, where all spacecraft depend on (“follow”) the behavior of a single master. Alternatively, the behavioral approach involves a continuous re-selection of the desired target configuration which is computed on the basis of the behavior of all the platforms. A third possibility is to define a “virtual” architecture, especially suitable with respect to the mission requirements, which is not dependent on the current kinematic state of the platforms. The paper proposes a unified treatment of these concepts by using some fundamental definitions of the consensus dynamics and cooperative control. The convergence to the targeted configuration is addressed both analytically, by using Lyapunov stability criteria, and numerically, by means of numerical simulations. The attitude requirements and constraints are highlighted and a solution for the control algorithm - involving continuous actuators on each platform – is developed. A comparative analysis of different optimal control strategies, the Linear Quadratic Regulation (LQR) and the State Dependent Riccati Equation (SDRE) - suitably modified to address the needs of coordination - is presented. The results show the general value of the proposed approach with respect to either linear or nonlinear models of the dynamics.

2.0903 A Framework for Orbital Performance Evaluation in Distributed Space Missions for Earth Observation

Sreeja Nag (Massachusetts Institute of Technology), Jacqueline Le Moigne (NASA - Goddard Space Flight Center), David Miller (Massachusetts Institute of Technology), Olivier De Weck (Space Systems Laboratory),

Presentation: Sreeja Nag, Thursday, March 12th, 05:20 PM, Gallatin

Distributed Space Missions (DSMs) are gaining momentum in their application to earth science missions owing to their unique ability to increase observation sampling in spatial, spectral and temporal dimensions simultaneously. DSM architectures have a large number of design variables and since they are expected to increase mission flexibility, scalability, evolvability and robustness, their design is a complex problem with many variables and objectives affecting performance. There are very few open-access tools available to explore the tradespace of variables which allow performance assessment and are easy to plug into science goals, and therefore select the most optimal design. This paper presents a design framework and software tool developed on the MATLAB engine interfacing with STK, for DSM orbit design and selection. It is capable of generating thousands of homogeneous constellation or formation flight architectures based on pre-defined design variable ranges and sizing those architectures in terms of pre-defined performance metrics. The metrics can be input into observing system simulation experiments, as available from the science teams, allowing dynamic coupling of science and engineering designs. Design variables include but are not restricted to constellation type, formation flight type, FOV of instrument, altitude and inclination of chief orbits, differential orbital elements, leader satellites, latitudes or regions of interest, planes and satellite numbers. Intermediate performance metrics include angular coverage, number of accesses, revisit coverage, access deterioration over time at every point of the Earth’s grid.

2.0904 The Constellation of LARES and LAGEOS Satellites for Testing General Relativity

Giampiero Sindoni (sapienza), Ignazio Ciufolini (Università del Salento and Centro Fermi), Claudio Paris (University of Rome, La Sapienza), Antonio Paolozzi (Dipartimento di Ingegneria Aerospaziale e Astronau),

Presentation: Claudio Paris, Sunday, March 8th, 09:00 PM, Elbow 1

LARES satellite was developed under the support of the Italian Space Agency. It has been successfully put in orbit on the 13th February 2012 with the VEGA launcher. The main objective of the LARES mission is to test frame-dragging, with the unprecedented accuracy of about 1%. Frame-dragging is that phenomenon, theorized by General Relativity, such that the currents of mass-energy drag spacetime, in the sense that they drag the inertial frames of reference. It is an intriguing effect that together with gravitational waves and other relativistic predictions is not present in classical Galilei-Newton mechanics. By determining very accurately the orbit of the constellation constituted by LARES and the two LAGEOS satellites, it is possible to achieve such an objective. In fact one of the key issues of the experiment is to have three independent observables

that are provided by the three satellites. We are showing that the use of the constellation is not the only ingredient required, and in particular LARES needed to be designed at the limit of current technology. Also the most updated and accurate determinations of the gravitational field of Earth are of paramount importance in the test. We will describe the main LARES mission components and show why it is so important the use of a constellation to reach the goal.

2.0905 Moderate Accuracy Relative Navigation in Formation Flying by Filtered Radio Measurements

Giovanni Palmerini (Sapienza Universita' di Roma), Marco Sabatini (Universita` Roma La Sapienza), Paolo Gasbarri (Sapienza Università di Roma), Michele Macellari (Sapienza Universita di Roma), Luigi Schirone (La Sapienza - DIAA),

Presentation: Giovanni Palmerini, Sunday, March 8th, 09:25 PM, Elbow 1

Formation flying missions involve relative navigation, or the determination of the relative kinematic state of the spacecraft involved. Different options do exist, both in visible and conventional radio-frequency bands, with passive and active architectures. All the solutions need to take into account the strict requirements in terms of mass, volume and power typical to spacecraft, not to forget that they are not directly part of the payload, so that the overall impact of this avionic subsystem needs to be minimized. This paper aims to discuss a simple solution for the relative navigation of a formation, especially suitable for moderate cost, moderate performance missions (like the ones exploited by cubesats). A field strength meter onboard the chief-satellite can provide the level of received signal power, which is an observable related – even if with a poor quality - to the inter-satellite distance. An extended Kalman filter including a suitable dynamical model can exploit these measurements in order to estimate the formation kinematic state at a very limited cost. The combination of the two elements makes up for a technique which is accurate enough even in the phases immediately following the release from the launcher, where the spacecraft are in close proximity. The presented numerical simulation proves the valuable performance of such a simple system, also useful as a possible back-up solution at a limited cost in terms of spacecraft requirements.

2.10 Radiation Issues and Modeling for Deep Space Missions

Session Organizer: Lembit Sihver (Chalmers University of Technology), Lawrence Heilbronn (University of Tennessee),

2.1001 EDAC Events during the LADEE Mission

Karen Gundy Burlet (NASA-Ames Research Center),

Presentation: Nathaniel Benz, Wednesday, March 11th, 10:35 AM, Lamar/Gibbon

The purpose of the Lunar Atmosphere Dust Environment Explorer (LADEE) mission was to measure the density, composition and time variability of the lunar dust environment. The successful mission launched Sept 6, 2013 and was de-orbited and impacted the moon's surface on April 18, 2014. The onboard flight software was designed using a layered modular approach leveraging model-based design concepts. High-level spacecraft control modules were autocoded from Simulink and integrated with reused executive and services modules and a small number of new hand-coded elements such as the software to control memory scrub hardware. Over the course of the mission, LADEE had to tolerate a varying space radiation environment during a period of relative solar maximum and multiple passes through the Earth's Van Allen Radiation Belt. In order to mitigate this challenging environment, the Integrated Avionics Unit (IAU) chosen for the mission (a Broadreach Engineering RAD-750) implemented memory scrub in hardware. Software developed for the mission initialized and controlled the Error Detection and Correction (EDAC) circuitry and categorized and reported on errors that occurred during

flight. The payloads, sensors and actuators each had varying degrees of tolerance to space radiation events, and events on these pieces of hardware were also tracked. This paper discusses the avionics and software for resilience to radiation events, and characterized the types of events during the course of LADEE's mission.

2.1002 Neutron Production from 100 and 230 AMeV He Interactions in Water, PMMA and Iron

Pi En Tsai (University of Tennessee), Lawrence Heilbronn (University of Tennessee), Yung Cheng Hsu (National Tsing Hua University), Bo Lun Lai , Rong Jiun Sheu (National Tsing Hua University),
Presentation: Pi En Tsai, Wednesday, March 11th, 11:00 AM, Lamar/Gibbon

Experiments conducted in June 2014 at the HIMAC facility in Chiba, Japan will provide important data on secondary neutron production from 100-AMeV and 230-AMeV He interactions in water, iron and PMMA targets. Analysis of the data completed up to this point indicate that in addition to secondary neutron production data, data on production of secondary proton, deuteron, triton, and He ions will also be obtained. In addition to experimental data, Monte Carlo simulations of the experiment have been performed with FLUKA and MCNP-X transport codes. Comparisons of the codes' predictions of light ion production indicate interesting differences between the two codes. As such, the data measured here will provide information needed to resolve those differences and help improve the codes' predictions.

2.1003 Improvements and Developments of Physics Models in PHITS for Space Applications

Lembit Sihver (Chalmers University of Technology),
Presentation: Lembit Sihver, Wednesday, March 11th, 11:25 AM, Lamar/Gibbon

In this paper, we present improvements and developments of some physics models used in the general purpose 3-D Monte Carlo code PHITS. We present comparisons of calculated and measured σR using the Kurotama Hybrid σR, model which is incorporated into PHITS. The default model for nuclear-nuclear reactions is JQMD in PHITS. However, JQMD cannot accurately enough describe the nucleon and d, t, 3He and 4He induced reactions. Therefore the Intra-Nuclear Cascade of Liège (INCL) has been selected as the default model for these reactions. Moreover, it has been realized that the production of light fragments is underestimated by conventional simulation codes based on a combination of intra-nuclear cascade and statistical decay models. This is because this combination cannot reproduce the high multiplicity events that are responsible for the production of light fragments. To better reproduce high multiplicity events, we have simulated fragmentation cross sections using a combination of JQMD/INCL, statistical multi-fragmentation model (SMM) and the generalized evaporation model (GEM). Examples of these simulations will be presented. A new approach to describe neutron spectra of deuteron-induced reactions in the Monte Carlo simulations has also been developed by combining the INCL and the Distorted Wave Born Approximation (DWBA) calculation. We have incorporated this combined method into PHITS and applied it to estimate (d,xn) spectra on light targets at incident energies ranging from 10 to 40 MeV. In this paper, we will show that the double differential cross sections obtained by INCL and DWBA successfully reproduced broad peaks and discrete peaks, respectively.

2.1004 Neutron Fluences in Lunar Habitats

Lawrence Heilbronn (University of Tennessee), Ashwin Srikrishna ,
Presentation: Lawrence Heilbronn, Wednesday, March 11th, 11:50 AM, Lamar/Gibbon

The radiation environment inside a lunar habitat is affected not only by the thickness of shielding, but also by the materials used for shielding and their layout. The radiation environment on the lunar surface is complex, and behind thick shields (greater than 20 g/cm^2) that environment has a significant component due to neutrons. Because of their high radiation weighting factors, these neutrons contribute an even more significant component of the effective dose inside the habitat. Here, calculations have been performed on Galactic Cosmic Ray (GCR) transport through several different configurations and types of shielding materials in a simplified hemispherical dome-shaped lunar habitat in order to investigate how the resulting neutron field can be minimized. The materials chosen in this first round of investigations are polythylene, aluminum, and lunar regolith. Polyethylene is chosen because of its known properties in reducing the production of neutrons from GCR interactions. Regolith is chosen because of its favorable properties of cost and convenience, and aluminum is chosen because of its common use in spacecraft and other structures in space. Initial results indicate that the choice of flooring material can have a significant impact in the overall reduction of the neutron flux.

2.11 Space Debris and Dust: The Environment, Risks, and Mitigation Concepts and Practices

Session Organizer: Douglas Mehoke (Johns Hopkins University Applied Physics Laboratory (JHU/APL)), Kaushik Iyer (Johns Hopkins University/Applied Physics Laboratory),

2.1101 Computational Evaluation of Metal Foam Orbital Debris Shielding

Eric Fahrenthold (University of Texas at Austin),
Presentation: Eric Fahrenthold, Thursday, March 12th, 08:30 AM, Gallatin

Aluminum honeycomb sandwich structures are widely used in aerospace applications, and are generally fa- vored for their high specific strength and stiffness. However, experimental studies of their orbital debris shielding perfor- mance have shown an undesirable tendency to channel impact debris from a front face sheet impact, towards the back face sheet, inhibiting lateral debris dispersion. Hence published experimental research has evaluated the orbital debris shielding performance of aluminum foam sandwich panels, as a potential structural alternative. The limitations of light gas gun technol- ogy mean that experimental studies of this type can only investi- gate the lower half of the impact velocity regime of interest in low earth orbit applications. Recent research has conducted a series of 49 impact simulations, employing a hybrid-particle element method, in order to estimate the orbital debris shielding perfor- mance of aluminum foam sandwich panels for impact conditions which cannot be duplicated in the laboratory. The simulation results suggest that published scaling laws which extrapolate the experimental data base outside the testable range provide an accurate estimate of metal foam shielding performance over the full impact velocity range of interest for spacecraft operating in low earth orbit.

2.1102 Glass Surface Spall Modeling for Interplanetary Dust Impacts

Kaushik Iyer (Johns Hopkins University/Applied Physics Laboratory), Douglas Mehoke (JHU-APL),
Presentation: Kaushik Iyer, Thursday, March 12th, 08:55 AM, Gallatin

This is the fourth in a series of papers presented at the IEEE Aerospace Conference by the Johns Hopkins University Applied Physics Laboratory on interplanetary dust hypervelocity impact (HVI) damage to NASA's Solar Probe Plus spacecraft. The first three papers described the methodology, advancement of shock hydrocode computations for enabling design decisions and shielding capability of thermal blankets. This paper describes damage to glass surfaces on solar arrays and one of the science instruments. The size of relatively large dynamic conchoidal fractures, i.e., surface spalls, immediately adjacent to and around interplanetary dust impact craters or pits in glass substrates is relevant to spacecraft solar cell and science instrument lens performance metrics, as well as glass pane design and safety in manned missions. One significant finding is that the average surface spall diameter obtained with dust-scale particles and glass in a layered substrate is approximately 1/5th of that obtained with macroparticles and a glass monolith. It is also found that a Ballistic Limit Equation (BLE) developed for glass

HVI cratering at relatively low velocities (< 10 km/s) can be modified for spalling and used successfully for bounding design calculations at the higher velocities considered (up to 150 km/s).

2.1103 Cooperative Multi-Satellite Mission for Active Debris Removal from Low Earth Orbit

Bogdan Udrea (VisSidus Technologies, Inc.), Michael Nayak (Red Sky Research),
Presentation: Bogdan Udrea, Thursday, March 12th, 09:20 AM, Gallatin

The paper presents the concept of operations and preliminary design of a multi-satellite mission for the active removal of large pieces of debris from low Earth orbit. The mission consists of a mothership minisatellite, that carries six nanosatellites. The mothership acquires a relative orbit of a few kilometers with respect to the piece of orbital debris of interest and determines the attitude state of the debris and good docking locations for the nanosatellites. The nanosatellites deploy sequentially and dock with the piece of debris. Once all the nanosatellites are docked with the debris they cooperatively perform its structural analysis to determine safe maneuvering profiles for its detumble and deorbit. The mothership then docks with the piece of debris and applies maneuvers to deorbit it. Systems engineering budgets have been determined for the mass and propellant and a preliminary mission cost has been estimated. They are presented together with the functional architectures of each spacecraft and the results of mission design obtained with the Systems Tool Kit.

2.1104 Electrical Threat from Hypervelocity Impacts in Space

Ashish Goel (Stanford University), Sigrid Close (Stanford University),
Presentation: Ashish Goel, Thursday, March 12th, 09:45 AM, Gallatin

This paper discusses the electrical threat from hypervelocity impacts in space. An analysis is performed using satellite anomaly databases and a detailed case study is presented for the Jason-1 satellite anomaly. Correlation studies show that while there is found to be no statistically significant correlation between the shower meteoroid flux and the incidence of anomalies, there is indeed a correlation between the incidence of anomalies and the sporadic background meteoroid flux. In the presentation, recent results from ground-based hypervelocity impact tests carried out at the Max Planck Institute for Nuclear Physics and the Colorado Center for Lunar Dust Acceleration Studies will also be presented.

2.1105 Detumbling Large Space Debris via Laser Ablation

Massimo Vetrisano (Elecnor Deimos), Nicolas Thiry (University of Strathclyde), Massimiliano Vasile (University of Strathclyde),
Presentation: Nicolas Thiry, Thursday, March 12th, 10:10 AM, Gallatin

This paper presents an approach to control the rotational motion of large space debris (the target) before the spacecraft starts deflecting its trajectory through laser ablation. A rotational control strategy based on the instantaneous angular velocity of the target is presented. The aim is to impart the maximum control torque in the direction of the instantaneous angular velocity while minimizing the undesired control components in the other directions. An on-board state estimation and control algorithm is then implemented. It simultaneously provides an optimal control of the rotational motion of the target through the combination of a LIDAR and a navigation camera. The instantaneous angular velocity of the debris is estimated through the application of the optic flow technique. The whole control and estimation technique is applied to the case of cylindrical and parallelepiped shapes as representative of upper stages and spacecrafts. When applied to the cylindrical shape, results show that the control strategy and laser technique fail to control along three directions unless the geometrical axes are different from the inertial ones. In general the thrust vector is aligned with the normal to the local surface meaning

that no control torque can be exerted along the longitudinal axis in the case of an ideal cylinder.

2.1106 ADReS-A: Mission Architecture for the Removal of SL-8 Rocket Bodies

Susanne Peters (Universität der Bundeswehr münchen),
Presentation: Susanne Peters, Thursday, March 12th, 10:35 AM, Gallatin

The paper introduction addresses a promising orbit to start a multiple target removal mission, followed by the presentation of the mission architecture. Due to space debris being an issue for all space faring nations, this paper introduces an exemplary removal mission for 5 to 7 Russian SL-8 rocket bodies in close vicinity to each other at an inclination of 83° and orbiting at an altitude of 970 km - an area crowded with space debris and thus involving a high collision risk. The mission itself consists of a main satellite (autonomous debris removal satellite – ADReS-A, also called chaser) and smaller deorbit-kits, which will be attached to the targets independently and one after the other. The setup is placed at a parking orbit, close to the target trajectory, before the chaser takes the first deorbit-kit to its designated target. While the deorbit-kits are equipped with a de-orbit thruster, the task of ADReS-A is, to approach the uncooperative target, berth, stabilize the compound system and attach the de-orbit kit onto the rocket body. In the scenario, the kits wait for their transportation at the parking orbit with the chaser shuttling between targets and deorbit-kits. The paper presents the different phases of the mission additionally, giving first calculations for the timeline and introduces future investigations which will address autonomy for the highly critical situations rising from an uncooperative target with unknown rotation rate, no signal reflectors and an absent predesigned point of contact for the berthing moment.

2.12 Asteroid Hazard Detection, Mitigation, and Retrieval Concepts

Session Organizer: Paul Chodas (Jet Propulsion Laboratory), Jeffery Webster (Jet Propulsion Laboratory), Mark Boslough (Sandia National Laboratories),

2.1201 Initial Asteroid Detection Results Using the Space Surveillance Telescope

Herbert Viggh (Massachusetts Institute of Technology), Greg Ushomirsky , Grant Stokes (MIT Lincoln Laboratory),
Presentation: Herbert Viggh, Wednesday, March 11th, 04:55 PM, Gallatin

The Lincoln Near Earth Asteroid Research (LINEAR) program, funded by the National Aeronautics and Space Administration (NASA), has conducted search for hazardous asteroids from 1998 to 2013 using two 1m telescopes at the MIT Lincoln Laboratory Experimental Test Site (ETS) in Socorro, NM. During this period, the LINEAR program has made significant contributions to the discovery of Near Earth Objects (NEOs), thereby improving the knowledge of the NEO size distribution and helping to characterize the threat from NEOs. The LINEAR program has now transitioned to operations using the new 3.5m wide-field-of-view Space Surveillance Telescope (SST) located at the Atom Site on White Sands Missile Range, NM. The SST was developed for the Defense Advanced Research Projects Agency (DARPA) by MIT Lincoln Laboratory to advance the nation’s capabilities in space situational awareness. The goals of LINEAR using SST are to continue discovering NEOs, improve knowledge of the NEO size distribution down to 140m, and to discover small 2-15m candidates for asteroid retrieval missions. This paper will describe the SST, LINEAR search using the SST, and the new LINEAR SST processing pipeline. Recent simulation, observing, and detection results will also be presented, along with planned improvements to the system. This work is sponsored by the Defense Advanced Research Projects Agency and the National Aeronautics and Space Administration under Air Force Contract #FA8721-05-C-0002. Opinions,

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2.1202 Orbit Estimation for Late Warning Impacts: The Case of 2014 AA

Steven Chesley (JPL), Davide Farnocchia , Peter Brown (University of Western Ontario), Paul Chodas (Jet Propulsion Laboratory),

Presentation: Steven Chesley, Wednesday, March 11th, 05:20 PM, Gallatin

The possibility that newly-discovered asteroids could impact the Earth within days or weeks of their first detection raises a number of challenges, from tracking and orbit estimation, to prediction and hazard assessment, and even for public communication and disaster response. Here we focus on the astrodynamics problem of identifying and analyzing potential near-term situations requiring a rapid response, both in the observer community and in the orbit arena. The observations for such cases will often include only an hour or so of tracking, leaving severe degeneracies in the orbit estimation. We get around this problem by exploring the poorly-constrained space of range and range rate to the observer, while the plane of sky position and motion is readily derived from the input observations. A raster scan in the two-dimensional range-range rate space allows us to identify regions in the space of possible orbits corresponding to collisions solutions. From this we can understand the possible impact times and locations, and even derive coarse estimates of impact probability. As an example, we shall consider the case of 2014 AA. This very small asteroid (2-3 m diameter) was discovered early on the morning of January 1 by the Catalina Sky Survey operating near Tucson, Arizona. Immediate follow up provided almost 70 minutes of tracking, enough for us to predict a nearly certain impact. Indeed, infrasound observations indicate that the object entered the Earth's atmosphere over the Atlantic Ocean about 21 hours after discovery, consistent with the predictions from our technique.

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2.1203 Updated Population and Risk Assessment for Airbursts from Near-Earth Objects (NEOs)

Mark Boslough (Sandia National Laboratories), Peter Brown (University of Western Ontario), Alan Harris (Jet Propulsion Laboratory),

Presentation: Mark Boslough, Thursday, March 12th, 08:30 AM, Madison

We present a new analysis of airburst risk based on updated estimates for the population of undiscovered NEOs, taking into account the enhanced damage potential of directed airbursts. We define airbursts as events in which small (meters to tens-of-meters in diameter) asteroids deposit most of their energy in the atmosphere as large bolides and where the total energy is comparable to or greater than small nuclear explosions (>0.1 kilotons of TNT). Our tens-of-meter population estimate from optical surveys is now much closer to bolide frequency estimates, resolving most of an earlier discrepancy. Our Tunguska-class (~40 meters) population estimate has doubled, and Chelyabinsk-class (~20 meters) has increased by a factor of 2.6. Uncertainty in this population remains quite large, and can only be unambiguously reduced by expanded surveys focused on objects in the tens-of-meters size range. The assessed risk from this population is also increasing for two reasons. First, airbursts are significantly more damaging than assumed in the original risk assessments, because for typical impact geometries they more efficiently couple energy to the surface than nuclear explosions of the same energy. Second, the greater numbers mean that they are more frequent than previously thought. We review the evidence that asteroid airbursts are more damaging than nuclear explosions, and provide arguments that such events are more frequent.

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2.1204 Apophis: Complex Rotation and Hazard Assessment

Davide Farnocchia , Steven Chesley (JPL),

Presentation: Davide Farnocchia, Thursday, March 12th, 08:55 AM, Madison

I will first give a brief review on the standard techniques to perform the asteroid impact hazard assessment. Then, I will focus on asteroid Apophis, which became famous in December 2004 as the probability of an Earth impact in 2029 reached a peak of 2.7%. Thanks to additional tracking data we now know that Apophis will safely pass the Earth in 2029 at 38000 km. However, impacts after 2029 are still possible. Apophis is one of the most challenging objects in terms of hazard assessment, as frequent Earth encounters make its orbital dynamics difficult to be modeled. In particular, the orbit of Apophis is deterministic up to the 2029 Earth encounter, after which its orbit can only be known in a statistical sense. An important role is played by the Yarkovsky effect, a subtle nongravitational perturbation that dominates the ephemeris uncertainty for Apophis. The computation of the Yarkovsky accelerations relies on the physical properties of Apophis and is further complicated by its non-principal axis rotation state. I will show how it is possible to model the Yarkovsky effect and the motion of Apophis to compute the probability of an Earth impact. The highest impact probability is 7 in a million for year 2068.

2.1204 Apophis: Complex Rotation and Hazard Assessment

Davide Farnocchia , Steven Chesley (JPL),

Presentation: Davide Farnocchia, Thursday, March 12th, 08:55 AM, Madison

I will first give a brief review on the standard techniques to perform the asteroid impact hazard assessment. Then, I will focus on asteroid Apophis, which became famous in December 2004 as the probability of an Earth impact in 2029 reached a peak of 2.7%. Thanks to additional tracking data we now know that Apophis will safely pass the Earth in 2029 at 38000 km. However, impacts after 2029 are still possible. Apophis is one of the most challenging objects in terms of hazard assessment, as frequent Earth encounters make its orbital dynamics difficult to be modeled. In particular, the orbit of Apophis is deterministic up to the 2029 Earth encounter, after which its orbit can only be known in a statistical sense. An important role is played by the Yarkovsky effect, a subtle nongravitational perturbation that dominates the ephemeris uncertainty for Apophis. The computation of the Yarkovsky accelerations relies on the physical properties of Apophis and is further complicated by its non-principal axis rotation state. I will show how it is possible

to model the Yarkovsky effect and the motion of Apophis to compute the probability of an Earth impact. The highest impact probability is 7 in a million for year 2068.

2.1205 Determining Position around an Asteroid Using Communication Relays and Trilateration

Evan Nelson (New Mexico State University),

Presentation: Evan Nelson, Thursday, March 12th, 09:20 AM, Madison

In this paper we consider the possibility of using a communications system that is operating between probes on the surface of an asteroid and an orbiting satellite to determine their relative spatial positions. This is accomplished by measuring the round trip communication delay between the orbiter and various surface probes to estimate distance and, thus, the position. By measuring the time it takes for a signal to be transmitted from the spacecraft, received by the surface probe, and then retransmitted back to the spacecraft, it is possible to get reasonable distance estimates without the need for high-precision, synchronized clocks on the surface probes. From these distance measurements, position can be determined using trilateration---the same basic technique behind the earth-based GPS system.

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2.1206 Sample-Return Mission Planning for an Asteroid on an Earth Fly-By Trajectory

Dhathri Somavarapu , Kamran Turkoglu (San Jose State University), Alexander Carlozzi (San Jose State University), Zachary Pirkl (San Jose State University),

Presentation: Kamran Turkoglu, Thursday, March 12th, 09:45 AM, Madison

This paper investigates a systematic mission design of robust and optimal orbital transfer maneuvers for a sample return mission from an asteroid. In this study, the aim is to establish a robust space flight procedure to obtain the minimum Delta V required for a rendezvous and sample return mission from an asteroid. Given the initial (observed) conditions of an asteroid, a genetic algorithm is implemented to determine the optimal choice of Delta V required for rendezvous. This is achieved for given constraints on orbital trajectory, payload-mass and maximum allowable Delta V. In that sense, we provide a procedure for a constrained optimization problem. The genetic algorithm has been utilized for the systematic solution, and presented are results obtained for a hypothetical example. Robustness analysis was also performed on the results showing that in case of any uncertainty associated with Delta V firings, the spacecraft could still complete the mission and rendezvous with the asteroid. One unique aspect of the paper is the conducted robustness analysis, which provides a feasible error bound for (still) achieving a successful mission. With this, in this paper, we present a robust optimal mission design approach for asteroid rendezvous problems.

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2.1207 Studies of Short Time Response Options for Potentially Hazardous Objects (PHOs)

Bernard Seery (NASA - Goddard Space Flight Center), Mark Boslough (Sandia National Laboratories), Brent Barbee (NASA - Goddard Space Flight Center), Paul Miller , Joseph Nuth (NASA - Goddard Space Flight Center), Luke Oman (NASA/Goddard Space Flight Center), Catherine Plesko ,

Presentation: Bernard Seery, Thursday, March 12th, 10:10 AM, Madison

NASA has been directed by Congress to undertake a comprehensive search to detect asteroids larger than 140m in diameter, with the expectation that early detection of an object can lead to well thought out and effective measures to deflect or otherwise mitigate the hazard from an object found to be on a collision course with the Earth. While many potential mitigation scenarios are possible given sufficient lead time between detection and a possible collision, there are some situations for which very little time will be available for effective action. One example of such a low-probability scenario would be a collision in the main asteroid belt that resulted in a drastic change in the orbit of a small body or in the production of a large fragment that fell directly into the inner solar system on a highly eccentric orbit. Another example is the appearance of a newly discovered comet on a trajectory that will impact or at least closely approach the Earth, much as comet Siding Spring will be approaching Mars. In both of these cases it might be wise to begin preparations for mitigation efforts before we could be certain that impact will occur, because delay will significantly reduce our chances for successful mitigation. NASA and NNSA have partnered to address these short warning time scenarios. The model output will inform space mitigation mission design studies for both kinetic impactors and nuclear devices. Results for modeling of Bennu and impactor mission concepts will be discussed.

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2.1208 Comparative Analysis of Asteroid-Deflection Approaches

Charles Weisbin (Jet Propulsion Laboratory), William Lincoln (Jet Propulsion Laboratory), Brian Wilcox (Jet Propulsion Laboratory), John Brophy (Jet Propulsion Laboratory), Paul Chodas (Jet Propulsion Laboratory), Brian Muirhead (Jet Propulsion Laboratory),

Presentation: Paul Chodas, Thursday, March 12th, 10:35 AM, Madison

Five potential methods of preventing an asteroid from colliding with Earth are compared, with the objective of helping to inform a NASA decision regarding which technology or technologies could be demonstrated in space on the proposed 2019 Asteroid Robotic Redirect Mission (ARRM). The candidates considered here are Kinetic Impactor (KI), Ion Beam Deflection (IBD), Gravity Tractor (GT), Enhanced Gravity Tractor (EGT), and Laser Ablation (LA). Under assumptions detailed in the study, we find the following: For asteroids up to about 200–300 meters in diameter, KI achieves the desired deflection with the least amount of warning time required, and its range of applicability increases to about 500–600 meters with a series of (e.g., three) missions. It has long been recognized that KI would require implementation of a second spacecraft to rendezvous with the threat object and enable precision tracking after the kinetic impact. Utilizing one of various possible “slow-push” technologies, it could also provide whatever supplementary deflection might be needed to achieve the desired trajectory change or to avoid a gravitational “keyhole” that would cause the asteroid to intercept Earth at another time. ARRM provides a good opportunity to use its high-power SEP system to perform a secondary deflection demonstration. For larger asteroids, LA shows the best performance under the single-mission scenarios, but its relatively low technology readiness level requires further work to validate key assumptions in the analysis. Nevertheless, if sufficient resources are available, testing the laser-ablation technique during ARRM is an attractive option.

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2.1209 Variation of Delivered Impulse as a Function of Asteroid Shape

Daniel Scheeres (The University of Colorado),

Presentation: Daniel Scheeres, Thursday, March 12th, 11:00 AM, Madison

This paper will review recent research results focused on the effect of realistic asteroid shapes on the linear momentum delivered to an asteroid during a mitigation attempt. We use simple models for the effect of kinetic impactors and convolve these with a realistic asteroid shape model. For the asteroid shape we use a radar-derived shape model for the asteroid Golevka that captures global topography. For a given impact site we use realistic error distributions and determine how variable the delivered linear and angular momentum impulse is. We find strongly non-Gaussian deviations in delivered momentum, indicating that it may be difficult to achieve a desired level of precision in a deflection attempt.

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Track Organizers: Farzin Manshadi (Jet Propulsion Laboratory), James Hoffman (Jet Propulsion Laboratory),

3.01 Phased Array Antenna Systems and Beamforming Technologies

Session Organizer: Janice Booth (AMRDEC Weapons Development and Integration Directorate),

3.0101 Thermal Analysis of Piezoelectric Actuators for Active Cooling of RF Phased Array Radars

Michael Kranz (EASI), Tracy Hudson (US Army AMRDEC), Janice Booth (AMRDEC Weapons Development and Integration Directorate), Michael Whitley (EngeniusMicro, LLC), Brian English (EngeniusMicro, LLC), Gregg Pohly (Dynetics), Vicki Le Fevre ,

Presentation: Michael Kranz, Monday, March 9th, 08:30 AM, Cheyenne

RF communications and radar systems present an extreme thermal management challenge. These systems are comprised of tightly packaged high wattage components requiring a controlled temperature to meet performance and reliability parameters. One approach being pursued to meet this thermal challenge is embedding piezoelectric actuators within the electronics to create synthetic air jet drives for localized cooling. Our team is developing and testing actuator test beds to mature the concepts and develop practical solutions. This investigation attempts to model these actuators in a CFD thermal analysis program, verify the results of the models with the current test beds, and then insert the model in conceptual designs of phased array antennas. The goal of the investigation is to gain insight into the practical application of this thermal management concept in a real application.

3.0102 Beam Former Development for the NASA Hurricane Imaging Radiometer

Glenn Hopkins (Georgia Tech Research Institute),

Presentation: Glenn Hopkins, Monday, March 9th, 08:55 AM, Cheyenne

The Hurricane Imaging Radiometer (HIRAD) is an airborne passive microwave synthetic aperture radiometer designed to provide high resolution, wide swath imagery of surface wind speed in tropical cyclones from a low profile planar array antenna. This paper will present the array radiometer system concept and summarize its development, including multiple flight tests on NASA's Genesis and Rapid Intensification Processes (GRIP, 2010) and Hurricane and Severe Storm Sentinel (HS3, 2012) campaigns. The paper will focus on the design goals, trades, and approach for the array antenna along-track beam former. The paper presents detail of the beam former design, implementation, integration approach, and measured performance. The paper concludes with a description of planned improvements for the next generation dual-polarized HIRAD antenna and the resulting impacts on the beam former design and integration.

3.0103 Analysis of a Polarization Agile Communication System

Michael Lockard , Frederick Block (MIT Lincoln Laboratory),

Presentation: Michael Lockard, Monday, March 9th, 09:20 AM, Cheyenne

A phased array system with polarization agility for the purpose of interference rejection is evaluated. Polarization agility is defined as a system which can transmit or receive any given polarization and switch its polarization in near real time. First, the efficiency that is sacrificed to gain polarization agility with a simple interleaved dual subarray (IDS) system is quantified. Second, the interference rejection which is gained with a random-

polarization-hopping technique is analyzed. Third, various approaches for processing the received signal are discussed and compared. The combined analysis provides a full picture of the true costs and benefits of employing a simplified communication system with polarization agility.

3.02 Ground and Space Antenna Technologies and Systems

Session Organizer: Farzin Manshadi (Jet Propulsion Laboratory), Vahraz Jamnejad (Jet Propulsion Laboratory),

3.0201 Radiation Pattern of a ULF Space-based Antenna for Controlled Removal of Energetic Trapped Protons

Maria De Soria Santacruz (University of California Los Angeles), Manuel Martinez Sanchez (MIT), Lunjin Chen (University of Texas at Dallas), Richard Thorne ,

Presentation: Maria De Soria Santacruz, Wednesday, March 11th, 08:30 AM, Jefferson

Highly energetic protons trapped in the inner Van Allen belt can disturb spacecraft operations, contaminate scientific measurements, and even cause early termination of missions. Earlier papers proposed that space-based coil antennas in the Electromagnetic Ion Cyclotron (EMIC) wave regime could potentially remove these particles by precipitating them into the atmosphere. The designs involve a coil antenna driven in DC but rotating at the desired EMIC frequency, which is capable of generating these waves and could serve as a payload on a scientific mission. This paper focuses on the radiation characteristics of this potential payload. We calculate the radiation pattern and radiation resistance of this transmitter operating in the EMIC band, taking into account the response of the plasma. We present a full-wave linear model capable of calculating the radiation pattern and radiation resistance in the far-field region of the rotating coil configuration immersed in a cold magnetized plasma consisting of protons and electrons. The model shows that the power flux is fairly confined within a very small cone around the geomagnetic field lines; the corresponding wave number vectors, however, are close to perpendicular to the Poynting flux direction. The radiation resistance is at a maximum for coil axis perpendicular to the geomagnetic field lines, which defines a preferred axis of rotation for the coil. Additionally, we show that the radiated power increases with increasing rotation frequency. We present at the end of the paper a brief discussion on thermal effects and other assumptions which should be reconsidered in future efforts.

3.0202 Phased Array-Fed Reflector (PAFR) Antenna Architectures for Space-Based Sensors

Michael Cooley (Northrop Grumman Electronic Systems),

Presentation: Michael Cooley, Wednesday, March 11th, 08:55 AM, Jefferson

Communication link and target ranges for satellite communications (SATCOM) and space-based sensors (e.g. radars) vary from approximately 400-1000 km for low earth orbits (LEO) to 35,800 km for geosynchronous orbits (GEO). At these long ranges, large antenna gains are required and most legacy systems use high gain reflectors with beams that are either fixed or mechanically steered. However, for some radio frequency (RF) sensor applications, mechanical beam scanning has inherent limitations. Phased Array Fed Reflector (PAFR) antennas provide improved performance by utilizing small feed arrays to provide electronic scanning over a limited field of view (FOV). Approximately ±5 to ±10 degrees of electronic scanning is typical for PAFRs, but this range depends on many factors. For LEO applications, the earth FOV is approximately ±55 degrees and this is well beyond therange of electronic scanning for PAFRs. However, for some LEO missions, a limited scan range is sufficient or the space vehicle design and operations can incorporate a combination of mechanical slewing and electronic scanning. In this paper, we review, compare and contrast various PAFR architectures

that are widely applicable to a diverse set of space missions (both earth sensing and interplanetary). We then compare the RF performance of these architectures and describe key hardware design and implementation trades. Space-based PAFR designs are highly multi-disciplinary, so we also describe the various design/analysis methodologies and relevant technologies. Finally, we summarize two PAFR prototype architectures that have been demonstrated at Northrop Grumman.

3.0203 Design of a New Smaller Lighter Faraday Rotator for ACERAD

Vahraz Jamnejad (Jet Propulsion Laboratory),
Presentation: Vahraz Jamnejad, Wednesday, March 11th, 09:20 AM, Jefferson

This paper describes a new Faraday rotator as part of the Quasi Optical Transmission Line (QOTL) on the Aerosol/Cloud/Ecosystems (ACE) mission. A QOTL design has been completed and laboratory tested and is the subject of a separate paper. A major component of the QOTL is a Faraday Rotator used in the simultaneous transmit and receive operation. It rotates the polarization of the transmitted and received signals by 45 degrees in opposite directions, thus creating a 90 degree polarization difference which is utilized by a linear polarizer to separate the two. This paper describes the design of a new rotator which is substantially lighter and smaller than a previous one used in the CloudSat radar jointly developed by JPL/NASA, Canadian Space Agency and other agencies. This is achieved by using better ferrite materials and a higher degree of optimization in the design. The weight and volume of the rotator have been substantially reduced to less than one third of the original. Furthermore, the RF performance of the new magnet design is much better than original design in the 94 GHz range. The new Faraday Rotator has been fabricated and tested with very good results.

3.0204 Design of a Quasi Optical Transmission Line for Cloud and Precipitation Radar System of ACE Mission

Vahraz Jamnejad (Jet Propulsion Laboratory),
Presentation: Vahraz Jamnejad, Wednesday, March 11th, 09:45 AM, Jefferson

This paper outlines the design and test of a new quasi-optical transmission line (QOTL) for feeding the reflector system in an optional instrument for deployment on the Aerosol/Cloud/Ecosystems (ACE) mission. The QOTL used to connect the transmitter and receiver to the antenna is designed for operation at W-band (94 GHz) frequency. A test-bed has been developed for the various critical components of the radar system. The challenge in using quasi-optics for ACERAD is that it must accommodate dual-polarized operation. We have developed a way to accomplish this that extends the design implemented in CloudSat radar jointly developed by JPL/NASA, Canadian Space Agency and other agencies. The new design has been prototyped using various components on a laboratory optical bench. Critical components of the QOTL have been fabricated and tested. Some results are presented.

3.03 RF/Microwave Systems

Session Organizer: James Hoffman (Jet Propulsion Laboratory),

3.0301 Transmission of Wireless Power in Two-coil and Four-coil System Using Coupled Mode Theory

Vikram Singh (VJTI), Chirag Warty (Quantspire), Manasi Bhutada (intelligent communication lab),
Presentation: Vikram Singh, Monday, March 9th, 09:45 AM, Cheyenne

Wireless Power Transfer (WPT) systems are considered as sophisticated alternatives for modern day wired power transmission. Resonance based wireless power delivery is an efficient technique to transfer power over a relatively long distance. This paper presents a summary of a two-coil wireless power transfer system with the design theory,

detailed formulations and simulation results using the coupled mode theory (CMT). Further by using the same theory, it explains the fourcoil wireless power transfer system and its comparison with the two-coil wireless transfer power system. A four-coil energy transfer system can be optimized to provide maximum efficiency at a given operating distance. Design steps to obtain an efficient power transfer system are presented and a design example is provided. Further, the concept of relay is described and how relay effect can allow more distant and flexible energy transmission is shown.

3.0302 Improved Design for Microstrip Hairpinline Bandpass Filter Using via Ground Holes and Capacitive Gap

Azhar Hasan (National University of Sciences and Technology),
Presentation: Azhar Hasan, Monday, March 9th, 10:10 AM, Cheyenne

A novel design methodology for an improved hairpinline microstrip narrowband bandpass filter is presented in this paper. The new proposed methodology incorporates use of via ground holes and a capacitive gap to improve the performance and dimensions of a conventional hairpinline bandpass filter. This design approach incorporates use of □/4 resonators thus reducing the overall size of the filter by 15.5% as compared to the conventional design. A capacitive gap is also introduced in the center of the center resonator. The proposed design achieves 3 dB Fractional Bandwidth (FBW) less than 4%, Insertion Loss (IL) less than 0.8 dB and Return Loss (RL) better than 40 dB at the center frequency of 1 GHz. The effects of tap point height, characteristic impedance and gap width are analyzed in detail and subsequent relationships are developed with the fundamental design parameters. Based on the proposed design, a bandpass filter is designed and fabricated on FR4 substrate, and good agreement is observed between measured and simulated results.

3.0303 Microwave and Millimeter-Wave Ranging for Coherent Distributed RF Systems

Jason Hodkin (Johns Hopkins Applied Physics Laboratory),
Presentation: Jason Hodkin, Monday, March 9th, 10:35 AM, Cheyenne

Microwave and millimeter-wave ranging systems, waveforms, and experimental results are described for coherent distributed RF systems applications. Measured results show that coherent distributed systems operating at carrier frequencies with coherence at $\lambda/10$ are possible well into the millimeter-wave regime by using widely separated two-tone ranging wave- forms. The two-tone waveform in the context of continuous-wave ranging is introduced. A method for overcoming the range-ambiguous output of the matched filter processing is de-scribed. Microwave and millimeter-wave ranging measurements are shown and compared to the Cramer-Rao lower bound for range accuracy.

3.0305 Digital Calibration System for the NI-SAR (NASA/ISRO) Mission

James Hoffman (Jet Propulsion Laboratory), Stephen Horst , Hirad Ghaemi (DLR (German Aerospace Center)),
Presentation: James Hoffman, Monday, March 9th, 11:00 AM, Cheyenne

The Synthetic Aperture Radar (SAR) instrument for the proposed NASA/ISRO mission would utilize a distributed architecture dubbed SweepSAR. This real-time On-orbit digital beamforming, combined with lightweight, large aperture reflectors, promises significant increases in instrument capability for solid earth and biomass remote sensing. These new instrument concepts require new methods for calibrating the multiple channels, which are combined on-board, in real-time. The benefit of this effort is that it enables a new class of lightweight radar architecture, Digital Beamforming with SweepSAR, providing significantly larger swath coverage than conventional SAR architectures for reduced mass and cost. This presentation will cover the final stages of the R&D effort, as the project transitions to a (hopefully approved) flight program.

3.04 Radio Astronomy and Radio Science

Session Organizer: Mark Bentum (University of Twente),

3.0401 The Dark Ages Radio Explorer Mission: Probing the Cosmic Dawn

Dayton Jones (Jet Propulsion Laboratory), Joseph Lazio (Jet Propulsion Laboratory), Jack Burns (University of Colorado Boulder),

Presentation: Dayton Jones, Thursday, March 12th, 11:50 AM, Gallatin

The period between the creation of the cosmic microwave background at a redshift of ~1000 and the formation of the first stars and black holes that re-ionize the intergalactic medium at redshifts of 10-20 is currently unobservable. The baryonic component of the universe during this period was almost entirely neutral hydrogen, which fell into local regions of higher dark matter density. This seeded the formation of large-scale structures including the cosmic web that we see today in the filamentary distribution of galaxies and clusters of galaxies. The only detectable signal from these dark ages is the 21-cm spectral line of hydrogen, redshifted down to frequencies of approximately 10-100 MHz. Space-based observations of this signal will allow us to determine the formation epoch and physics of the first sources of ionizing radiation, and potentially detect evidence for the decay of dark matter particles. JPL is developing low frequency antennaa, receivers, and calibration techniques to enable both all-sky spectral measurements of neutral hydrogen and ultimately to map the spatial distribution of the signal as a function of redshift. A specific application of these technologies is the Dark Ages Radio Explorer (DARE) mission. This small Explorer class mission is designed to measure the sky-averaged hydrogen signal from above the far side of the Moon. Data from DARE will complement ground-based radio observations of the final stages of intergalactic re-ionization at higher frequencies.

3.05 Miniaturized RF/Microwave Technologies Enabling Small Satellite and UAV Systems

Session Organizer: Tushar Thrivikraman (Jet Propulsion Laboratory), Dimitris Anagnostou (South Dakota School of Mines and Technology),

3.0501 High Efficiency LINC Transmitters for Nano-Satellite Missions.

Visweswaran Karunanithi (Innovative Solutions In Space.BV),

Presentation: Visweswaran Karunanithi, Thursday, March 12th, 08:30 AM, Cheyenne

The growing interest in the area of nano-satellite development has escalated in the recent years. Space agencies and private industries have started developing nano-satellites for more serious missions in the areas of Space Operations, remote sensing and Space Research. The sudden increase in the number of nano-satellite missions has led to a challenge in frequency coordination, this has led to investigating spectrally efficient modulation schemes. This paper deals with the challenges in incorporating spectrally efficient modulation schemes such as 16-APSK, 32-APSK and QAM modulations.
The major challenges is to design a transmitter/PA that can both efficiently and linearly amplify such signals, this paper describes a trade-off performed on various efficiency and linearity enhancement techniques to choose the most appropriate transmitter/PA architecture for nano-satellites and discusses the measurement results performed on a LINC PA that was designed for 900MHz.

3.0502 X-Band Deep Space Cubesat Radio Microwave and Power Electronics

Fernando Aguirre (JPL),

Presentation: Fernando Aguirre, Thursday, March 12th, 08:55 AM, Cheyenne

This paper describes the design, fabrication and test results of the X-Band hardware for the Jet Propulsion Laboratory's (JPL) INSPIRE Cubesat deep space radio also known as Iris. The radio communicates with NASA's Deep Space Network (DSN) and is the first known deep space Cubesat radio to take part in the DSN communication link. The complete RF electronics stack weighs less than 300 grams, has a modulation bandwidth of greater than 100MHz, puts out greater than 24dBm of RF power and has greater than 50dB of receiver adjustable gain control (AGC) range. The antennas are Right-Hand Circular Polarized (RHCP) patches and are designed to attach to the top and bottom of the Cubesat structure to allow for broad coverage in the case of tumbling. The electronics is composed of Commercial off the Shelf (COTS) parts selected in order to meet the typical Cubesat budget constraints and avoid long lead times. The RF electronics is designed to accommodate the use of custom aluminum covers and commercially available gasket shielding. These cover assemblies were designed and put in place in order to reduce Electromagnetic Interference (EMI), crosstalk and also provide a relatively large thermal mass to help stabilize and spread the heat resulting from dissipated power in the electronics.

3.0503 K-Band 26GHz Tone Generator for ISARA Cubesat

Fernando Aguirre (JPL),

Presentation: Fernando Aguirre, Thursday, March 12th, 09:20 AM, Cheyenne

This paper describes the design and fabrication of a 26GHz tone generator for the ISARA Cubesat. The tone generator uses a phase locked loop (PLL) frequency multiplier to get to 26GHz from an on board temperature compensated crystal oscillator (TCXO). The output of the PLL feeds a solid state power amplifier (SSPA) that puts out approximately 27dBm of RF power. The SSPA output then feeds a monolithic microwave integrated circuit (MMIC) switch which toggles between a high gain and low gain antenna as part of the ISARA experiment. The microwave electronics is packaged in an aluminum chassis and utilizes hybrid assembly technology. There are bare die with ribbon and wire interconnects in addition to printed circuit boards (PCB) which use surface mount technology (SMT) for assembly. Custom distributed circuits were designed for implementing the 26GHz filters, couplers and power detectors. A key aspect of this module's performance is its overall thermal stability which is highly dependent upon its assembly technology. The order of operations of each assembly phase, attachment materials, contamination control and reliability of interconnects all determine how well the hardware performs in flight.

3.0504 Adaptive Flexible Antenna Array System for Deformable Wing Surfaces

Dimitris Anagnostou (South Dakota School of Mines and Technology), Mina Iskander ,

Presentation: Dimitris Anagnostou, Thursday, March 12th, 09:45 AM, Cheyenne

A 4x1 coplanar and flexible antenna array for deformable surfaces is studied under different bending angles. It is assumed that the array is bent from one edge on top of an insulating cylinder (single-edge cylindrical bending). Due to flexing, the array radiates a tilted main beam. The beam can be redirected back toward its original direction by applying the correct phase difference between the elements. This compensation phase vector is calculated using a closed-form equation. Simulated results are presented, showing successful recovery of the intended radiation direction. The autonomous array can be used in unmanned aerial vehicles with wings that bend or flex on demand, morphing wings, adaptive wings, as well as on other surfaces where it is required to focus an antenna pattern toward a specific location with respect to the mounting surface. Measurement results will be presented at the Conference.

TRACK 4: COMMUNICATION & NAVIGATION SYSTEMS & TECHNOLOGIES

Track Organizers: Shirley Tseng (Tseng LLC), Phil Dafesh (Aerospace Corporation)

4.01 Evolving Space Communication Architectures

Session Organizer: Shervin Shambayati (SSL),

4.0101 Architecting Space Communication Networks under Mission Demand Uncertainty

Marc Sanchez Net (Massachusetts Institute of Technology), Inigo Del Portillo (Massachusetts Institute of Technology), Daniel Selva (Massachusetts Institute of Technology), Bruce Cameron (Massachusetts Institute of Technology),

Presentation: Marc Sanchez Net, Monday, March 9th, 08:30 AM, Amphitheatre

NASA's Space Network has been a successful program that has provided reliable communication and navigation services for three decades. As the third generation of satellites is being launched, alternatives to the current architecture of the system are being studied in order to improve the performance of the system, reduce its costs and facilitate its integration with the Near Earth Network and the Deep Space Network. Within this context, past research has proven the feasibility of efficiently exploring a large space of alternative network architectures using a tradespace search framework. Architecting a space communication network is a complex task that requires consideration of uncertainty, namely (1) factoring in customer demand variability, (2) predicting technology improvements and (3) considering possible budgetary constraints. This paper focuses on adding uncertainty associated with (1) to the existing communications network architecture tool by describing a heuristic-based model to derive mission concept of operations (conops) as a function of communication requirements. The accuracy of the model is assessed by comparing real conops from current TDRSS-supported missions with the predicted concept of operations. The model is used to analyze how customer forecast uncertainty affects the choice of the future network architecture. In particular, four customer scenarios are generated and compared with the current TDRSS capabilities.

4.0102 The Role of Margin in Link Design and Optimization

Kar Ming Cheung (Jet Propulsion Laboratory),

Presentation: Kar Ming Cheung, Monday, March 9th, 08:55 AM, Amphitheatre

Link analysis is a system engineering process in the design, development, and operation of communication systems and networks. In this paper, we perform in-depth analysis on the relationship between BER/FER requirement, operating SNR, and coding performance curve. We compute the "true" SNR design point that would meet the BER/FER requirement by taking into account the fluctuation of signal power and noise power at the receiver, and the shape of the coding performance curve. This analysis yields a number of valuable insights on the design choices of coding scheme and link margin for the reliable data delivery of a communication system – space and ground. We illustrate the aforementioned analysis using a number of standard NASA error-correcting codes.

4.02 Communication Protocols and Services for Space Networks

Session Organizer: Loren Clare (Jet Propulsion Laboratory), Steven Berson (Aerospace Corporation),

4.0201 A Self-Stabilizing Hybrid-Fault Tolerant Synchronization Protocol

Mahyar Malekpour (NASA-LaRC),
Presentation: Mahyar Malekpour, Monday, March 9th, 04:30 PM, Amphitheatre

This paper presents a strategy for solving the Byzantine general problem for self-stabilizing a fully connected network from an arbitrary state and in the presence of any number of faults with various severities including any number of arbitrary (Byzantine) faulty nodes. The strategy consists of two parts: first, converting Byzantine faults into symmetric faults, and second, using a proven symmetric-fault tolerant algorithm to solve the general case of the problem. A protocol (algorithm) is also presented that tolerates symmetric faults, provided that there are more good nodes than faulty ones.

4.0202 NCSR: Multicast Transport of BGP for Satellite Network Based on Network Coding

Wei Han , Baosheng Wang , Zhenqian Feng , Zhu Tang , Baokang Zhao , Wanrong Yu ,
Presentation: Jinzhen Bao, Monday, March 9th, 04:55 PM, Amphitheatre

To integrate the satellite systems into the terrestrial IP network, border gateway protocol BGP is considered as a promising candidate. Taking advantage of wireless broadcast property could significantly improve the bandwidth occupation of BGP routing transport in GEO satellite network. However, its performance would be seriously degraded when interfered with the environment. This paper proposes NCSR (Network Coding for Satellite network BGP Routing transport) which applies network coding to multicast transport of BGP in GEO satellite network. NCSR exploits the broadcasting feature and achieves reliable multicast transport of BGP over the lossy space links. Representative mechanisms in transport layer are chosen to evaluate bandwidth improvement in typical scenario of DVB-S2/RCS. Through theoretical analysis and extensive simulations, we compared NCSR with other existing proposals. Results show that NCSR can not only tolerate more packet losses, but also significantly reduce more bandwidth cost of BGP. Moreover, the benefits of NCSR increase sharply with the number of participated ground terminals and the rate of packet loss.

4.03 Navigation and Communication Systems for Exploration

Session Organizer: Patrick Stadter (Johns Hopkins University/Applied Physics Laboratory), David Copeland (Johns Hopkins University/Applied Physics Laboratory),

4.0301 Monopulse Autotrack Methods Using Software-defined Radios

Norman Adams (Johns Hopkins University/Applied Physics Laboratory), Brian Sequeira , Matthew Bray (Johns Hopkins Applied Physics Laboratory), Dipak Srinivasan (Johns Hopkins University/Applied Physics Laboratory), Ron Schulze (Johns Hopkins University/APL), Simmie Berman (Johns Hopkins University Applied Physics Laboratory), Hollis Ambrose (Johns Hopkins University/Applied Physics Laboratory),
Presentation: Matthew Bray, Sunday, March 8th, 04:30 PM, Amphitheatre

Space missions with large-aperture Ka-band antennas face challenging pointing requirements. We propose a monopulse autotrack technique to mitigate this challenge. The proposed system receives an X-band uplink and estimates angle error to assist with Ka-band downlink pointing. Rather than rely on high-order modes or passive RF hardware, we implement the monopulse using traditional digital carrier-recovery methods. Modern space-born software-defined radios provide accurate and flexible phase tracking capability. This capability can be leveraged for both phase and amplitude monopulse sensors. With appropriate integration and filtering the proposed system provides point-

ing estimates with RMS error less than 0.01 degrees even at receive power levels as low as -150 dBm. By avoiding implementations that use passive hardware, the system designer has greater flexibility. For example, both 3-element and 4-element systems can be realized, and antenna spacing is flexible and need not be equal or mutually orthogonal. Furthermore, this method can operate both as a closed-loop autotrack system or as an open-loop calibration system where absolute angle estimates are required, and can reuse hardware that supports radio functionality. Simulation results are presented and practical implementation and calibration methods are discussed. NASA's Europa Clipper mission is used as an example to evaluate the efficacy of this method for outer planets exploration.

4.0302 MESSENGER Solar Scintillation Measurements at Superior Solar Conjunction

Nelli Mosavi (Johns Hopkins University/Applied Physics Laboratory), Curtis Menyuk (UMBC), David Copeland (Johns Hopkins University/Applied Physics Laboratory), Brian Sequeira ,

Presentation: Nelli Mosavi, Sunday, March 8th, 04:55 PM, Amphitheatre

During the superior solar conjunction of spacecraft, the spacecraft have a very limited communication with the ground station due to the effects of the Sun on the RF signal transmission. I will talk about our analyses of data received during a recent solar conjunction of MESSENGER (MErcury Surface, Space ENivornment, GEochmeisty, and Ranging) , which shown that within the time during which a single frame is transmitted, the RF signal propagation is strongly dominated by amplitude scintillation. I will also talk about the X-band scintillation data which follows a curve that is representative of Ka-band performance as predicted by a previous model.

4.0303 Telemetry Ranging Using Software Defined Radios

Joseph Hennawy (JHU/APL), Norman Adams (Johns Hopkins University/Applied Physics Laboratory), Jon Hamkins (Jet Propulsion Laboratory), Peter Kinman (California State University Fresno), Dipak Srinivasan (Johns Hopkins University/Applied Physics Laboratory), Victor Vilnrotter (Jet Propulsion Laboratory),

Presentation: Joseph Hennawy, Sunday, March 8th, 05:20 PM, Amphitheatre

Telemetry ranging is a technique that inserts ranging data measured by the spacecraft into the downlink telemetry stream, thereby avoiding the need to allocate downlink power for a ranging signal. This technique has many benefits depending on the mission profile, from increased data return to operational simplification. The present study considers a variation to the ranging technique presented in [K Andrews et al., Telemetry-Based Ranging, 2010] in order to facilitate implementation in a software-defined radio (SDR). This implementation tracks an uplink PN range code and measures the code phase coincident with the start of downlink telemetry frames. The phase is then embedded in subsequent telemetry frames. The method is implemented in the JHU/APL Frontier Radio and leverages the PN ranging design from the NASA New Horizons communication system. Initial test results are summarized and indicate that the method is viable for space exploration.

4.04 Relay Communications for Space Exploration

Session Organizer: David Israel (NASA - Goddard Space Flight Center), Charles Edwards (Jet Propulsion Laboratory),

4.0401 Commercialization and Standardization Progress towards an Optical Communications Earth Relay

Bernard Edwards (NASA), David Israel (NASA - Goddard Space Flight Center),

Presentation: Bernard Edwards, Sunday, March 8th, 09:00 PM, Amphitheatre

This paper and presentation will describe NASA efforts in the on-going deployment, commercialization, and standardization of optical communications. Commercialization and standardization are seen as critical to making optical communications a reality on future NASA science and exploration missions. Commercialization is important because NASA would like to eventually be able to simply purchase an entire optical communications terminal from a commercial provider. Inter-operability standards are needed to ensure that optical communications terminals developed by one vendor are compatible with the terminals of another. International standards in optical communications would also allow the space missions of one nation to use the infrastructure of another.

4.0402 MAVEN Relay Operations

Neil Chamberlain (Jet Propulsion Laboratory), Phil Barela (Jet Propulsion Laboratory), Kristoffer Bruvold (Jet Propulsion Laboratory), Roy Gladden (Jet Propulsion Laboratory),

Presentation: Neil Chamberlain, Sunday, March 8th, 09:25 PM, Amphitheatre

The Mars Atmosphere and Volatile EvolutioN (MAVEN) mission launched in late 2013 and began operations in November 2014 following a 10 month cruise to Mars. The mission will study the upper atmosphere of the planet. In addition to the science instruments, the MAVEN spacecraft is equipped with an Electra UHF transceiver to support relay communication with landed assets. This paper describes how the UHF relay service was developed and validated through assembly test and launch operations (ATLO) as well as during cruise and transition to Mars orbit. The discussion includes a brief description of the Electra payload, a description of various functional and thread tests conducted during ATLO, a description of checkout activities during Cruise, a ground-based operational readiness test to simulate a future contact with the Mars Science Laboratory (MSL) rover, and a description of an actual overflight with MSL during Transition.

4.0403 NASA Relay Planning for the 2016 Mars Mission Opportunity

Charles Edwards (Jet Propulsion Laboratory), Phil Barela (Jet Propulsion Laboratory), Roy Gladden (Jet Propulsion Laboratory), Charles Lee (Jet Propulsion Laboratory),

Presentation: Charles Edwards, Sunday, March 8th, 09:50 PM, Amphitheatre

2016 promises to be a busy year for Mars exploration. NASA's InSight Lander mission will arrive at the Red Planet on Sep 28, 2016. Three weeks later, on Oct 19, ESA's ExoMars/Trace Gas Orbiter (TGO) will insert into Mars orbit, carrying a NASA-provided Electra relay payload. That same day, ESA's Entry, Descent and Landing (EDL) Demonstrator Module (EDM), Schiaparelli, will land in the Meridiani Planum, after having separating from the ExoMars/TGO cruise stage three days earlier. In this paper we discuss the plans for support of these two landers by NASA's suite of relay orbiters, including Odyssey, the Mars Reconnaissance Orbiter (MRO), and the Mars Atmosphere and V olatile EvolutioN (MAVEN) mission.

4.05 Panel: Space Communication Systems Roundtable: Networking the Solar System

Session Organizer: Shirley Tseng (Tseng LLC),

4.06 Innovative Space Communications and Tracking Techniques

Session Organizer: Kar Ming Cheung (Jet Propulsion Laboratory), Alessandra Babuscia (NASA Jet Propulsion Laboratory),

4.0601 Full-Duplex (Simultaneous Transmit and Receive) for LEO Satellites

Eugene Grayver (Aerospace Corporation),

Presentation: Eugene Grayver, Monday, March 9th, 09:20 AM, Amphitheatre

Simultaneously transmitting and receiving on the same frequency has long been considered a fundamental impossibility in wireless communication. Recent research activity has sought to challenge this limit. The main challenge is dealing with very high self-interference due to the high power transmit (TX) signal leaking into the receive (RX) path. The larger the difference between the TX and RX power, the more challenging the problem. A link to a low Earth orbit (LEO) satellite requires at least 130 dB of cancellation for full duplex communication to be achievable. This paper presents initial results for a ground-LEO full-duplex link. Starting with a link budget, we derive the expected power levels, and therefore the required cancellation. We then formulate features of the satellite channel that make it feasible to even consider achieving 130 dB of cancellation. Unlike previous efforts that focused on relatively low-cost implementations suitable for commercial market, this effort relies on expensive and hand-tuned components. The initial goal is to develop a link suitable for a small LEO satellite (e.g. cubesat) with limited (1MHz) bandwidth. The paper then provides initial experimental results using high-end RF and mixed-signal components. Cancellation is achieved using a combination of RF and baseband techniques. This paper presents the best known amount of self-interference cancellation with RF and baseband techniques. This goal is clearly ambitious and the work is not yet complete. However, the results are promising enough to warrant additional research.

4.0602 Multi-Target Tracking via Multiple Cost-Reference Particle Filtering

Monica Bugallo (Stony Brook University),
Presentation: Jordi Vilà Valls, Monday, March 9th, 09:45 AM, Amphitheatre

We address the problem of multitarget tracking in a network of sensors collecting received signal strength measurements. In order to deal with the nonlinear nature of the system, we apply the particle filtering methodology. The focus is on high-dimensional systems, i.e., scenarios with large number of targets. This justifies the use of an interconnected bank of particle filters. At each algorithmic step, each individual particle filter tracks one target, thereby minimizing the load of each filter. The filters need to send/receive the necessary information to/from other filters for correct functioning and accurate performance. The individual filters do not use any probabilistic assumption about the noises in the system in order to obtain a more robust scheme. Alternatively, they employ a user-defined cost function, which makes the resulting method more flexible. Computer simulations show the validity of the approach and reveal a good performance of the proposed method when compared to existing techniques.

4.0603 Inflatable Antennas and Arrays for Interplanetary Communication Using CubeSats and SmallSats

Alessandra Babuscia (NASA Jet Propulsion Laboratory), Kar Ming Cheung (Jet Propulsion Laboratory), Charles Lee (Jet Propulsion Laboratory), Thomas Choi (Jet Propulsion Laboratory),
Presentation: Alessandra Babuscia, Monday, March 9th, 10:10 AM, Amphitheatre

In the past, great progress has been made in the development of small satellites and CubeSats, mainly for low Earth orbit. Currently, a new technological trend is the development of technologies and strategies for potential interplanetary applications of small platforms (CubeSats/Satellites). Given the limited size, mass and power capabilities of these small platforms, one of the most interesting problems is how to allow small satellites to communicate from very far distance in the solar system. This paper aims to review and possibly combine two solutions for the problem: the use of inflatable antenna reflectors and the arrays across multiple spacecraft. An overview of the inflatable antenna technology, its development and tests, its applicability in terms of frequencies and sizes, and the advantages with respect to other technologies is described. An overview of cooperative communication techniques across small platforms is presented and the main challenges of arraying antennas on different spacecraft are underlined. Finally, the two solutions are combined to provide a first order quantification of the advantages in terms of EIRP, data rate and range.

4.0604 SOARX-8 Suborbital Experiments 2014 a New Paradigm for Small Spacecraft Communication

Thom Stone (NASA - Ames Research Center), Richard Alena (NASA Ames Research Center), Marcus Murbach (NASA Ames), Ray Gilstrap (NASA Ames Research Center),

Presentation: Marcus Murbach, Monday, March 9th, 10:35 AM, Amphitheatre

The SOAREX-8 sounding rocket payload will launch from the NASA Wallops Flight Facility in May, 2015 and will achieve an apogee of ~280km. It will be a test-bed for several interesting technologies. Primarily is the Exo-Brake, a passive drag-based de-orbit system to bring small payloads back from the ISS and deep space sample return and Mars exploration. Also included are several communication technologies for sub-orbital and nano-satellite missions. Key components were developed in modular form, which made testing of the satellite bus and communications elements easier. Module 0 is a 28v ‘sounding rocket’ system deck with a c-band transponder. Module 1 is the TechEdSat-5 nano-satellite deck – which includes an ZigBee wireless base station and sensors. An Iridium Short Burst Data (SBD) modem sends the packetized wireless sensor data to the ground. Module 2 is a new PhoneSat-3 bus that includes a one-way Wifi demonstrator which will broadcast to a dish on the ground. Module 3 includes an experimental space camera tied to a nano-satellite-sized x-band transmitter. The ZigBee sensor experiment will demonstrate in-flight wireless capability. Also, the Iridium, Wifi and x-band represent future data transmission protocols useful to NASA and to future nano-satellite projects. The Wifi and x-band transmitters represent 1 and 10 MBS overflight solutions for dramatically increasing the data transmitted from LEO.

4.07 Space Navigation Techniques

Session Organizer: Amir Emadzadeh (Qualcomm),

4.0702 X-ray Pulsar Navigation Algorithms and Testbed for SEXTANT

Luke Winternitz (NASA - Goddard Space Flight Center), Munther Hassouneh (NASA), Jason Mitchell (NASA - Goddard Space Flight Center), Samuel Price (NASA), Sean Semper (NASA Goddard Space Flight Center), Wayne Yu , Paul Ray (Naval Research Laboratory), Kent Wood (Naval Research Laboratory), Zaven Arzoumanian , Keith Gendreau (NASA - Goddard Space Flight Center),

Presentation: Munther Hassouneh, Thursday, March 12th, 10:35 AM, Amphitheatre

The Station Explorer for X-ray Timing and Navigation Technology (SEXTANT) is a NASA funded technology demonstration. SEXTANT will, for the first time, demonstrate real-time, on-board X-ray Pulsar-based Navigation (XNAV), a significant milestone in the quest to establish a GPS-like navigation capability available throughout our Solar System and beyond. This paper describes the basic design of the SEXTANT system with a focus on core models and algorithms, and the design and continued development of the GSFC X-ray Navigation Laboratory Testbed (GXLT) with its dynamic pulsar emulation capability. We also present early results from GXLT modeling of the combined NICER X-ray timing instrument hardware and SEXTANT flight software algorithms.

4.0703 Laboratory Testing of a Relative Navigation System for Spacecraft Docking

Zoran Milenkovic (Charles Stark Draper Laboratory), Fred Clark (Charles Stark Draper Laboratory), Jack Brazzel (NASA),

Presentation: Zoran Milenkovic, Thursday, March 12th, 11:00 AM, Amphitheatre

Presenting methods to test relative navigation algorithms in a laboratory setting. The components involved in the testing include hardware in the form of flash LIDAR etc. The software includes a 6DoF simulation and the aforementioned navigation algorithms.

4.0704 Improve EKF and UKF Algorithm with RTS Smoother on Ground Base Orbit Determination

Hamed Heydarifar (Iran University of Science and Technology),
Presentation: Hamed Heydarifar, Thursday, March 12th, 11:25 AM, Amphitheatre

In order to reduce the effects noise and bias on position and velocity of satellite and tracking by a single non-moving observer an improved UKF algorithm based on Rauch-Tung-Striebel smoother (RTS) is presented and an explicit analysis of its location performance is made. To evaluate the performance of this smoother, compared this algorithm with an extended Rauch-Tung-Striebel algorithm through the simulations of a Radar tracking problem.

4.08 Communication System Analysis & Simulation

Session Organizer: James Hant (Aerospace Corporation), Yogi Krikorian (Aerospace Corporation),

4.0802 Robust Low-Density-Parity-Check Decoder Design to Mitigate Pulsed Radio Frequency Interference

Jianjun (David) Ni (NASA - Johnson Space Center), Chatwin Lansdowne (NASA - Johnson Space Center),
Presentation: Jianjun (David) Ni, Monday, March 9th, 11:00 AM, Amphitheatre

Low-Density Parity-Check (LDPC) codes are a class of forward error correction (FEC) linear block codes which provide near-capacity performance for power-efficient communications. Optimum decoding requires accurate combining ratio estimation to scale the input signal in an additive white Gaussian noise channel (AWGN). Test data and analysis show that the performance of the optimal LDPC decoding algorithm is severely degraded when encountering pulsed radio frequency interference (RFI) from sources such as ground based radars. This research effort first reveals that the LDPC performance degradation under pulsed RFI is not due to the burst of errors but to the inaccurate combining ratio estimation. Although an ideal combining ratio estimator (symbol-wise) could mitigate the degradation caused by pulsed RFI, it is not practical for implementation. Some near optimal LDPC decoding algorithms which do not require combining ratio estimation are investigated. One near optimum decoding algorithm "min-scale" is proposed in the robust decoder design to mitigate pulsed RFI. Analysis shows that "min-scale" only loses about 0.2 dB performance compared to the optimal decoding algorithm under nominal condition; in a pulsed RFI environment, the designed performance can be achieved if the system design has adequate margin. Without combining ratio estimation, the decoder design complexity is reduced and the risk of performance degradation due to combining ratio estimation error is eliminated. This robust decoder design enables reliable communications to space vehicles which may encounter strong pulsed RFI signals from high power radar systems.

4.09 Wideband Communications Systems

Session Organizer: David Taggart (Self), Claudio Sacchi (University of Trento),

4.0901 Three Dimensional Diversity for Close Proximity MIMO Systems

Aditi Parthasarathy (University of Mumbai), Chirag Warty (Quantspire),
Presentation: Aditi Parthasarathy, Wednesday, March 11th, 08:30 AM, Cheyenne

The problem that needs to be consider in a multi user distributes and decentralized network is the interception of transmitted signal by an undesirable node.A decentralized system is nothing but a data processing system in which all information is processed locally without the need for a Central Processing Facility where various effects like multipath and scattering causes non- orthogonality of the symbols. To overcome these problems spatial, time and frequency diversity can be used. This paper proposes a three dimensional (Space, Time and Frequency) diversity involving frequency hopping and space time coding technique. A three dimensional system is demonstrated to support heterogeneous networks in LTE advanced standards.Because of limited spectrum and absence of a protected physical boundary, wireless systems face much more serious challenges in capacity and security than wired networks. When transmitted through the air link, wireless signals are more prone to jamming and interception. The main purpose of Frequency hopping (FH) technique is to avoid the interference which is likely to happen in wireless systems. To improve system performance against malicious nodes a space time coded frequency hopping (STC-FH) based on the orthogonal frequency division multiple access (OFDMA) is proposed. The system considers Almouti block codes and Trellis codes to achieve diversity. The results considers orthogonal frequency division multiplexing which uses cyclic prefix in a space time block coding (STBC) transmission scheme.

4.0902 Effects of Turn-around-command on SGLS Carrier, Ranging, and Telemetry Services

Jack Kreng (Aerospace Corporation),
Presentation: Jack Kreng, Wednesday, March 11th, 08:55 AM, Cheyenne

This paper deals with command and control of a satellite with the effects of turnaround-command signal (TAC) and intermod products (IMs) in the downlink services, with and without the effects of TAC in the downlink services. For a small uplink command modulation index of 0.3 radians, our analyses for both USB and SGLS signals show that the loss of downlink power to TAC and IM is less than 10% or about 0.5 dB. However, when the uplink command modulation index increases to a nominal operating value of 1.0 radian, the loss of downlink service power to TAC and IM increases to 40% which is equivalent to a loss of about 2.2 dB. This increase in the TAC and IM powers will reduce the power to all desired downlink services, which in turn could result in reduced or denial of services to many ground users or stations.

4.0903 Implementing High Data Rate, Low Density Parity Check (LDPC) Decoders for Large Codes Using FPGAs

John Porcello (Blueprint Signal Processing, Inc.),
Presentation: John Porcello, Wednesday, March 11th, 09:20 AM, Cheyenne

This paper considers High Data Rate FPGA implementation issues of LDPC Codes for large LDPC codes. The focus of this paper is on high data rate FPGA architectures based on the Sum-Product Algorithm that support decoding large LDPC codes in FPGAs. Performance charts and design data are provided to support an implementation approach for high data rate, large LDPC codes and quantify required hardware resources. A discussion of trade space for LDPC code implementation based on FPGA resources is also provided. Finally, an example design is provided to illustrate the concepts discussed in the paper and provide insight into the challenging task of implementing high data rate, LDPC decoders for large codes in FPGAs.

4.0904 Coded Sub Band Replacement DWT Based Space Image Compression

Jaypal Baviskar (Veermata Jeebai Technological Institute (VJTI), Mumbai, India), Afshan Mulla (Veermata Jeejabai Technological Institute, Mumbai, India),
Presentation: Vikram Singh, Wednesday, March 11th, 09:45 AM, Cheyenne

One of the application in satellite communication is to capture and transmit high quality and hyper-spectral images back to the ground station. These images require very high bandwidth, more transmission time and large storage memory. Moreover, the link used for communication is susceptible to various noises. Hence, need for image compression with high compression ratio and channel encoding technique with minimum distortion becomes imperative. In this paper, we have proposed a quality constrained compression algorithm for space images based on novel Sub-band Replacement-DiscreteWavelet Transform (SR-DWT) technique. It has spatial-frequency decomposition property that provides quality assessment for captured images. Also, a Low-Density Parity Check (LDPC) encoder for channel coding is proposed to minimize the effect of noise over the transmission channel. The various image quality parameters viz. Peak Signal to Noise Ratio (PSNR), Processing Time, Compression ratio etc are evaluated and plotted against bits per pixel (bpp).

4.0905 De Bruijn Sequences for DS/CDMA: Efficient Generation, Statistical Analysis, Performance Evaluation

Claudio Sacchi (University of Trento), Susanna Spinsante (Universita' Politecnica delle Marche), Chirag Warty (Quantspire), Ennio Gambi (Università Politecnica delle Marche),

Presentation: Claudio Sacchi, Wednesday, March 11th, 10:10 AM, Cheyenne

Nowadays, Direct Sequence Code Division Multiple Access (DS/CDMA) still represents the core technology for the physical layer of several commercially-remunerative applications and standards. In many applications, a very critical issue of Spread Spectrum and CDMA is represented by the necessity of keeping the probability of intercept as lowest as possible. As shown in some recent works, the use of De Bruijn sequences may represent a valuable solution to the aforesaid issue. De Bruijn sequences are nonlinear shift register sequences, whose sets are characterized by a cardinality much larger than the sequence length. This paper aims at considering some significant aspects about the usage of De Bruijn sequences in DS/CDMA not yet addressed by prior works: i) provision of a computationally-efficient algorithm able at generating large-cardinality subsets of De Bruijn and modified De Bruijn sequences of arbitrary length; ii) formal analysis of De Bruijn (and modified De Bruijn) sequence randomness in terms of estimated linear complexity; iii) statistical analysis of the multi-user interference (MUI) in terms of 2nd order (variance) and 4th order (normalized kurtosis) statistics and comparison with theoretical lower bounds; iv) Link performance evaluation in terms of average Bit-Error-Probability (BEP) computed with tight upper and lower bounds [3] and closed-form approximated analytical expressions (Gaussian approximation and non-Gaussian evaluation of [4]) for what concerns the matched filter receiver. Results yielded by De Bruijn sequences, modified De Bruijn sequences have been discussed in the final paper and compared with those of state-of-the-art Gold sequences.

4.0906 Link Performance Analysis of Cooperative Transmission Techniques for LTE-A Uplink

Claudio Sacchi (University of Trento), Talha Rahman (University of Trento), Christian Schlegel (Dalhouse University),

Presentation: Claudio Sacchi, Wednesday, March 11th, 10:35 AM, Cheyenne

A very recent trend in wireless communications is to counteract the effects of large-scale fading and multipath propagation by means of cooperation [1]. More recently, a new concept based on cooperation is introduced for latest release of LTE-A standard, known as Coordinated Multipoint communications (CoMP). Virtual/network MIMO is another interesting application of cooperative communications, which is strictly related to CoMP. As stated in [2], multi-cell MIMO cooperation can literally exploit inter-cell interference by allowing users to be jointly processed by several interfering base stations. In [2], different levels of multi-cell cooperation are considered, namely: 1. Interference coordination, based on the Channel State Information (CSI) sharing among different cells obtained via feedback channels. Such a kind of coordination is targeted at interference cancellation; 2. MIMO cooperation, where different cells share not only CSI, but also the full data signal of their respective users in order to exploit diversity; 3. Rate-limited MIMO cooperation, based on limited sharing of CSI and allowing partial interference cancellation; 4. Relay-assisted cooperation, based on the relay nodes assistance instead of direct cell backhauling.

4.0907 Green BIC-OFDM-based Cooperative Communications Using Bargaining Game Algorithm

Claudio Sacchi (University of Trento),
Presentation: Claudio Sacchi, Wednesday, March 11th, 11:00 AM, Cheyenne

In this paper, a relay-based energy-efficient cooperative communication strategy is proposed, under the hypothesis that the relay transmits with power drawn from energy-harvesting (EH) sources. Assuming a deterministic EH model under which the harvested amount of energy is known prior to transmission, a spectrally efficient adaptive Bit-Interleaved Coded (BIC) OFDM modulation scheme has been investigated. To guarantee the successful reception of a packet, Automatic Repeat Request (ARQ) protocol has been adopted. Assuming a long term static channel, the expected goodput (EGP) metric is used as cost function to be optimized. In order to obtain an easy, yet accurate, formulation of the EGP, its analytical expression is provided resorting to the link performance evaluation method known as effective SNR (ESM) mapping. The most significant step-ahead of the proposed approach with respect to state-of-the-art is to increase the cooperation gain by using a bargaining game algorithm. The bargaining game algorithm takes into account the energy status of the relay and helps the source node to decide whether to cooperate or not with the relay. The players of the game are two: the source node and the relay and they can choose different cooperation strategies. Simulation results show that the bargaining game algorithm actually helps the nodes to select the right strategy, with a substantial goodput improvement, in particular when the energy availability of relay becomes intermittent due to the harvesting.

4.0908 A High Speed Transmission System Using QAM and Direct Conversion with High Bandwidth Converters

Marc Stackler (e2v), Andrew Glascott Jones (e2v),
Presentation: Marc Stackler, Wednesday, March 11th, 11:25 AM, Cheyenne

After a brief introduction explaining the objective behind the system and its component, the presentation will explain the architecture of the modulator and demodulator. Then it will focus in particular on the interface between DAC and FPGA and the timing difficulties encountered at these frequencies. It will then present the different application such a system can be implemented in and what advantage it brings.

4.0909 Adaptive Physical Layer Security Using Code Bank of Sequences for CDMA

Preetha Pillai , Shraddha Kharat , Chirag Warty (Quantspire), Susanna Spinsante (Universita' Politecnica delle Marche),
Presentation: Shraddha Kharat, Wednesday, March 11th, 04:30 PM, Amphitheatre

Wireless security is an important concern in today's technological world. Wireless devices are used to access data and private applications. From broadband to Wi-Fi, 3G to LTE Advanced, WiMAX to satellite communication every network demands on-the-air security from attacks. Tapping or Jamming attacks leak the secret data, while Service Disruption Attacks affecting QoS (Quality of Service) are relatively easy to perform.In CDMA, the channel and antenna dependent attacks are quite critical to avoid because of its wide bandwidth usage. The critical exchange of time and frequency parameters makes the physical layer elements vulnerable to security related attacks. In order to enable data security and secrecy, there is need of signal protection at the physical layer of CDMA system. Gold codes, M-sequences, OVSF and De-Bruijn sequences were used individually in wireless systems for scrambling purposes in previous proposals. These codes have their own advantages and disadvantages, when channel bandwidth and noise conditions change.This paper proposes a system which would select scrambling codes from a bank of all these mentioned codes depending upon the Signal to Noise Ratio (SNR) or Channel State Information(CSI). This code bank technique is shown as a highly practical solution in selection of proper code for mitigation of attacks and hence, to provide security at the physical layer of CDMA.

4.0910 CDMA Communications Systems with Constant Envelope Modulation for CubeSats

Dariush Divsalar (Jet Propulsion Laboratory), Alessandra Babuscia (NASA Jet Propulsion Laboratory), Kar Ming Cheung (Jet Propulsion Laboratory),

Presentation: Alessandra Babuscia, Wednesday, March 11th, 04:55 PM, Amphitheatre

A communication system for CubeSats in formation to operate in the vicinity of the Lunar Lagrangian L1 is proposed. CubeSats will collect lunar scientific data and will perform surface observations. An improved low complexity CDMA system for CubeSats for communications between the Lunar L1 and Earth station is considered. The complexity of a coded CDMA transmitter is lower than the complexity of the CDMA receiver with decoder. Therefore for downlink communications it makes sense to use encoders such as space standard LDPC code followed by a spread spectrum transmitter for CDMA systems for CubeSats. For the uplink an uncoded CDMA system is chosen since the uplink transmit power is expected to be high enough to support the use of uncoded CDMA system. The uncoded CDMA yields receivers for CubeSats that have low complexity implementation. For the downlink, based on the available bandwidth, and the data rates, a reasonable processing gain could be obtained. Thus the multiuser interference degradation due to the other CubeSats could be made small. We analyzed and simulated the proposed improved CDMA system for a concept Constellation of CubeSats. For highly efficient nonlinear power amplifiers a filtered offset QPSK with phase modulation, which is a CCSDS standard for constant envelope signaling is used. This allows a nonlinear amplifier at CubeSat to operate at saturation point for the highest efficiency. The rectangular pulses will not satisfy the bandwidth limitation imposed by the spectral standard. A Filtered offset QPSK with phase modulation is much more bandwidth efficient scheme.

4.0911 MM-Wave LTE-A Small-Cell Wireless Backhauling Based onTH-IR Techniques

Talha Rahman (University of Trento), Cosimo Stallo (University of Rome Tor Vergata), Claudio Sacchi (University of Trento),

Presentation: Giorgia Parca, Wednesday, March 11th, 05:20 PM, Amphitheatre

The back-hauling will be one of the key issues for future wireless networking in the framework of LTE- A (Long Term Evolution-Advanced) standardization. 3GPP (3rd Generation Partnership Project) standardization committee has decided to study different alternative solutions for small cell back-hauling, considering also broadband wireless solutions based on MM-wave Point-to-Point (P-t-P) and Pointto-multi Point (P-t-mP) transmissions. Currently, E-band (81-86GHz) is preferred for LOS back-hauling, while the 28 GHz band has been intensively studied for NLOS (Not Line of Sight) back-hauling. In this paper, we aim at propos ing feasible and effective solutions for LOS small-cell wireless back-haul based on UWB (Ultra Wide Band) Time-Hopping Impulse Radio (TH-IR) techniques in E-band. The motivation of the choice of TH-IR lies in the robustness of such kind of signals and in ease of generation and detection. The intrinsically low spectral efficiency is compensated by the possibility of spanning the transmitted signal over the entire available bandwidth, keeping the power spectral density as lo w as required.

Typical channel impairments affecting MM- wave transmission (nonlinear distortions, rain fading, o xygen absorption, phase noise, etc.) have been considered in our simulations. Results have shown the capability of TH-IR to reach a net capacity of 3.48 Gb/s at a distance superior to 1 Km in a point-to-multipoint 4-to-1 back-haul configuration.

4.10 Communications and/or Related Systems: Theory, Simulation, and Signal Processing

Session Organizer: Rajendra Kumar (California State University), David Taggart (Self),

4.1001 Transmission of Big Data over MANETS

Aditi Parthasarathy (University of Mumbai), Chirag Warty (Quantspire),
Presentation: Aditi Parthasarathy, Tuesday, March 10th, 09:45 AM, Madison

Big data recently has gained tremendous importance in the way information is being disseminated. Transaction based data, unstructured data streaming to and fro from social media, increasing amounts of sensor and machine-to-machine data and many such examples rely on big data in conjunction with cloud computing. It is desirable to create wireless networks on-the-fly as per the demand or a given situation. In such a scenario reliable transmission of big data over mobile Ad-Hoc networks plays a key role. Limitations like low bandwidth, congestion and loss of packets pose a challenge for such systems. Hence an effective routing mechanism plays an important role. The proposed protocol is Multipath QoS Routing (MPQR) protocol. Existing protocols try to establish a single path for communication. The proposed paper focuses on distributing tickets in the network. Also it can be divided into sub-tickets to get an optimum multipath. The principal advantage is its high performance in the case of bandwidth limited environments when compared to existing protocols.

4.1002 Radio Science Measurements Using Phase Modulated Optical Links

Dariush Divsalar (Jet Propulsion Laboratory), Victor Vilnrotter (Jet Propulsion Laboratory), Sami Asmar , Kar Ming Cheung (Jet Propulsion Laboratory),
Presentation: Kar Ming Cheung, Tuesday, March 10th, 10:10 AM, Madison

Radio Science experiments currently rely on unmodulated continuous wave RF signal carrier for spectral purity and maximized signal-to-noise ratio. This requires missions to carefully schedule them away from periods of high rate telemetry. In the era of optical communications, currently designed systems experience the same problem. In this paper, a data processing architecture is derived that will yield high-accuracy link science type of information on the ground from readily transmitted communication signals coming from space assets, through optical links. This technique is intended to save power, bandwidth and scheduling demands on the spacecraft. Our proposed technical approach is applicable to a phase modulated laser thus providing an architectural improvement to present state-of-the-art optical communication systems utilized by NASA as well as to future systems. The approach is to, first, obtain the achievable performance of Radio Science measurements from the received optical telemetry signals. This extends our previous results presented on Radio Science measurements for suppressed carrier RF signals. Secondly, a practical system is proposed that approaches the ultimate theoretical performance for estimating the amplitude, phase, and frequency variations due to the changes in the planet atmosphere. For optical links, our previous results to phase modulated CW laser communications are extended. The same information required for radio science data can be extracted by using either differential methods of encoding or phase modulated orthogonal signals and at the optical receiver a non-coherent local laser and an array of photon detectors are used. The performance of these phase modulated schemes is analyzed.

4.1003 Wind Farm Performance Validation through Machine Learning

Scott Evans (GE Research),

Presentation: Scott Evans, Tuesday, March 10th, 10:35 AM, Madison

recent methods to optimize wind farm performance require new methods to assess and validate wind farm level performance. This paper introduces a machine learning approach based on sector wise honest brokers in order to determine expectation of wind energy and validate performance improvements. The approach treats every turbine in the wind farm as a virtual Metmast. Farm level expectation of power is determined based on machine learning models trained on baseline data with input features reflecting "Honest Brokers": turbines that experience similar conditions in both a training interval and a testing interval in which we are expecting a change in farm performance. Our approach is able to validate farm level improvements even in the face of farm optimization technologies for controlling wakes that change the wind profile within the farm.

4.11 Global Navigation Satellite Systems

Session Organizer: Gabriele Giorgi (Technische Universität München), Arun Vydhyanathan (Xsens Technologies B.V.),

4.1101 Estimation of Code Ionospheric Biases Using Kriging Method

Zhibo Wen (Technische Universitaet Muenchen), Yuji Zhu (Technische Universität München), Patrick Henkel (Technische Universität München), Christoph Günther ,

Presentation: Zhibo Wen, Wednesday, March 11th, 09:00 PM, Amphitheatre

The GPS code and phase measurements include not only the geometric distance, the clock offsets, the atmospheric delays, etc., but also link-biases which are observed stable over long time. It is thus beneficial to determine the biases and provide them to the user. These link-biases are further assumed to split into receiver- and satellite-dependent parts, which enables the estimation of the biases using a network of receivers. The code ionospheric bias, also known as the Differential Code Bias (DCB), is an important correction term for single-frequency receiver. In order to estimate the biases as well as the vertical ionospheric delays, a proper modeling for the ionosphere is needed. This paper proposes a new method using Kriging estimator. Kriging estimates an unknown variable based on a set of known parameters and a variogram describing the spatial correlation. It is the best estimator in the sense of minimizing the estimation variance. With the help of the Kriging estimator, the vertical delays could be reconstructed based on a subset to overcome the rank deficiency. A Kalman filter is introduced, and a suboptimum solution has been obtained based on an iterative Greedy Algorithm. Simulation results have shown cm-level accuracy on the ionospheric bias estimates. The algorithm has also been applied with real GPS data for multiple days, which showed high bias repeatability. The bias estimates have been verified by comparison with published (DCB) values.

4.1102 Advanced KF-based Methods for GNSS Carrier Tracking and Ionospheric Scintillation Mitigation

Jordi Vilà Valls (CTTC), Pau Closas (CTTC), Carles Fernández Prades (CTTC),

Presentation: Jordi Vilà Valls, Wednesday, March 11th, 09:25 PM, Amphitheatre

Ionospheric scintillation is the name given to the disturbance caused by electron density irregularities along the propagation path of electromagnetic waves through the ionosphere. These non-nominal propagation conditions mainly cause carrier phase variations and amplitude fades. Regarding the carrier synchronization problem under harsh propagation conditions, such as high dynamics, multipath effects or ionospheric scintillation, ionospheric canonical fades make the latter the most challenging scenario.

This phenomenon particularly affects satellite-based positioning systems in the equatorial regions and at high latitudes. In this work, both amplitude and phase variations due to scintillation are first modeled using an autoregressive (AR) model, and then included into the system state-space formulation. Therefore, a Kalman filter (KF) based solution can be aware of both dynamics and scintillation phase evolutions. This arises as the natural solution to mitigate those undesired propagation effects. Moreover, in order to counteract the main drawbacks of standard KF-based tracking solutions, an extended KF (EKF) architecture is considered, tracking both the phase dynamics, scintillation phase and amplitude. This implies directly operating with the baseband received signal's complex samples, avoiding the use discriminators and thus its saturation and the loss of Gaussianity. Simulation results are provided to support the theoretical discussion and to show the performance improvements of such new approach.

4.1103 On the Identifiability of Noise Statistics and Adaptive KF Design for Robust GNSS Carrier Tracking

Jordi Vilà Valls (CTTC), Pau Closas (CTTC), Carles Fernández Prades (CTTC),

Presentation: Jordi Vilà Valls, Wednesday, March 11th, 09:50 PM, Amphitheatre

Carrier synchronization is of paramount importance in any communications or positioning system. Mass-market Global Navigation Satellite System (GNSS) receivers typically implement traditional carrier tracking techniques based on well-established phase-locked loop architectures, which are only reliable in quite benign propagation conditions. Under non-nominal harsh propagation conditions, the signal may be affected by shadowing, strong fading, multipath or severe ionospheric scintillation, and thus, traditional architectures are not valid anymore and there exists an actual need for robust tracking solutions. Several approaches to overcome the conventional PLL limitations have appeared during the last decade, being the Kalman filter (KF) based architectures the most promising research line. The main drawback of standard KFs is the assumption of perfectly known process and measurement noise statistics, a knowledge that is always constrained by the system model accuracy. Beyond heuristic solutions, a general framework for the design of adaptive KFs correctly dealing with both process and measurement noises, that would be of capital importance for the practitioner, has not been established. The main goal of this contribution is to provide a clear answer to this fundamental question. Within this framework, a comprehensive discussion is given for the correct design of adaptive KF architectures for robust carrier tracking applications. The design choice is supported by a discussion on the identifiability of the noise statistics' parameters.

4.12 Software Defined Radio and Cognitive Radio Systems and Technology

Session Organizer: Eugene Grayver (Aerospace Corporation), Genshe Chen (Intelligent Fusion Technology, Inc),

4.1201 Software Defined Radio Architecture Contributions to Next Generation Space Communications

Thomas Kacpura (NASA),

Presentation: Thomas Kacpura, Thursday, March 12th, 04:30 PM, Amphitheatre

Space communications architecture concepts, comprising the elements of the system, the interactions among them, and the principles that govern their development, are essential factors in developing National Aeronautics and Space Administration (NASA) future exploration and science missions. Accordingly, architectural attributes encompass flexibility, future capability insertion, and enable interoperability with other current and future systems. Space communications architectures and technologies for this century must satisfy a growing set of requirements, including those for Earth sensing, collaborative observation missions, robotic scientific missions, human missions for exploration of the Moon and Mars and space observatories. Importantly, the cost/value proposition of the future architecture is integral; an affordable and sustainable architecture is indispensable within future budget environments. Effective architecture design provides insight into the capabilities needed to satisfy the future space missions. The architecture must be extensible for new requirements and new capability insertion, as new functionality and new technologies are infused into the network infrastructure. A key architectural attribute is interoperability with other NASA communications systems, as well as those communications and navigation systems operated by international space agencies and civilian and government agencies. The structure of next-generation communication architectures for space must address technologies, architectural attributes, mission services, and communications capabilities by using software defined radios (SDRs). Evaluating lessons learned from development and operation of the early space SDRs on the NASA Space Communications and Navigation (SCaN) Testbed on the International Space Station provide feedback for defining the communications architecture. An important attribute is leveraging SDR reconfigurability, which changes operations.

4.1202 Software Defined Radio for Picosats and CubeSats

Eugene Grayver (Aerospace Corporation), Andrew Chin (Aerospace Corporation), David Hinkley (Aerospace Corporation),

Presentation: Eugene Grayver, Thursday, March 12th, 04:55 PM, Amphitheatre

Nanosatellites offer relatively lost-cost access to space. They are being actively used for a wide range of scientific studies and technology development efforts. The small size, relatively low available power, and highly constrained cost have typically limited the radios on these satellites to low data rates. In this paper we present our first AeroCube 915 MHz software defined radio based on a Zynq processor and using Lime Micro transceiver developed to address the low-cost constraint while at the same time offering a state-of-the-art communications link. The radio supports a wide range of modulations and a range of powerful error correction codes capable of 10 Mbps. The coding and modulation can be adapted in real-time as the range from the ground station to the satellite changes to maximize downlink throughput.

4.1203 A Probabilistic Reasoning and Decision-making Methodology for Satellite Communications

Todd Martin , Kc Chang (George Mason University), Erik Blasch (-), Genshe Chen (Intelligent Fusion Technology, Inc),

Presentation: Genshe Chen, Thursday, March 12th, 05:20 PM, Amphitheatre

This paper presents a satellite communications (SATCOM) situational awareness and decision-making methodology that incorporates situational uncertainty with a probabilistic reasoning representation of the SATCOM network and operating environment. The situational awareness and decision model is developed using probabilistic Functional Causal Modeling (FCM) and multiattribute utility theory. The probabilistic FCM is a Bayesian Network developed from the mathematical functions that represent the underlying phenomena of the SATCOM system, operating environment, and operational dynamics. The model provides a formal system for representing cause and effect of system reconfiguration and is built upon well-established engineering models for SATCOM systems. The multiattribute decision model provides a formal basis for in situ decision-making that combines user goals and situational uncertainty. The paper presents the theoretical basis of the technique as well as implementation examples with quantitative analyses. Characteristics of the model components, associated sources of uncertainty,

and associated impact on performance and decision making are addressed. The discussion demonstrates the model's use for performance prediction as well as inference of SATCOM resource allocations needed to meet performance goals with desired levels of confidence.

4.1205 Software Defined Radio (SDR) Architecture to Support Multi-Satellite Communications

Mamatha Maheshwarappa (University of Surrey), Mark Bowyer (Airbus Defence and Space Ltd), Christopher Bridges (Surrey Space Centre),

Presentation: Mamatha Maheshwarappa, Thursday, March 12th, 08:25 PM, Amphitheatre

Software Defined Radio (SDR) is a key area to realise new software implementations for adaptive and reconfigurable communication systems without changing any hardware device or feature. A review on efficient use of limited bandwidth and increasing distributed satellite missions can conclude that there is need for a generic yet configurable communication platform that can handle multiple signals from multiple satellites with various modulation techniques, data rates and frequency bands that must be compatible to typical small satellite requirements. SDR is beneficial for space applications as it can provide the flexibility and re-configurability and this is driven by fast development times, new found heritage, reduced cost, and low mass Commercial Off-The-Shelf (COTS) components. This presentation proposes a SDR architecture in which Field Programmable Gate Array (FPGA) System-on-Chip (SoC) is paired with a Radio Frequency (RF) programmable transceiver SoC to solve back-end and front-end re-configurability challenges respectively. The test-bed is aimed at implementing the signal processing software functions in both the dual-core ARM processors and the associated FPGA fabric. The distribution of the functions between the FPGA fabric and dual-processor is based on profiling experiments using gprof in order to identify where bottlenecks exist. Aspects of implementing and testing the transceiver blocks on the chosen platform are presented together with initial results. Thus the proposed technology not only contributes for a lightweight and portable ground station but can also be further extended to distributed satellite systems.

4.13 CNS Systems and Airborne Networks for Manned and Unmanned Aircraft

Session Organizer: Denise Ponchak (NASA Glenn Research Center),

4.1301 Functional Decomposition of Unmanned Aircraft Systems (UAS) for CNS Capabilities in NAS Integration

Laurence Mutuel (CGH Technologies, Inc.), Chris Wargo (Mosaic ATM, Inc.),

Presentation: Laurence Mutuel, Monday, March 9th, 04:30 PM, Elbow 2

The presentation discusses the approach developed for the partial MASPS level document DO-344 “Operational and Functional Requirements and Safety Objectives”. Following the principles described in the Department of Defense Architecture Framework, the overall UAS architecture and major interfaces are defined. Furthering the level of details, a functional decomposition is produced independently from any allocation onto UAS architectures. These functions cover domains including communication, control, navigation, surveillance, and health monitoring. The communication function covers all elements in the UAS connected with external interfaces. The control function addressed the interface between the ground control station and the unmanned aircraft for the purpose of flying in the NAS. The navigation function covered the capability to determine and fly a trajectory using conventional and satellite based navigation means. The surveillance function addressed the capability to detect and avoid collisions with hazards, including other traffic, terrain and obstacles, and weather. Finally, the health monitoring function addressed the capability to oversee UAS systems, probe for their status and feedback issues related to degradation or loss of performance. An additional function denoted ‘manage’ was added to the functional decomposition to complement the heath monitoring coverage and included manual modes for the operation of the UAS. The presentation discusses possible approaches for determining requirements for UAS considering both reusability of existing systems from manned aviation and novel development specific to UAS. The functional architecture can be used in downstream system engineering efforts by either standard groups or civil applicants.

4.1302 A Study of Future Communications Concepts and Technologies for the National Airspace System–Part IV

Denise Ponchak (NASA Glenn Research Center),
Presentation: Denise Ponchak, Monday, March 9th, 04:55 PM, Elbow 2

The National Aeronautics and Space Administration (NASA) is investigating current and anticipated wireless communications concepts and technologies that the National Airspace System (NAS) may need in the next 50 years. NASA has awarded three NASA Research Announcements (NAR) studies with the objective to determine the most promising candidate technologies for air-to-air and air-to-ground data exchange and analyze their suitability in a post NextGen NAS environment. This paper presents the final results describing the communications challenges and opportunities that have been identified as part of the study.

4.1303 Impact of Co-Site Interference on L/C-Band Spectrum for UAS Control and Non-payload Communications

Robert Kerczewski (NASA Glenn Research Center),
Presentation: Robert Kerczewski, Monday, March 9th, 05:20 PM, Elbow 2

In order to provide for the safe integration of unmanned aircraft systems into the National Airspace System, the control and non-payload communications (CNPC) link connecting the ground-based pilot with the unmanned aircraft must be highly reliable. A specific requirement is that it must operate using aviation safety radiofrequency spectrum. The 2012 World Radiocommunication Conference (WRC-12) provided a potentially suitable allocation for LOS CNPC spectrum in C-Band at 5030-5091 MHz band which, when combined with a previous allocation in L-Band (960-1164 MHz) may satisfy the LOS spectrum requirement and provide for high reliability through dual-band redundancy. However, the L-Band spectrum hosts a number of aeronautical navigation systems which require high-power transmitters on-board the aircraft. These high-power transmitters co-located with sensitive CNPC receivers operating in the same frequency band have the potential to create co-site interference, reducing the performance of the CNPC receivers and ultimately reducing the usability of the L-Band for CNPC. This paper examines the potential for co-site interference, as highlighted in recent flight tests, and discusses the impact on the UAS CNPC spectrum availability and requirements for further testing and analysis.

4.1304 A Cognitive Radio System for Improving the Reliability and Security of UAS/UAV Networks

Nickolas Gellerman , Naima Kaabouch (University of North Dakota),
Presentation: Nickolas Gellerman, Monday, March 9th, 09:00 PM, Elbow 2

This presentation describes a system based on cognitive radio technology to improve the reliability and security of wireless communications of unmanned aerial systems and vehicles (UAS/UAV) networks. UAS/UAV networks can experience problems with connectivity and thus with data reception and delivery. Since UAS/UAV are mobile, their connectivity is dynamic; thus, link status changes are more frequent than for traditional networks. Specifically, link losses due to jamming, interference, fading, and multipath are common problems. Another factor is the way the radio spectrum is used at each specific location. The availability of specific spectrum frequency bands can vary from one location to another, thus making it crucial for aircraft to be frequency agile to maintain connectivity.

4.1305 A Terrain Avoidance Algorithm Based on the Requirements of Terrain Awareness and Warning Systems

Nickolas Gellerman , Naima Kaabouch (University of North Dakota),
Presentation: Nickolas Gellerman, Monday, March 9th, 09:25 PM, Elbow 2

In this presentation, we describe a method in which databases of terrain and obstacles maintained by government agencies are combined into a single database with the final goal of implementation into a sense-and-avoid algorithm currently in development at the University of North Dakota. With the new regulations set forth by the Federal Aviation Administration, strict requirements have to be met before unmanned aerial vehicles are allowed integration into the national airspace. Amongst these requirements is an ability to automatically avoid large obstacles, i.e., buildings, hills, mountains, and airports

4.14 Aerospace Information Systems and Cyber Security

Session Organizer: Radhakrishna Sampigethaya (University of Maryland), Radha Poovendran (University of Washington),

4.1401 A HMAC-based Approach to Secure ADS-B Networks

Thabet Kacem (George Mason University), Duminda Wijesekera (George Mason University), Paulo Costa (George Mason University),
Presentation: Thabet Kacem, Monday, March 9th, 09:50 PM, Elbow 2

We propose a novel approach to provide authenticity and integrity of Automatic Dependent Surveillance-Broadcast (ADS-B) messages. We employ a keymanagement schema for authentication and rely on a keyedhashed message authentication code (HMAC) for integrity. Our approach avoids scalability and compatibility issues, as we neither change the packet format nor its size.

4.15 Space Information Systems Security

Session Organizer: Marcio Juliato (University of Waterloo),

4.1501 Small Satellite Communications Security and a Student Ground Station

Scott Kerlin (University of North Dakota), Jeremy Straub (University of North Dakota),
Presentation: Scott Kerlin, Thursday, March 12th, 08:50 PM, Amphitheatre

Communications security is gaining importance as small spacecraft include actuator capabilities (i.e., propulsion), payloads which could be misappropriated (i.e., high resolution cameras), and research missions with high value/cost. However, security is limited by capability, interoperability (particularly across national borders) and regulation. Additionally, as the small satellite community becomes more mainstream and diverse, the lack of cheap, limited-to-no configuration, pluggable security modules for small satellites also presents a limit for user adoption of security. This paper discusses a prospective approach for incorporating robust security into a student-developed ground station created at the University of North Dakota as part of a Computer Science Department senior design project.

TRACK 5: OBSERVATION SYSTEMS AND TECHNOLOGIES

Track Organizers: Ifan Payne (Magdalena Ridge Observatory), Gene Serabyn (Jet Propulsion Laboratory)

5.01 Large Optical Systems

Session Organizer: Ryan Mc Clelland (SGT, Inc.), David Robinson (NASA GSFC),

5.0101 Mechanical Aspects of the Thermal Infrared Sensor (TIRS) on Landsat 8

David Robinson (NASA GSFC),

Presentation: David Robinson, Sunday, March 8th, 04:30 PM, Cheyenne

The Thermal InfraRed Sensor (TIRS) instrument was launched into space on board Landsat 8 in February 2013. This instrument was added to Landsat 8 to measure water evaporation and transpiration as well as provide two thermal infrared bands to complement the optical suite. TIRS has a refractive telescope which focuses a light onto a focal plane cooled to 43K with a two-stage cryocooler. This paper will detail the mechanical aspects of TIRS including a description of its composite honeycomb box design, flexures, large deployable earth shield, and accommodations for the telescope, detector, and cryocooler. The design, build, test, and delivery of TIRS was accomplished in three years on an accelerated schedule at NASA Goddard Space Flight Center. The assembly and test flow are discussed including qualification of the structure in vibration and acoustic tests.

5.0102 Design and Testing of Lightweight and High Resolution X-ray Mirror Modules

Ryan Mc Clelland (SGT, Inc.),

Presentation: Ryan Mc Clelland, Sunday, March 8th, 04:55 PM, Cheyenne

Lightweight and high resolution optics are needed for future space-based X-ray telescopes to achieve advances in high-energy astrophysics. The Next Generation X-ray Optics (NGXO) team at NASA GSFC is nearing mission readiness for a 10 arc-second Half Power Diameter (HPD) slumped glass mirror technology while laying the groundwork for a future 1-2 arc-second technology based on polished silicon mirrors. Technology Development Modules (TDMs) have been designed, fabricated, integrated with mirrors segments, and extensively tested to demonstrate technology readiness. Tests include X-ray performance, thermal vacuum, acoustic load, and random vibration. The thermal vacuum and acoustic load environments have proven relatively benign, while the random vibration environment has proven challenging due to large input amplification at frequencies above 500 Hz. Epoxy selection, surface preparation, and larger bond area have increased bond strength while vibration isolation has decreased vibration amplification allowing for space launch requirements to be met in the near term. Preliminary steps are being taken to enable mounting and testing of 1-2 arc-second mirror segments expected to be available in the future. A Vertical Beam Line (VBL) test facility will minimize mirror gravity distortion and allow for less constrained mirror mounts, such as fully kinematic mounts. Permanent kinematic mounting into a modified TDM has been demonstrated to achieve 2 arc-second level distortion free alignment.

5.0103 Large Volume, Ambient, Optical and Opto-mechanical Metrology Techniques for ISIM on JWST

Theodore Hadjimichael (NASA - Goddard Space Flight Center), Raymond Ohl (NASA/Goddard Space Flight Center),

Presentation: Theodore Hadjimichael, Sunday, March 8th, 05:20 PM, Cheyenne

The final, flight build of the Integrated Science Instrument Module (ISIM) element of the James Webb Space Telescope is the culmination of years of work across many disciplines and partners. This paper covers the large volume, ambient, optical and opto-mechanical metrology techniques used to verify the mechanical integration of the flight instruments in ISIM, including optical pupil alignment. We present an overview of ISIM's integration and test program, which is in progress, with an emphasis on alignment and optical performance verification. This work is performed at NASA Goddard Space Flight Center, in close collaboration with the European Space Agency, the Canadian Space Agency, and the Mid-Infrared Instrument European Consortium.

5.02 Optical Instruments

Session Organizer: Thomas Johnson (NASA - Goddard Space Flight Center/Wallops Flight Facility), Tyler Evans (SGT, Inc.),

5.0201 ICESat-2 ATLAS Telescope Testing

Tyler Evans (SGT, Inc.),

Presentation: Tyler Evans, Wednesday, March 11th, 04:30 PM, Cheyenne

Many lessons were learned in the comprehensive testing of the one meter Beryllium flight telescope for the ICESat-2 mission. The Optical Development System Lab (ODSL) at NASA's Goddard Space Flight Center (GSFC) was developed to build up experience using engineering test units. This experience was applied to testing the flight telescope. Several tests were able to be performed on the telescope itself, helping drive down risk, cost, and schedule during the integration phase of the telescope onto the instrument and box structure. The lab consisted of a clean room with a one meter parabola collimator system with a point source fiber-coupled 532nm laser and a CCD detector. This was used to feed collimated light into the telescope that was recorded with a CCD detector in the telescope focal plane. A large one meter flat mirror was used to certify the collimator system. Fiber optic cables were also used to back-illuminate the telescope and image in the collimator focal plane. The telescope was mounted in a gimbal that allowed for three degrees of rotational freedom allowing the telescope to be steered to each respective science field point. The setup worked well for accomplishing the testing. Through well written procedures and prior experience, the testing was carried out according to plan and on schedule despite obstacles along the way such as late ground support equipment and tests that needed to be repeated. Lessons learned will be shared for optical alignment of a receiver telescope assembly to promote future mission success.

5.0202 Tests of LARES and CHAMP Cube Corner Reflectors on Simulated Space Environment

Claudio Paris (University of Rome, La Sapienza),

Presentation: Claudio Paris, Wednesday, March 11th, 04:55 PM, Cheyenne

There are more than two thousands retroreflectors orbiting the Earth. Many are on geodetic satellites typically used for geodesy and geodynamics but also for testing fundamental physics such as in the case of the LARES and LAGEOS satellites. Other are mounted on GPS and GALILEO navigation satellites. Most retroreflectors are Cube Corner Reflectors (CCRs) that rely on the very accurate dihedral angles to return laser pulses towards the ground emitting stations. It is very important to know the thermal conditions of the CCRs and verify that the CCR dihedral angles are not deformed sensibly thus causing the return laser pulse to miss the station. Sapienza University of Rome designed and built a specific thermovacuum chamber to test CCRs in simulated space environment. The chamber feature 5 nitrogen cooled walls, a Sun and a Earth simulator and a vacuum enclosure that operates between 10^(-6) and 10^(-9) millibar. The chamber is equipped with several feedthrough for electrical signals and several optical windows. One of this is used for sending a laser beam inside the chamber. The beam will hit a CCR and will exit the chamber through the same window engaging an optical circuit for Far Field Diffraction Pattern acquisition. The lab tested CCRs from LARES and CHAMP missions. The two satellites mounted CCRs with different design. The experimental results of some tests are presented.

5.0203 Projection and Acquisition Optical Assembly for DEEP Remote Microscopy

Keith Nowicki (Southwest Research Institute), Daniel Feldkhun (University of Colorado, Boulder), Kelvin Wagner (University of Colorado, Boulder),

Presentation: Keith Nowicki, Wednesday, March 11th, 05:20 PM, Cheyenne

Microscopic imaging systems currently used on plan- etary exploration rovers operate over a short range, are de- pendent on ambient lighting and have a constrained depth of field requiring image stacking and increasing the data download requirement. The Structured Light Imaging Module Remote Microscope illuminates a target with acousto-optic generated traveling-wave sinusoidal patterns to measure the Fourier com- ponents of the object. It can resolve □10 μm features at a distance of 5 meters with a □20 mm depth of field enabling a rover to evaluate remote targets for further study. In this paper we present the optical and mechanical design, and initial characterization of the first to-scale SLIM-RM prototype.

5.0204 Progress towards Non-Intrusive Optical Measurement of Gas Turbine Exhaust Species Distributions

Paul Wright (The University of Manchester),

Presentation: Paul Wright, Wednesday, March 11th, 09:00 PM, Cheyenne

This paper reports on the development of three tomographic systems for the measurement of key pollutant species distributions in aero engine exhaust plumes (carbon dioxide, soot, unburnt hydrocarbons). In the carbon dioxide case, we present preliminary (single-path) results using the novel method of tunable fiber laser absorption spectroscopy and an overview of the proposed imaging system's architecture. Secondly, we report progress towards the glasses and fibers needed for the extension of this method into the mid-IR region, as needed for unburnt hydrocarbon studies. Finally, in regard of soot imaging, we summarize our previous findings on fiber laser induced incandescence and describe how this work will be extended to the imaging case.

5.0205 The NIRSPEC ASSEMBLY INTEGRATION and TEST STATUS

Thomas Johnson (NASA - Goddard Space Flight Center/Wallops Flight Facility),

Presentation: Maurice Te Plate, Wednesday, March 11th, 09:25 PM, Cheyenne

The Near-Infrared Spectrograph (NIRSpec) is one of the four instruments on the James Webb Space Telescope (JWST) scheduled for launch in 2018. NIRSpec has been manufactured and tested by an European industrial consortium led by Airbus Defence and Space and delivered to the European Space Agency (ESA) and NASA in September 2013. Since then it has successfully been integrated onto the JWST Integrated Science Instrument Module (ISIM) and has completed ISIM Cryo-Vacuum Test#2. Since two of its most important assemblies, the Focal Plane Assembly (FPA) and the Micro-Shutter Assembly (MSA) need to be replaced by new units, we will present the status of the instrument, the status of its new flight assemblies and give an outlook on the planned exchange activities and the following instrument re-verification.

5.03 Atmospheric Turbulence: Phenomenology, Measurement, Mitigation

Session Organizer: Milo Hyde (Air Force Institute of Technology), Jack Mc Crae (Air Force Institute of Technology),

5.0301 Simulation of Atmospheric Compensation for a Laser Phased Array in the Presence of Target Speckle

Jack Mc Crae (Air Force Institute of Technology),
Presentation: Jack Mc Crae, Tuesday, March 10th, 10:35 AM, Jefferson

Propagation of a laser beam from a phased array source through atmospheric turbulence to a target and techniques to compensate for this atmospheric turbulence are simulated. A large rough target is simulated which causes speckle on the returned light. This return is used as a beacon to command the phased array to correct for aberrations caused by the atmosphere; however, this target speckle degrades the performance of the compensation algorithm over that which could be achieved with an ideal beacon. One way to reduce this degradation is to repetitively apply this compensation and measurement procedure until convergence. If the light field scattered back from the target due to each element of the phased array can be independently measured, the relative phase between these transmitters can be removed. These two approaches are simulated and compared for a 127 element piston-only controlled phased array in a 10 km tactical engagement. Performance of these techniques is evaluated using Strehl ratio (peak intensity) metric.

5.0302 Wave Optics Simulation of Anisotropic Turbulence

Xifeng Xiao (New Mexico State University), David Voelz (New Mexico State University),
Presentation: Xifeng Xiao, Tuesday, March 10th, 11:00 AM, Jefferson

A numerical wave optics approach is introduced for simulating beam propagation through anisotropic turbulence. Anisotropic turbulence refers to turbulence cells that are asymmetric, e.g., oval shaped. A recently proposed model for anisotropic turbulence is applied and Gaussian beam propagation through the turbulence is implemented for various turbulence strengths and spectral power law α ranging from 3 to 4. The spectral power parameter α indicates the turbulence power spectrum shape. Theoretical irradiance expressions are derived and are used to provide comparisons and verification of the wave optics simulation results. Good agreement is found between the simulations and theory except when the spectral index α approaches 4. This work provides a good starting point for understanding the behavior of Gaussian beam propagation in anisotropic turbulence.

5.0303 Low Cost Digital Photography Approach to Monitoring Optical Bending and Guiding in the Atmosphere

David Voelz (New Mexico State University), Xifeng Xiao (New Mexico State University), Ivan Dragulin (New Mexico State University), Jose Barraza (New Mexico State University), Santasri Basu (Air Force Institute of Technology), Jack Mc Crae (Air Force Institute of Technology), Zachary Pollock (Air Force Institute of Technology),
Presentation: Jose Barraza , Tuesday, March 10th, 11:25 AM, Jefferson

A low-cost system consisting of a commercial DSLR camera and a long focal length zoom lens is introduced for the purpose of recording the guiding and bending phenomena caused by atmospheric refraction in the planetary boundary layer. A significant advantage of this system is that long duration monitoring (weeks or months) is possible with the camera operated in a time-lapse mode. Recent experiments were performed with this type of system over a 12.8 km path in Dayton, OH and a 15.3 km path in Las

Cruces, NM. The measured downward vertical drift of the target images in daytime (10 to 50 pixels) are roughly consistent with an approximate theory involving the vertical temperature and index of refraction gradients.

5.04 Photonic Devices and Systems for Aerospace Applications

Session Organizer: Kent Choquette (University of Illinois), David Peters (Sandia National Laboratories),

5.0401 Silicon Photonics Platform for National Security Applications

Anthony Lentine (Sandia National Laboratories),

Presentation: Anthony Lentine, Monday, March 9th, 09:00 PM, Lake/Canyon

We review Sandia's silicon photonics platform for national security applications. Silicon photonics offers the potential for extensive size, weight, power, and cost (SWaP-c) reductions compared to existing III-V or purely electronics circuits. Unlike most silicon photonics foundries in the US and internationally, our silicon photonics is manufactured in a trusted environment at our Microsystems and Engineering Sciences Application (MESA) facility. The Sandia fabrication facility is certified as a trusted foundry and can therefore produce devices and circuits intended for military applications. We will describe a variety of silicon photonics devices and subsystems, including both monolithic and heterogeneous integration of silicon photonics with electronics, that can enable future complex functionality in aerospace systems, principally focusing on communications technology in optical interconnects and optical networking.

5.05 Astrophysics and Exoplanet Missions

Session Organizer: Gene Serabyn (Jet Propulsion Laboratory), Stefan Martin (Jet Propulsion Laboratory),

5.0501 Exo-C: A Space Mission for Direct Imaging and Spectroscopy of Extrasolar Planetary Systems

Karl Stapelfeldt (NASA Goddard Space Flight Center), Michael Brenner (Jet Propulsion Laboratory), Frank Dekens (Jet Propulsion Laboratory), Paul Brugarolas (Jet Propulsion Laboratory), Kerri Cahoy (Massachusetts Institute of Technology), Serge Dubovitsky (Jet Propulsion Laboratory), Mark Marley , Gene Serabyn (Jet Propulsion Laboratory), Stephen Unwin (Jet Propulsion Laboratory),

Presentation: Karl Stapelfeldt, Monday, March 9th, 04:30 PM, Lake/Canyon

Exo-C is NASAs first community study of a modest aperture space telescope designed for high contrast observations of exoplanetary systems. The mission will be capable of taking optical spectra of nearby exoplanets in reflected light, discovering previously undetected planets, and imaging structure in a large sample of circumstellar disks. It will obtain unique science results on planets down to super-Earth sizes and serve as a technology pathfinder toward an eventual flagship-class mission to find and characterize habitable Earth-like exoplanets. We present the mission/payload design and highlight steps to reduce mission cost/risk relative to previous mission concepts. Key elements are an unobscured telescope aperture, an internal coronagraph with deformable mirrors for precise wavefront control, and an orbit and observatory design chosen for high thermal stability. Exo-C has a similar telescope aperture, orbit, lifetime, and spacecraft bus requirements to the highly successful Kepler mission (which is our cost reference). The needed technology development is on-course for a possible mission start in 2017. This paper summarizes the study final report completed in January 2015. During 2015 NASA will make a decision on its potential development.

5.0502 Liquid Crystal Polymer Based Vector Vortex Waveplates with Sub-micrometer Singularity

Nelson Tabiryan (BEAM Engineering for Advanced Measurements Co.), Gene Serabyn (Jet Propulsion Laboratory), Haiqing Xianyu (Beam Engineering for Advanced Measurements),

Presentation: Nelson Tabiryan, Monday, March 9th, 04:55 PM, Lake/Canyon

Small singularity size is critical for achieving low light loss and high contrast for vector vortex waveplate (VVW) based coronagraph. In the opto-mechanical system for recording VVW with photoalignment, reshaping the center light intensity distribution and precision alignment can effectively decrease singularity size. We have developed methods for redistributing the light intensity near the singularity. A new direct alignment method is introduced. This method helps in reaching the optimized alignment position by allowing to depict the beam profile at the photoalignment surface. Employing these techniques and new liquid crystal polymer materials, we have fabricated VVWs with sub-micrometer defect size for UV, and subs-wavelength defect size for 1.5 micrometer wavelength range. Inversely twisted layers method was used for fabrication of broadband VVW for the near infrared region.

5.0505 GM-APD Imaging Arrays for Direct Imaging of Exoplanets

Kimberly Kolb (Rochester Institute of Technology), Donald Figer (RIT),

Presentation: Kimberly Kolb, Monday, March 9th, 05:20 PM, Lake/Canyon

Exoplanet detection and characterization is one of NASA's main science goals. Current missions, such as Kepler, are identifying exoplanet candidates for further study at an unprecedented pace. The upcoming Wide Field InfraRed Survey Telescope (WFIRST) mission is the top-ranked large space mission in the New World New Horizons decadal survey, and will "settle essential questions" in exoplanet research. This paper evaluates photon-counting Geiger-mode avalanche photodiode (GM-APD) imaging arrays for use in the WFIRST Astrophysics Focused Telescope Assets (AFTA) mission design, specifically in the area of direct imaging of exoplanets. A review of both current and state-of-the-art performance for GM-APD devices is presented, including the effects of radiation damage on device performance. Projected performance for next-generation devices is presented based on preliminary testing and state-of-the-art benchmarks for the technology. Simulated data for typical exoplanet signals is used to compare GM-APD performance with a state-of-the-art electron-multiplying charge coupled device (EMCCD), a current candidate for the WFIRST-AFTA mission.

5.06 Imaging of Objects in Space

Session Organizer: Theo Ten Brummelaar (The CHARA Array), Michelle Creech Eakman (New Mexico Institute of Mining and Technology),

5.0601 Simultaneous Processing of Visible and Long-Wave Infrared Satellite Imagery

Daniel Thompson (Boeing Company), Michael Werth (Boeing Company), Brandoch Calef (Boeing), Stacie Williams (AFRL), David Witte ,

Presentation: Daniel Thompson, Thursday, March 12th, 10:10 AM, Lamar/Gibbon

One of the challenges of imaging satellites in the daytime is that the sun is generally behind the satellite from the observer’s point of view. This means that much of the satellite structure can be in shadow at any given time. The Air Force Maui Optical and Supercomputing (AMOS) site’s 3.6 meter telescope has the capability of recording data simultaneously in two bands of long-wave infrared (LWIR) as well as visible. This presents the possibility of performing joint processing of the infrared and visible imagery, which is appealing because the thermal imagery will not have any shadows. We describe exploitation strategies for this type of data, show the results of joint multiband processing, and compare with single-band images

5.0602 Using a Constellation of CubeSats for In-Space Optical 3D Scanning

Jeremy Straub (University of North Dakota),
Presentation: Jeremy Straub, Thursday, March 12th, 10:35 AM, Lamar/Gibbon

The assessment of in-space objects is an area of ongoing research. Characterization of resident space objects (RSOs) can be useful for assessing the operating status of operator-affiliated or non-affiliated space assets, identifying unknown objects or gathering additional details for known objects. This paper proposes an approach to RSO assessment based on prior terrestrial, visible light imaging-based 3D scanning. This technique has been demonstrated to be effective in modeling objects imaged under controlled conditions, terrain features, buildings, architectural sites and objects in their natural surroundings. Under the proposed approach, a ring-like constellation of CubeSats (possibly multiple rings, depending on whether movement of the object being imaged is expected during imaging) passes around the target (at a distance) collecting imagery. This imagery is then utilized to create a 3D model of the target. Additional data can be concurrently collected (such as the mass distribution via tracking the gravitational impact of the object on the CubeSat constellation and data that could be collected via other sensor types) to further enhance the model. The paper considers several key elements. First, it describes the constellation design and imaging capabilities required. Then, it considers the astrodynamics required. Next, work on imaging spacecraft-like objects of different configurations and sizes is presented. This is followed by a discussion of the impact of the locations of the lighting sources (representing the light sources of the Sun and reflected light from the Earth) on data collection. Finally, the utility of this data for a variety of applications is considered.

5.07 Image Processing

Session Organizer: Matthew Sambora (Air Force Institute of Technology), Martha Bancroft (MBC),

5.0701 Vision-Based Pose Estimation for Space Objects by Gaussian Process Regression

Haopeng Zhang (Beihang University), Zhiguo Jiang (Beihang University), Yuan Yao (BeiHang University), Gang Meng (Beijing Institute of Remote Sensing Information),
Presentation: Haopeng Zhang, Thursday, March 12th, 08:30 AM, Lamar/Gibbon

In this paper, we address the problem of vision-based pose estimation for space objects, which is to estimate the relative pose of a target spacecraft using imaging sensors. We develop a novel monocular vision-based method by employing Gaussian process regression (GPR) to solve pose estimation for space objects. GPR is a powerful regression model for predicting continuous quantities, and can easily obtain and express uncertainty. Assuming that the regression function mapping from the image (or feature) of the target spacecraft to its pose follows a Gaussian process (GP) properly parameterized by a mean function and a covariance function, the predictive equations can be easily obtained by a maximum-likelihood approach when training data are given. The mean value of the predicted output (i.e. the estimated pose) and its variance (which indicates the uncertainty) can be computed via these explicit formulations. Besides, we also introduce a manifold constraint to the output of GPR model to improve its performance for spacecraft pose estimation. We performed extensive experiments on a simulated image dataset that contains satellite images of 1D and 2D pose variation, as well as images with noises and different lighting conditions. Experimental results validate the effectiveness and robustness of our approach. Our model can not only estimate the

pose angles of space objects but also provide the uncertainty of the estimated values which may be used to choose convincing results in applications.

5.0702 Recent Improvements in Advanced Automated Post-Processing at the AMOS Observatories

Michael Werth (Boeing Company), Daniel Thompson (Boeing Company), Brandoch Calef (Boeing), Kathy Borelli ,

Presentation: Michael Werth, Thursday, March 12th, 08:55 AM, Lamar/Gibbon

An automated post-processing system has been developed to facilitate the processing of data recorded with the 1.6m and 3.6m telescopes of the Air Force Maui Optical & Supercomputing site. This system automatically transfers raw data from these telescopes to supercomputing hardware at sea level, and then the data is processed as imagery, photometry, or both, depending on collection parameters. A new user interface displays the metadata associated with each collection as well as the status of all file transfers and automated processing jobs. This interface also provides access to many additional utilities, including a bispectrum image reconstruction algorithm and other basic image manipulation features. These utilities allow users to create new processing results or to further process and annotate existing results. This new data handling and processing system has significantly enhanced the capabilities of the AMOS site while also reducing the time that it takes for data to be processed and disseminated.

5.0703 Enhanced Quality LANDSAT Image Processing Based on 4-Level Sub-Band Replacement DWT

Jaypal Baviskar (Veermata Jeebai Technological Institute (VJTI), Mumbai, India), Afshan Mulla (Veermata Jeejabai Technological Institute, Mumbai, India),

Presentation: Vikram Singh, Tuesday, March 10th, 11:00 AM, Madison

Satellite images are multi-spectral in nature that operate over wavelengths of wide range frequencies known as bands. Hence, they need to be processed cautiously. This paper presents a 4-Level DWT based Sub-Band Replacement (SR-DWT) Image Compression scheme, for LANDSAT satellite images. The algorithm is designed to compress various color band images captured by the satellite payload. By performing compression on these images and converting them to unique textured images, it exploits the sub-bands generated by the wavelet transform. Since the algorithm is a reversible process, it facilitates retrieval of the images back to colored format at the receiver. Due to the property of possessing spatial-frequency decomposition, the recovered images are of high quality with improved Peak Signal to Noise Ratio (PSNR) of 20dB and correspondingly very low MSE value. Using an astrophysical image database, the performance analysis of the 4-Level SR-DWT algorithm is illustrated.

5.0704 High-Speed Cluster Scanning Scheme for 3-Dimensional Constellated Image Processing

Jaypal Baviskar (Veermata Jeebai Technological Institute (VJTI), Mumbai, India), Afshan Mulla (Veermata Jeejabai Technological Institute, Mumbai, India),

Presentation: Aditi Parthasarathy, Tuesday, March 10th, 11:25 AM, Madison

Due to the Human Visual System (HVS) the response to well brightened images is frequency dependent. The Discrete Cosine Transform (DCT)- based compression schemes are capable of separating the perceptually significant information in an image from the information that the eye cannot perceive. Hence, DCT is most widely used to transform in image compression. In this paper, an algorithm for compressing hyperspectral images based on Cluster 3D-DCT technique is proposed. This method converts two-dimensional images into a three-dimensional cube formation of 8*8*8 pixels and is processed with DCT. Thereafter the quantization and zig-zag scanning processes are

implemented. After completing the processes, the 1D data vector formed facilitates in achieving better compression using run-length coding. The performance of the algorithm is verified by plotting quality measurement graphs, and determining its dominance over other primitive scanning techniques. The cluster scanning which is a parallel progression proves faster processing compared to Spiral, ZigZag and Interleaving scanning schemes. The results show better quality performance for images having significant amount of background.

5.0705 Space Object Image Enhancement Based on Intrinsic Image Decomposition

Yuan Yao (BeiHang University), Zhiguo Jiang (Beihang University), Haopeng Zhang (Beihang University), Jun Shi (Beihang),

Presentation: Yuan Yao, Thursday, March 12th, 09:45 AM, Lamar/Gibbon

Space object image enhancement is an important problem in computer vision, which is also a fundamental issue for space observation. Instead of single image enhancement methods, we introduce a method based on intrinsic image decomposition by using an image sequence to solve the problem of space object image enhancement. We first capture several space object image sequences via ground simulation and 3ds Max digital simulation. The sequences are under different lighting conditions including changes of the camera exposure time and the lighting directions. Then the intrinsic image decomposition is applied to the sequences and finally we can obtain the enhanced images which contain more information. Experimental results on our dataset show that the enhanced images are better than the input sequences both in qualitative visual effects and quantitative criteria, e.g. image entropy.

5.0708 Improving Star Tracker Centroiding Performance in Dynamic Imaging Conditions

Laila Kazemi (Ryerson University), John Enright (Ryerson University), Tom Dzamba (Ryerson University),

Presentation: Laila Kazemi, Thursday, March 12th, 09:20 AM, Lamar/Gibbon

We present an assessment of various image thresholding and centroiding algorithms to improve star tracker centroiding accuracy at moderate slew rates (<10\degree/s). Star trackers generally have arc-second accuracy in stationary conditions, however their accuracy degrades as slew rate increases. In dynamic conditions, blur effects add to the challenges of star detection. This work presents an image processing algorithm for star images that preserves star tracker detection accuracy and is able to detect dim stars up to slew rates less than $10\degree/s$. Most of star detection algorithms in literature are designed to work in stationary conditions. We evaluate a number of algorithms from literature and measure their performance in motion. The performance of the algorithms are assessed using simulations. The primary performance metrics are false positive ratio, and false negative ratio of star pixels. We introduced a new algorithm for star acquisition in moderate slew rates that combines positive features of existing algorithms. This algorithm increases the star detection accuracy in moderate slew rates and it is robust to stray light.

5.08 Laser Communications and Atmospheric Propagation

Session Organizer: Aleksandr Sergeyev (Michigan Technological University), Mathieu Aubailly (Optonicus),

5.0801 Path Dependency and Angular Anisoplanatism in non-Kolmogorov Turbulence

Jeremy Bos ,

Presentation: Jeremy Bos, Thursday, March 12th, 11:25 AM, Lamar/Gibbon

We examine the effect of non-Kolmogorov turbulence on angular anisoplanatism. Generalized expressions for the isoplanatic angle in turbulence with non-Kolmogorov power-laws are developed in terms of the effective turbulence height, related turbulence

moments, and characteristics lengths such as Striblings equivalent Fried parameter. We then compare the effective turbulence height and isoplanatic angle using the Hufnagel-Valley 5-7 (HV 5-7) and Mauna Kea (HV-MK) turbulence profiles at both the upper and lower power-law limits. In addition, using the HV-MK profile we consider the effect of a single non-Kolmogorov turbulent shear layer. We find that, for fixed path length and spatial coherence, a smaller power-law reduces the isoplanatic angle while larger power-laws increase it relative to the Kolmogorov case. In contrast, when the turbulence strength profile is fixed smaller power law exponent the isoplanatic angle increases and decreases when the power law exponent is larger than the Kolmogorov value. Similar results are shown for the case of non-Kolmogorov shear layers.

5.0802 A Comparison of Spectral Models Used in Developing Non-Kolmogorov Wave Structure Functions

Jeremy Bos ,

Presentation: Jeremy Bos, Thursday, March 12th, 11:50 AM, Lamar/Gibbon

We compare the Wave Structure Function (WSF) resulting from various models for refractive index fluctuation spectra in non-Kolmogorov turbulence. Closed form, analytical expressions for the WSF based on the generalized Kolomogorov, von Karman, analytical, and exponential models are presented and compared. We find that the generalized von Karman model is essentially identical to the WSF resulting from numerical integration of the Analytic spectrum at separations larger than the inner scale. In addition, we demonstrate that certain approximations to the Analytic model introduce significant inaccuracies at separations as small as a hundredth of the outer scale size. Asymptotic expressions for the WSF and phase variance in non-Kolmogorov turbulence with a finite outer scale are also presented.

5.09 Laser Radar

Session Organizer: Rengarajan Sudharsanan (Spectrolab Inc.), Joseph Paranto (The Boeing Company),

5.0901 Space Lidar Technologies Supporting Upcoming NASA Earth Science & Laser Communications Missions

Mark Storm (Fibertek Inc),

Presentation: Mark Storm, Thursday, March 12th, 11:00 AM, Lamar/Gibbon

Abstract—This paper describes Fibertek, Inc.'s participation in lidar technology development for recent and future NASA space lidar missions. The paper reports on progress on the upcoming NASA ISS Cloud Aerosol Transport System (CATS) and NASA ICESat-2 missions. CATS was launched in January 2015 and NASA ICESat-2 is expected to launch in 2017. Lidar systems elements discussed include lidar systems controllers, data system, photon counting electronics and space flight lasers. Current and recently completed flight programs are discussed including the NASA CALIPSO transmitters, ISRO lunar altimeter, and ISS Orion docking technology. The paper also describes progress toward TRL-6 development for a deep space communications transmitter and carbon dioxide DIAL lidar transmitter.

Track Organizers: Jordan Evans (Jet Propulsion Laboratory), Darin Dunham (Lockheed Martin)

6.01 End to End Remote Sensing: Approaches and Challenges

Session Organizer: Karen Kirby (JHU-APL), Todd Bayer (NASA Jet Propulsion Lab),

6.0101 Internet-To-Orbit Gateway as Online Tool for Real-Time Monitoring of Natural Disasters

Ghulam Jaffer (Institute of Space Technology (IST)),

Presentation: Ghulam Jaffer, Sunday, March 8th, 09:00 PM, Cheyenne

The Ecuadorian Space Agency (EXA) has conceived and built HERMES, an online and real time ground station (GS) available to participating schools/ universities for free access to NOAA and other remote sensing satellites. The GS is being used by students and scientists in Austria, USA, Japan and Ecuador to access NOAA satellites and spacecrafts online using only a computer and an internet connection with immediate access to satellite imaging and science data for their educational and research projects. The accuracy of analysed data can be used in research areas like forecasting, monitoring and damage assessment caused by eruptions. The HERMES internet-to-orbit gateway transforms a laptop into a full space-qualified GS on-the-move. The purpose of this paper is to present results of Andean mountain area in Ecuador being a ected by high temperatures over 30 degree Celsius located over 3000 m high. The measured were validated by the records from the local meteorological stations network. We got the image of the fleeting ash cloud due to unique location of HERMES GS which remarks the importance of having this kind of stations around the world and the scientists have remote access via HERMES GS. NOAA has already granted free access to the world, now users must move forward to build new or network existing worldwide ground stations to get composite, 3D and animated information of the meteorological and atmospheric conditions to keep an eye on the abrupt changes for proper mitigation.

6.0102 Remote Sensing Signatures Database – Challenges and Opportunities

Nigel Tzeng (Johns Hopkins University Applied Physics Laboratory), Vignesh Ramachandran (Johns Hopkins University Applied Physics Laboratory), Benjamin Rodriguez (Johns Hopkins University/Applied Physics Laboratory), Samantha Jacobs ,

Presentation: Nigel Tzeng, Sunday, March 8th, 09:25 PM, Cheyenne

Growing use of remote sensing in scientific and forensic analysis requires collecting large quantities of signature data from a variety of sensors using a variety of techniques in a variety of environmental conditions. The quantity of collected signature data continues to grow rapidly and the challenge of storing, classifying, searching and exchanging of signatures has significantly increased. We will discuss our approach for standardizing metadata across different phenomenology; data interchange formats; unique identification of signatures; signature quality metrics; facilitating third party analysis tools and large signature library management.

6.0103 Enhancements to cSAM Spectral Comparison

Vignesh Ramachandran (Johns Hopkins University Applied Physics Laboratory), Mallory De Coster (Johns Hopkins University/Applied Physics Lab), Samantha Jacobs , Nigel Tzeng (Johns Hopkins University Applied Physics Laboratory), Benjamin Rodriguez (Johns Hopkins University/Applied Physics Laboratory),

Presentation: Vignesh Ramachandran, Sunday, March 8th, 09:50 PM, Cheyenne

The original 'Characteristic Spectral Angle Mapping' methodology for spectral classification and identification, presented at IEEE Aerospace last year, has been enhanced using custom Fourier series functions, rather than sinusoids, as classifiers and a Kohonen self-organizing map, rather than k-Means clustering, as the classification method. These modifications result in a significant increase in classification accuracy with minimal impact on run-time as compared with the original cSAM. We present our results and opportunities for future enhancements, as well as opportunities for other applications of this capability.

6.02 Instrument and Sensor Architecture and Design

Session Organizer: Alexander Eremenko (Jet Propulsion Laboratory), Michael Amato (NASA GSFC),

6.0201 Hyperspectral Microwave Atmospheric Sounder (HyMAS) - New Capability in the CoSMIR/CoSSIR Scanhead

Lawrence Hilliard (NASA - Goddard Space Flight Center), William Blackwell (MIT Lincoln Laboratory), Paul Racette , Christopher Galbraith (MIT Lincoln Laboratory), Erik Thompson (MIT Lincoln Laboratory),
Presentation: Lawrence Hilliard, Tuesday, March 10th, 08:30 AM, Elbow 1

MIT Lincoln Laboratory and NASA's Goddard Space Flight Center have teamed to adapt an existing instrument platform, the CoSMIR/CoSSIR system for atmospheric sensing, to develop and demonstrate a new capability in a hyperspectral microwave atmospheric sounder (HyMAS). This new sensor comprises a highly innovative intermediate frequency processor (IFP), that provides the filtering and digitization of 52 radiometric channels and the interoperable remote component (IRC) adapted to CoSMIR, CoSSIR, and HyMAS that stores and archives the data with time tagged calibration and navigation data.

6.0202 Monitoring Earth’s Shortwave Reflectance: GEO Instrument Concept

Emily Brageot (Jet Propulsion Laboratory), Michael Mercury , Robert Green (Jet Propulsion Laboratory),
Presentation: Emily Brageot, Tuesday, March 10th, 08:55 AM, Elbow 1

In this paper we present a GEO instrument concept dedicated to monitoring the Earth’s global spectral reflectance with a high revisit rate. Based on our measurement goals, the ideal instrument needs to be highly sensitive (SNR>100) and to achieve global coverage with spectral sampling (≤10nm) and spatial sampling (≤1km) over a large bandwidth (380-2510 nm) with a revisit time (≥3×/day) sufficient to fully measure the spectral-radiometric-spatial evolution of clouds and confounding factor during daytime. After a brief study of existing instruments and their capabilities, we choose to use a GEO constellation of up to 6 satellites as a platform for this instrument concept in order to achieve the revisit time requirement with a single launch. We derive the main parameters of the instrument and show the above requirements can be fulfilled while retaining an instrument architecture as compact as possible by controlling the telescope aperture size and using a passively cooled detector.

6.0203 Space Launch System Data Acquisition and Sensor System for Human Space Flight

Mary Highsmith , John Brock (Boeing Company), Damon Stephens (The Boeing Company),
Presentation: Mary Highsmith, Tuesday, March 10th, 09:20 AM, Elbow 1

The Boeing Company is designing, developing and manufacturing the Core Stage and Avionics for NASA’s heavy lift rocket, the Space Launch System (SLS), which will support missions beyond low earth orbit for the first time since the Apollo days. On the SLS vehicle many sensors are selected and used to provide critical information for testing, ground operations, and vehicle flight environments. Appropriate data acquisition systems that can interface and process the selected sensors is important to the success

of the program. In this program, multiple data acquisition systems are used to interface with sensors at various development stages of the SLS vehicle, and at different sensor criticality levels. One challenge that engineers are faced with pertains to how the data acquisition system is defined prior to understanding the quantity and type of sensors required for the application. This paper focuses mainly on the SLS flight system and provides a general overview of the system architecture. The paper also addresses the strategy used to define the data acquisition system, along with the methodology for selecting data acquisition cards that fit with the application.

6.0204 Solar Science from Manned Suborbital Vehicles - the SwRI Solar Instrument Pointing Platform

Jedediah Diller (Southwest Research Institute), Craig De Forest (Southwest Research Institute), Glenn Laurent (Southwest Research Institute), Judy Brownsberger ,

Presentation: Jedediah Diller, Tuesday, March 10th, 09:45 AM, Elbow 1

The SwRI Solar Instrument Pointing Platform (SSIPP) is a protoflight system that leverages the low cost, reusability of suborbital vehicles. SSIPP enables observatory-like solar instrument development at a fraction of the cost and risk of traditional sounding rockets. It also enables solar science at important wavelengths and timescales. SSIPP Mk 1 is being developed to fit the payload space of the XCOR Lynx. It is an electrically self-contained, pilot-in-loop pointing system designed to provide sub-arcsecond pointing to remote sensing solar instruments. SSIPP is wavelength agnostic and includes a standard optical bench for rapid buildup of novel instrumentation. Assembly and testing complete, SSIPP awaits a demonstration test flight in late 2015 or early 2016. This paper will discuss SSIPP's motivation, design, current development, planned test flight, and future expansion of the instrument's technology

6.03 Imaging Spectrometer Systems, Science, and Science Applications

Session Organizer: Robert Green (Jet Propulsion Laboratory), David Tratt (The Aerospace Corporation),

6.0301 A Multispectral Thermal Imaging System for Measuring Volcanic Ash Mass Loading

Russell Carroll (University of Alaska Fairbanks), Joseph Hawkins (University of Alaska Fairbanks), Denise Thorsen (University of Alaska Fairbanks),

Presentation: Russell Carroll, Tuesday, March 10th, 10:10 AM, Elbow 1

Small spacecraft with thermal infrared (TIR) imaging capabilities are needed to detect dangerous levels of volcanic ash that can severely damage jet aircraft engines and must be avoided. Grounding aircraft after a volcanic eruption may cost the airlines millions of dollars per day, while accurate knowledge of volcanic ash density might allow for safely routing aircraft around dangerous levels of volcanic ash. There are currently limited numbers of satellites with TIR imaging capabilities so the elapsed time between revisits can be large, and these instruments can only resolve total mass loading along the line-of-sight. Multiple small satellites could allow for decreased revisit times as well as multiple viewing angles to reveal the three-dimensional structure of the ash cloud through stereoscopic techniques. This paper presents the design and laboratory evaluation of a TIR imaging system that is designed to fit within the resource constraints of a multi-unit CubeSat to detect volcanic ash mass loading. The detection threshold of volcanic ash density of this TIR imaging system is found to be from 0.35 mg/m3 to 26 mg/m3 for ash clouds that have thickness of 1 km, while ash cloud densities greater than 2.0 mg/m3 are considered dangerous to aircraft. This analysis demonstrates that a TIR imaging system for determining whether the volcanic ash density is dangerous for aircraft is feasible for multi-unit Cubesat platforms.

6.04 Advances in Radar Signal Processing

Session Organizer: Larry Smith (Georgia Tech Research Institute), Thomas Backes (Georgia Tech Research Institute),

6.0401 Monopulse Direction of Arrival Estimation Using Adjacent Matched Filter Samples

John Glass (Georgia Tech Research Institute), William Blair (Georgia Tech Research Institute),
Presentation: John Glass, Monday, March 9th, 04:30 PM, Cheyenne

In modern surveillance radar systems, amplitude comparison monopulse techniques improve target angle estimation. Radars using pulse compression techniques typically use a sampled version of the matched filter output for detection and estimation purposes, and the target energy is often assumed to be contained in a single sample. In practice this assumption is often not valid; target energy is usually contained in multiple adjacent samples. Therefore, the correlation between matched filter samples is often ignored. Recently, the correlation between matched filter samples has been shown useful for a variety of estimation purposes such as resolving multiple targets and fine estimation of target range. In this work, we use an explicit model of multiple adjacent samples for the sum and difference channels of a monopulse radar system and find maximum likelihood estimates of direction of arrival for a single target. Performances of the maximum likelihood estimator and generalized maximum likelihood estimator are compared to conventional monopulse techniques that use the real part of the monopulse ratio, with an emphasis on low signal-to-noise and off boresight targets.

6.05 Tracking Theory

Session Organizer: Robert Lynch (Consultant, Analytic Information Fusion Systems), Stefano Coraluppi (Systems & Technology Research),

6.0501 Advances in Multi-Target Filtering of Evasive Targets

Stefano Coraluppi (Systems & Technology Research), Craig Carthel (Compunetix Inc),
Presentation: Stefano Coraluppi, Monday, March 9th, 09:00 PM, Cheyenne

This paper introduces multi-target filtering advances for challenging multi-target tracking scenarios. First, we propose an Interacting Multiple Model (IMM) filter for tracking evasive move-stop-move targets, by exploiting a modified Ornstein Uhlenbeck (OU) process model for target motion. Second, we introduce an asynchronous approach to data association that is applicable to multi-sensor settings where update rates and information content vary greatly across sensors. We validate improved performance using global nearest neighbor (GNN) data association and discuss its applicability to multi-target tracking (MTT) under the MHT paradigm.

6.0502 Extracting Speed, Heading and Turn-Rate Measurements from Extended Objects Using the EM Algorithm

Steven Bordonaro , Peter Willett (University of Connecticut), Yaakov Bar Shalom (University of Connecticut), Marcus Baum (University of Connecticut), Tod Luginbuhl (Naval Undersea Warfare Center),
Presentation: Steven Bordonaro, Monday, March 9th, 09:25 PM, Cheyenne

In active sonar and radar target tracking, measurements consist of position and often Doppler. Tracking algorithms use these measurements over time to estimate target state comprising position, velocity and turn rate. In most cases there is an underlying assumption in the tracking algorithm that the target is a “point target” (i.e. the target has no physical extent). Another common assumption is that, at most, one measurement per scan originates from the target. For certain combinations of transmitted waveform and target type, the resolution of the waveform is such that the target is “overresolved” (i.e. the error in the measurements is small enough that the spatial characteristics of the target can be measured). For such cases the point target assumption must be replaced with an extended target assumption. This work provides a methodology to exploit the extended nature of the target for the case of a rigid target whose spatial characteristics are fixed with respect to the line of motion. By employing a combination of the expectation maximization (EM) algorithm and allowing more than one measurement per scan to originate from the target, a measurement conversion technique is developed. This technique converts a single scan of raw measurements that include position and Doppler into an estimate of target position, velocity, heading and turn rate.

6.06 Multisensor Fusion

Session Organizer: William Blair (Georgia Tech Research Institute), Laura Bateman (Johns Hopkins University/Applied Physics Laboratory),

6.0601 Track Registration Assignment Using Image Correlation

Stephen Stubberud (Oakridge Technology),

Presentation: Stephen Stubberud, Wednesday, March 11th, 04:30 PM, Elbow 1

An association technique for the target registration problem is presented. The technique uses an image correlation technique referred to as the phase-only filter. The tracks are mapped to image representation and then compared. The correlation technique generates a peak which is used to generate an association score which can be used in a variety association schemes. Here, the techniques is a Munkres assignment technique. The technique is describe and applied to static registration problems that contain both rotation and translation. The target tracks are both maneuvering and nonmaneuvering. The application is also shown with different levels of noise on the target tracks.

6.0603 Multi-Spectral Detection and Tracking in Cluttered Urban Environments

Peter Zulch (Air Force Research Laboratory), Casey Demars , Michael Roggemann (Michigan Technological University),

Presentation: Peter Zulch, Wednesday, March 11th, 04:55 PM, Elbow 1

Automatic detection and tracking of moving targets in full motion video (FMV) from aerial imaging systems has significant interest in the defense and security community. The overall goal of this work is to increase the probability of detection and track association in cluttered urban environments while simultaneously suppressing false alarms by fusing the detection results and features from different spectral bands. We use a Gaussian mixture model (GMM) to detect background pixels, and define potential targets as being in regions that are found to be non-background. Detections from each spectral band are fused to form multi-spectral target candidates. Detected target candidates are associated with targets from a tracking database by matching features from the scale invariant feature transform (SIFT). We create tracking profiles consisting of location history and vector velocity history for all targets in the scene. This algorithm was evaluated with synthetically generated datasets from the Digital Imaging and Remote Sensing Image Generation (DIRSIG) software model producing visible, near infrared, mid-wave infrared and long-wave infrared FMV that include moving vehicles in an urban environment. It is demonstrated that the fusion algorithm improves the detection performance over individual spectral band performance.

6.0604 Improved Error Estimation in Cases of Occasional Full Covariance

Mark Briski (Institute for Defense Analyses), Laura Bateman (Johns Hopkins University/Applied Physics Laboratory),

Presentation: Mark Briski, Wednesday, March 11th, 05:20 PM, Elbow 1

Correct track-to-track correlation is a key component of multi-sensor tracking and fusion. Some tracking systems provide full covariance only upon request, making the already difficult problem of multi-sensor track correlation even more difficult. To improve the correctness of correlation results involving track updates from such systems that contain state data without covariance, an estimated covariance can be formed (sometimes from other information contained within the track update). In this paper, an approach is proposed that uses the occasional transmitted full covariance to derive sensor position and compute model parameters. Once determined, the information will be used to create an estimated covariance for subsequent state vector updates that do not have full covariance.

6.0606 Air Autonomous Vehicle Benchmark

Darin Dunham (Lockheed Martin), Terry Ogle (Georgia Tech Research Institute), Larry Smith (Georgia Tech Research Institute), William Blair (Georgia Tech Research Institute),

Presentation: Darin Dunham, Wednesday, March 11th, 09:00 PM, Elbow 1

The term benchmark originates from the chiseled horizontal marks that surveyors made, into which an angle-iron could be placed to bracket ("bench") a leveling rod, thus ensuring that the leveling rod can be repositioned in exactly the same place in the future. A benchmark in computer terms is the result of running a number of standard tests and trials against it. The Benchmark simulation environments began in the 1990s and continue today with many different variants including the Ballistic Missile Defense (BMD), Integrated Air/Missile Defense (IAMD), Chemical Biological Defense (CBD), Multiple-Input, Multiple-Output (MIMO) Radar, Electronic Countermeasures (ECM), and Electronic Attack (EA) Benchmarks. This latest variant of a benchmark, Air Autonomous Vehicle (AAV), for target tracking applications models autonomous air vehicles flying over littoral regions tracking surface vessels. This paper covers the capabilities of the AAV Benchmark, the initial scenario that was developed, and results showing the tradeoff between two centralized tracking algorithms.

6.07 Applications of Target Tracking

Session Organizer: Yaakov Bar Shalom (University of Connecticut), John Glass (Georgia Tech Research Institute),

6.0701 Reconstructing Estimates from Noisy Transmissions with Serially-Connected Kalman Filters

Donald Brown (Worcester Polytechnic Institute), Yaakov Bar Shalom (University of Connecticut),

Presentation: Donald Brown, Sunday, March 8th, 04:55 PM, Elbow 2

This paper considers the problem of tracking a time-varying variable with serially-connected Kalman filters. Two nodes are assumed to be serially connected to the target such that only node 1 can directly observe a noisy signal from the target. Node 2 can only observe noisy signals from node 1 corresponding to a linear combination of the current observation and current state estimate at node 1. The objective is to find the linear combination at node 1 that minimizes the mean squared error of the state estimates at node 2 under a transmit power constraint for the signals from node 1 to node 2. An augmented state model is developed to facilitate tracking at node 2. Transmission scaling factors are also derived to satisfy the power constraint. Numerical results are presented for two-node serial tracking in two scenarios: scalar parameter tracking and two-state oscillator phase and frequency tracking. In the scalar parameter tracking example, the results demonstrate that a non-trivial combination of the observation and state estimate at node 1 can improve performance at node 2 with respect to a baseline scenario of simply forwarding scaled observations. In the two-state clock tracking example, an optimal transmission strategy is developed which allows node 2 to achieve the same tracking performance as at node 1.

6.0702 Space Object Tracking and Maneuver Detection via Interacting Multiple Model Cubature Kalman Filter

Genshe Chen (Intelligent Fusion Technology, Inc),
Presentation: Bin Jia, Sunday, March 8th, 05:20 PM, Elbow 2

Space object tracking and maneuver detection play an essential role in space situation awareness (SSA). The ordinary Kalman filter and its variants may give large error due to the maneuver of the space object. In this paper, to consistently track a maneuvering space object, the interacting multiple model (IMM) filter is utilized. Multiple Models with different process noise levels are used to distinguish the maneuvering effects. The IMM cubature Kalman filter (IMM-CKF) is used to track the maneuvering space object which considers of the geometric relations between the space object, space based optical (SBO) sensor, and the sun. The geometric relation highly affects the quality of the observation. A scenario which contains a target spacecraft and four SBO sensors is used to test performance of the IMM-CKF. We also compare the IMM-CKF and the ordinary cubature Kalman filter (CKF). The results indicate that IMM-CKF is more robust than the CKF when the space object undergoes a maneuver. In addition, the detection of a maneuver can be obtained by using the IMM-CKF. Hence, IMM-CKF could facilitate future SBO based SSA mission awareness.

6.0703 Modeling and Tracking Phase and Frequency Offsets in Low-Precision Clocks

Radu David (Worcester Polytechnic Institute), Donald Brown (Worcester Polytechnic Institute),
Presentation: Radu David, Sunday, March 8th, 09:00 PM, Elbow 2

This paper considers the problem of tracking carrier phase offsets in distributed multi-input multi-output (DMIMO) systems. Unlike conventional MIMO systems, each antenna in a DMIMO system is driven by an independent oscillator. To achieve coherent communication, e.g., distributed beamforming and/or nullforming, the time-varying offsets of these oscillators must be accurately tracked and compensated. While Kalman filtering has been used to optimally track phase and frequency offsets, it is well-known that the Kalman filter requires exact knowledge of the process and measurement noise parameters. This paper presents a general method for computing oscillator process and measurement noise parameters from an Allan vari- ance characterization of the carrier phase offset measurements. Numerical results are presented using measured data from sev- eral N210 Universal Software Radio Peripherals (USRPs) at two different carrier frequencies. Using the estimated process and measurement noise parameters, the tracking performance is also evaluated on measured data from the USRPs and compared to theoretical predictions. Distributed beamforming and nullforming performance is also characterized using empirical phase prediction error statistics from the measured data.

6.0704 Single Aircraft Passive Doppler Location of Radios

Hanna Witzgall ,
Presentation: Hanna Witzgall, Sunday, March 8th, 09:25 PM, Elbow 2

This paper examines the performance of the Doppler Particle Filter (DPF) algorithm to locate a push-to-talk handset from the its radio frequency transmissions recorded on-board an aircraft. The technical challenge resides in the mathematical solution to solve for the stationary radio location based on the received Doppler shifted frequency measurements from an emitter with a non-stationary or drifting carrier frequency. The proposed DPF solution is motivated by the failure of the standard techniques (e.g. Gauss-Newton iterative descent technique, Extended Kalman Filter) to this application. The DPF is based on a particular implementation of a particle filter that tracks the carrier frequency at the same time as estimating the radio location and whose approach has

been described in previous papers. Its location performance is examined on data collected on both continuous and intermittent radio operation. The search area was 10x10 km2 and for most of the data collected the closest the sensor got to the target was 2 -3 km. For these ranges, the results show median miss distances of 55 m for continuous transmission and 131 m for intermittent transmissions over almost 150 different collections. Its performance is also compared and shown to approach the FOA Cramer-Rao lower bound (CRLB).

6.0705 A Factor Graph Approach for Efficient JPDA Implementation in Multi-target Tracking

Viji Panakkal (Central Research Laboratory), Rajbabu Velmurugan (Indian Institute of Technology Bombay),

Presentation: Rajbabu Velmurugan, Sunday, March 8th, 09:50 PM, Elbow 2

This paper develops a factor graph (FG) based efficient implementation scheme for joint probabilistic data association (JPDA). The association hypotheses probabilities in JPDA are computed using the sum-product algorithm in a factor graph framework. The multi-target tracking (MTT) data association constraint of not having more than one track assigned to a measurement is incorporated in the proposed approach by modifying the sum-product algorithm. Using the modified sum-product algorithm, this paper shows in detail the message passing in a tree structured factor graph. Compared to other fast JPDA implementation techniques, such as suboptimal JPDA and near optimal JPDA, the proposed method obtains the exact JPDA association probabilities in data association scenarios having tree structured graphs with significant reduction in computational cost. The message passing scheme developed for tree structured graphs are used for scenarios consisting of graphs with loops, and the advantage is shown in this paper using simulations. The computational advantage of the proposed FG based approach is also analyzed for the implementation of the recently proposed Iter-JPDA algorithm for avoiding track coalescence when targets move close. Monte Carlo simulations, comparing the root mean square (RMS) positional error and the computational reductions obtained by the proposed approach, standard JPDA and Iter-JPDA, are presented.

6.0706 Fusion of Range-Only Measurements from Multistatic Configurations for Air Collision Warning

Yaakov Bar Shalom (University of Connecticut),

Presentation: Yaakov Bar Shalom, Monday, March 9th, 08:30 AM, Elbow 2

A requisite for unmanned aircraft systems (UAS) to operate within a controlled airspace is a capability to sense and avoid collisions with non-cooperative aircraft. Ground-based transmitters and UAS-mounted receivers are preferred due to the limitations on the size, weight and power of UAS. This paper assumes a constant velocity motion of an intruder (target) aircraft and presents a method to estimate the state (motion parameters --- position and velocity) of the target so as to predict a possible collision point. Bistatic range and Doppler are assumed the only measurements available, with the employment of low-cost omni-directional antennas. Several configurations are investigated from a parameter observability point of view. The target motion parameter is shown not to be observable in a bistatic configuration and a change of course of the receiver merely yields marginal observability. In a multistatic configuration, one has marginal observability using two transmitters but good observability with three transmitters. Simulation results show that the position estimate of the possible collision point is statistically efficient in the 3-transmitter multistatic configuration.

6.0707 Gaussian Mixture Approach to Long Range Radar Tracking with High Range Resolution

Benjamin Davis (Georgia Tech Research Institute), William Blair (Georgia Tech Research Institute),
Presentation: Benjamin Davis, Monday, March 9th, 08:55 AM, Elbow 2

For precise, long range radars, the distribution of the polar measurements becomes highly non-Gaussian as the range resolution is increased . Tracking performance with conventional Extended Kalman Filter (EKF) techniques degrades as the resolution is increased. Attempts to fit this distribution with an inflated Gaussian result in a larger-than-necessary region in which measurements may pass traditional Chi-square distance gating metrics. In this paper, a method of parameterizing the radar contact lens distribution for a given measurement is developed such that parameters for a closely fitted Gaussian mixture distribution may be derived by simple lookup and interpolation. This mixture distribution is then used to update the EKF in a way similar to the PDAF approach by combining the different measurement mixture components into a single update according to their posterior probabilities, while maintaining a tight gating region which admits a larger number of true measurements, in proportion to its Euclidian size, than traditional methods. Simulation results that compare the new approach to other popular non-linear filtering techniques are presented with respect to accuracy, consistency, and size of the gating region.

6.0708 RF Localization Solution Using Heterogeneous TDOA

Andrew Sinclair , Jacob Darling (Missouri University of Science and Technology), Alan Lovell ,
Presentation: Alan Lovell, Monday, March 9th, 09:20 AM, Elbow 2

This paper presents a solution for the localization of an RF transmitter using time-difference-of-arrival (TDOA) measurements that do not share any common receiver location. Localization requires three independent TDOA measurements, and previous solutions have assumed that the three measurements all share a common receiver location. Relaxing this assumption is here referred to as heterogeneous TDOA. The approach presented formulates the TDOA measurements as a system of three quadratic equations for the transmitter position components, and solves these equations using the Macaulay resultant. The heterogeneous TDOAs allow for improved measurement geometry resulting in more accurate localization. The solution also allows for localization by two moving receivers, such as orbiting satellites, collecting TDOA measurements at three instants in time.

6.0709 Evaluation of Algorithms for Urban Vehicle Tracking

Ray Byrne (Sandia National Laboratories), Joshua Love (Sandia National Labs), Ross Hansen (Sandia National Laboratory), David Melgaard (Sandia National Laboratories), Todd Pitts , David Karelitz ,
Presentation: Ross Hansen, Monday, March 9th, 09:45 AM, Elbow 2

Low signal-to-noise data processing algorithms for improved detection, tracking, discrimination and situational threat assessment are a key research challenge. As sensor technologies progress, the number of pixels will increase significantly. This will result in increased resolution, which could improve object discrimination, but unfortunately, will also result in a significant increase in the number of potential targets to track. Many tracking techniques, like multi-hypothesis trackers, suffer from a combinatorial explosion as the number of potential targets increase. As the resolution increases, the phenomenology applied towards detection algorithms also changes. For low resolution sensors, “blob” tracking is the norm. For higher resolution data, additional information may be employed in the detection and classification steps. The most challenging scenarios are those where the targets cannot be fully resolved, yet must be tracked and distinguished for neighboring closely spaced objects. Tracking vehicles in an urban environment is an

example of such a challenging scenario. This report evaluates several potential tracking algorithms for large-scale tracking in an urban environment. The algorithms considered are: random sample consensus (RANSAC), Markov chain Monte Carlo data association (MCMCDA), tracklet inference from factor graphs, and a proximity tracker. Each algorithm was tested on a combination of real and simulated data and evaluated against a common set of metrics. The main challenge observed with all algorithms was broken tracks and the difficulty maintaining a single track over long periods.

6.08 Missile Guidance, Navigation and Control

Session Organizer: Fabrizio Reali (Telespazio),

6.0801 Linear Analysis of Zero-Lift Pitching Moment Coefficient and Gravity Effects on Missile Autopilots

Naz Ovec (Roketsan), Koray Erer (Roketsan), Ali Kutay (Middle East Technical University),
Presentation: Naz Ovec, Thursday, March 12th, 04:30 PM, Madison

Linear autopilot design process is conducted by the way of linear mathematical models where the linearization is mostly based on proper assumptions. Mathematical model of any aerial platform is linearized around a desired trim condition in which the vehicle does not have any aerodynamic forces or moments acting on the body. This condition is usually granted with zero control surface deflection in missiles; however non-symmetric structural elements on the missile body could bring forth some aerodynamic forces or moments under zero control surface deflection as well. These unintended forces and moments are usually neglected based on the fact that they are considerably small compared to the forces and moments produced intentionally for desired maneuvers. In regard to this assumption, the controller is designed supposing the missile is in its optimum trim condition. Another commonly used assumption is ignoring the gravity force depending on the fact that its effect on the missile is much less than the aerodynamic forces. In this study, how the different missile rate autopilot structures are affected from these neglected parameters, zero lift pitching moment and gravity force, is analyzed in linear simulation and one of the analyzed structures is proven to have better performance under these disturbances.

6.0804 A Novel Missile Autopilot with Remarkable Robustness

Ray Sells (DESE Research, Inc.),
Presentation: Ray Sells, Thursday, March 12th, 04:55 PM, Madison

A missile lateral autopilot is described and demonstrated that exhibits a high degree-of-robustness to model uncertainty and external disturbances. The novel aspect of the autopilot is a new feedback-loop topology that is a combination of feed-forward and feedback loops. This topology, called the Integral Command Augmentation for Robustness (ICAR) loop, is designed to be added as an additional layer to an existing, fully functional closed-loop autopilot. It does not alter the existing system dynamics except to add a high degree-of-robustness to model uncertainty in the original closed-loop autopilot. The mathematical basis for the ICAR loop is derived and its operation is demonstrated, first, using a simple plant followed by application to an autopilot. Results of a series of simulation experiments are presented demonstrating exceptional robustness and disturbance rejection capability. The paper concludes with observations that the ICAR loop can be applied to a much broader domain of control systems beyond the missile autopilot.

TRACK 7: SPACECRAFT AVIONICS SYSTEMS, SUBSYSTEMS, & TECHNOLOGIES

Track Organizers: John Samson (Honeywell Aerospace), Harald Schone (Jet Propulsion Laboratory)

7.01 High Performance Space Processing and High-Speed Interconnect Satellite Architectures and Standards

Session Organizer: Joseph Marshall (BAE Systems), Jamal Haque (Honeywell),

7.0101 Bringing High-Performance Microprocessors up to Space Level Reliability

Sébastien Frasse Sombet (e2v Semiconductors),

Presentation: Sébastien Frasse Sombet, Sunday, March 8th, 04:30 PM, Lamar/Gibbon

An increasingly rapid race for high performance systems has led satellite manufacturers to look for alternatives to traditional radiation hardened microcircuits. One of the approaches is to benefit from existing commercial technology with proven radiation tolerance and focus on specific assembly, test and qualification capabilities to ensure long term reliability once exposed to space environment. This paper will describe the development of PC7448, a 1.2GHz/5GFlop radiation tolerant microprocessor. It will provide insight on how we have implemented space level manufacturing of this advanced digital microcircuit in compliance with the new MIL-PRF-38535 Class Y (QML Y). Access to COTS based microprocessors will enable space systems manufacturers to increase performance and flexibility of satellite payloads. In particular, PC7448 is bringing attractive digital signal processing capabilities useful to compute-intensive applications such as Earth Observation, Weather Monitoring, SAR systems and telecommunication equipment.

7.0102 Introducing Radiation Tolerant Heterogeneous Computers for Small Satellites

Fredrik Bruhn (Bruhnspace), John Hines , Lars Asplund (Malardalen University), Magnus Norgren (BAP), Kjell Brunberg (BAP),

Presentation: Fredrik Bruhn, Sunday, March 8th, 05:20 PM, Lamar/Gibbon

The presentation covers the development of a radiation tolerant heterogeneous computer for onboard data processing using CPU, GPU, and FPGA. Architectural design, benchmarking, and form factor trade-offs are presented.

7.0103 Achieving High-Speed Box-to-Box Interconnects in Space Systems

Ian Troxel (Betrokor, Inc.), Bob Campanini (Micropac Industries Inc),

Presentation: Ian Troxel, Sunday, March 8th, 04:55 PM, Lamar/Gibbon

A distance limitation of about 14 feet has been observed on a program of record between Engineering Model boxes with shielded quadrax cables carrying an aggregate of 36Gbps of user data. Estimates for the performance of the flight design suggest the interconnect would be further distance limited given flight components and a desire to increase signaling rates. The fundamental challenge is achieving high-speed, while meeting distance, environmental, power, EMI/EMC and manufacturability requirements. Higher rate sensors and data-intensive missions that are currently under development will further exacerbate distance limitations due to copper cables. Recent advances in optical fiber and transceiver components that can survive the space environment are poised to eliminate this limitation. Solutions derived from these advances will be presented along with test data and their development roadmap.

7.0104 Next Generation Space Interconnect Standard (NGSIS): A Modular Open Standards Approach for Space

Patrick Collier (AFRL), Joseph Marshall (BAE Systems),
Presentation: Patrick Collier, Sunday, March 8th, 09:00 PM, Lamar/Gibbon

The Next Generation Space Interconnect Standard (NGSIS) effort is a Government-Industry collaboration effort to define a set of standards for interconnects between space system components with the goal of cost effectively removing bandwidth as a constraint for future space systems. The NGSIS team has selected the ANSI/VITA 65 OpenVPX standard family for the physical baseline. The RapidIO protocol has been selected as the basis for the digital data transport. The NGSIS standards are developed to provide sufficient flexibility to enable users to implement a variety of system configurations, while meeting goals for interoperability and robustness for space. The NGSIS approach and effort represents a radical departure from past approaches to achieve a Modular Open System Architecture (MOSA) for space systems and serves as an exemplar for the civil, commercial, and military Space communities as well as a broader high reliability terrestrial market.

7.0105 SpaceFibre: A Multi-Gigabit/s Interconnect for Spacecraft Onboard Data Handling

Steve Parkes (University of Dundee),
Presentation: Steve Parkes, Sunday, March 8th, 09:50 PM, Lamar/Gibbon

SpaceFibre is a spacecraft on-board data-link and network technology developed by University of Dundee for the European Space Agency (ESA), which runs over both copper and fibre optic cables. Initially targeted at very high data rate payloads such as Synthetic Aperture Radar (SAR) and multi-spectral imaging instruments, SpaceFibre is able to fulfil a wider set of spacecraft on-board communications applications because of its inbuilt QoS and FDIR capabilities and its backwards compatibility with the ubiquitous SpaceWire technology. With current flight qualified technology, SpaceFibre operates at 2.5 Gbits/s providing 12 times the throughput of a SpaceWire link. The innovative QoS mechanism in SpaceFibre provides concurrent bandwidth reservation, priority and scheduled QoS. This simplifies spacecraft system engineering through integrated quality of service (QoS), which reduces system engineering costs and streamlines integration and test. Novel integrated FDIR support provides galvanic isolation, transparent recovery from transient errors, error containment in virtual channels and frames, and “Babbling Idiot” protection. SpaceFibre enhances on-board network robustness through its inherent FDIR and graceful degradation techniques incorporated in the network hardware. This simplifies system FDIR software, reducing development and system validation time and cost. SpaceFibre includes low latency event signalling and time distribution with broadcast messages. A single network can then be used for several functions including: transporting very high data rate payload data, carrying SpaceWire traffic, deterministic delivery of command/control information, time distribution and event signalling. SpaceFibre is backwards compatible with existing SpaceWire equipment at the packet level allowing simple interconnection of SpaceWire devices into a SpaceFibre network.

7.0106 On-Board Networks with Radiation-Hardened 45nm SOI Standard Components

Dale Rickard (BAE Systems),
Presentation: Dale Rickard, Sunday, March 8th, 09:25 PM, Lamar/Gibbon

This paper describes the key components for implementing a modern network for intra-satellite communications at the backplane and spacecraft local area network (LAN) levels. The objective network is capable of supporting orders of magnitude more on-board processing than current architectures based on parallel PCI-bus, MIL-STD-1553B and

SpaceWire alone. The RADNET™ family supports the emerging SpaceVPX standard at the backplane level including RapidIO data plane, SpaceWire control plane, and I2C utility plane. RapidIO, SpaceWire and MIL-STD-1553B are the primary interfaces supported at the spacecraft local area network (LAN) level. Heritage network components are available to support parallel PCI-bus, SpaceWire and MIL-STD-1553B. The latest RADNET components use BAE System's RH45™ radiation-hardened by design (RHBD) 45nm silicon-on-insulator (SOI) ASIC library and are manufactured at the IBM Trusted foundry. These include a RapidIO network endpoint, an 18-port, 192-Gb/s RapidIO packet switch, and a 16-by-16-lane, 5-Gbaud per lane physical layer serializer-deserializer (SerDes) crosspoint switch. Network architecture, technical challenges, component architectures, development methodology, implementation, programming and path to flight are discussed.

7.02 Onboard Signal, Data, Command Processing and Data Handling Technologies

Session Organizer: Michael Mclelland (Southwest Research Institute), Jamal Haque (Honeywell), Patrick Phelan (Southwest Research Institute)

7.0201 Application of an Image Processing Architecture for the Solar Orbiter SPICE Instrument

Patrick Phelan (Southwest Research Institute), Buddy Walls (Southwest Research Institute), Presentation: Patrick Phelan, Monday, March 9th, 11:50 AM, Cheyenne

The ongoing development of avionics to support the Spectral Imaging of the Coronal Environment (SPICE) Electronics Box (SEB) program as part of the European Space Agency's (ESA) Solar Orbiter mission has resulted in the development of an Image Processing Field Programmable Gate Array (FPGA) (IPF). The IPF is a single FPGA containing functions to communicate with a Front End Electronics (FEE) assembly/extreme ultraviolet camera, to apply data corrections on incoming pixels, and to compress the final image product for transmission to the ground. The IPF is used as part of a larger science "observation" campaign envisaged as a series of "studies" that are scheduled using a macro execution engine maintained by the Flight Software (FSW). A macro is a lookup table (LUT) stored in memory which contains a series of SPICE commands with relative time tags for each, which determines when each command is executed. This paper discusses the design and architecture of the IPF and associated controlling software employed to meet the various engineering and science requirements of the SPICE instrument.

7.03 Multi- and Many-Core Computing in Space: Hardware and Software

Session Organizer: Martha Bancroft (MBC), Stephen Crago (University of Southern California)

7.0301 Quad-Core Radiation-Hardened System-on-Chip Power Architecture Processor

Richard Berger (BAE Systems), Dale Rickard (BAE Systems), Joseph Marshall (BAE Systems), Presentation: Richard Berger, Monday, March 9th, 08:30 AM, Elbow 1

Based on the QorIQ® system-on-chip processor architecture from Freescale Semiconductor with additional unique features for space applications, the RAD55xx™ system-on-chip platform integrated circuit can be personalized into multiple processor solutions. The RAD55xx includes four 32/64 bit Power Architecture® processor cores, three levels of on-die cache memory, dual interleaved DDR3 DRAM controllers, data path acceleration architecture (DPAA) on-die hardware accelerators, a NAND Flash controller, and high I/O throughput based on serializer/deserializer high speed links. Manufactured at the IBM trusted foundry in 45nm silicon-on-insulator (SOI) process technology with copper interconnect and leveraging the radiation-hardened by design RH45™ technology, the RAD55xx optimizes power/performance to deliver processor throughput of up to 5.6 GOPS/3.7 GFLOPS, memory bandwidth of up to 102 Gb/s, and I/O throughput of up to 64 Gb/s. Each of the highly efficient RAD5500™ 64 bit cores offers direct addressability to 64 GB of memory, improves double precision floating point performance, and achieves 3.0 Dhrystone MIPS/MHz. The RAD55xx platform is designed for insertion into systems using the SpaceVPX standard, supporting the RapidIO data plane, SpaceWire control plane, and I2C utility plane. Architectural trades, the development methodology, technical challenges, and single board computer solutions are discussed.

7.0302 Implementing a Software Defined Radio Using the Maestro 49-tile Processor

Herschel Loomis (Naval Postgraduate School), George Dinolt (Naval Postgraduate School), Frank Kragh (Naval Postgraduate School),
Presentation: Herschel Loomis, Monday, March 9th, 08:55 AM, Elbow 1

The Maestro 49-tile Radiation-Hard-by-Design chip was developed to demonstrate the application of space-qualified, multicore hardware. We have investigated the implementation of a single precision floating–point pipeline FFT to be used as part of a Software Defined Radio (SDR) application. The details of the software architecture that can adapt to the use of different numbers of tiles and the performance of the N-point FFTs for N = 128, 512, 1024, and 2048 are described. The maximum throughput achieved for a 2048-point FFT is 27 million samples per second when 20 of the 49 available tiles are used for separate FFT blocks, one tile is used for input data distribution, and one tile is used for output data collection. We also report on the performance of the SDR based upon the FFT experiments.

7.0303 A Method for Efficient Radiation Hardening of Multicore Processors

Jonathan Ballast (Boeing Research and Technology),
Presentation: Jonathan Ballast, Monday, March 9th, 09:20 AM, Elbow 1

This paper describes a method for developing Radiation Hardened by Design (RHBD) multicore processor Integrated Circuits (ICs) that meet specific single-event error rate targets in space environments with minimal impacts on power, area, and speed.

7.04 Memory and Data Storage Technologies for Space and Missile Applications

Session Organizer: Douglas Sheldon (Jet Propulsion Laboratory), Michael Epperly (Southwest Research Institute), Matthew Marinella (Sandia National Laboratories)

7.0401 γ Ray Radiation Effects on TiN/HfOx/Pt RRAM Devices

Fang Yuan (Tsinghua University), Shanshan Shen (Tsinghua University), Zhigang Zhang ,
Presentation: Fang Yuan, Monday, March 9th, 10:35 AM, Elbow 1

Resistive random access memory (RRAM) is widely recognized to be an excellent candidate of non-volatile memory for the next generation, especially for potential application in aerospace or nuclear industry due to its intrinsic radiation-hard superiority to other non-volatile memories. Therefore, a classical RRAM device with the structure of TiN/HfOx/Pt is fabricated and the total ionizing dose (TID) effects of γ-ray irradiation on the switching behaviors and memory performance are studied in this work. The switching behavior and memory performance of the irradiated devices are investigated and compared to the pre-irradiation ones. The switching mechanism, device resistances and operation voltages are affected, in varying degrees. The irradiation-induced oxygen vacancies and holes are proposed to be the cause of the variation. The TiN/HfOx/Pt

RRAM device exhibits a good immunity to the γ-ray irradiation since the performance variation are tolerable in application.

7.0402 Reliability Considerations and Radiation Testing of Memristor Devices

Erica Deionno (The Aerospace Corporation), Allyson White ,

Presentation: Erica Deionno, Monday, March 9th, 11:00 AM, Elbow 1

Resistive random access memories (RRAM) can be made of a variety of materials, including metal oxides and metal-doped chalcogenides, that exhibit memristive behavior. RRAMs have been identified as a leading candidate to replace flash memory and may also be suitable as replacements for other types of memory, including DRAM and SRAM. When sandwiched between two electrodes, specially grown thin films can be switched with applied bias between a high (off) and a low resistance (on) state. Since 2007, these devices have been considered as candidates for space applications due to their device properties. There is a high density of inherent defects in the as-fabricated devices, which is likely to contribute to their tolerance to displacement damage. In addition, the nanometer length scale of the active device layers allows the devices to dissipate the charge deposited from ionizing dose. However, the testing of devices over several different radiation studies has revealed potential reliability concerns, including device to device variation, device sensitivity to measurements and physical device changes that occur with cycling between states. In this paper, we will discuss these concerns and present initial results of biased radiation testing of TaOx and TiO2 devices with ionizing radiation.

7.0403 Overview of the Radiation Response of TaOx-based Memristive Devices

Michael Mc Lain (Sandia National Laboratories), Matthew Marinella (Sandia National Laboratories),

Presentation: Michael Mc Lain, Monday, March 9th, 11:25 AM, Elbow 1

In this paper, we provide an overview of the current knowledge of radiation effects in anion-based memristive devices. We will specifically look at the impact of high dose rate ionizing radiation, total ionizing dose (TID), and heavy ions on the electrical characteristics of tantalum oxide (TaOx), titanium dioxide (TiO2), and hafnium oxide (HfOx) memristors. The primary emphasis, however, will be placed on TaOx memristors. While there are several other anion-based memristive devices being fabricated by the semiconductor community for possible use in valence change memories, most of the present radiation work has focused on one of these types of devices. There have also been numerous studies on radiation effects in cation-based chalcogenides such as germanium sulfides and selenides. However, that will not be discussed in this paper.

7.05 High Performance Reconfigurable Computing for Space

Session Organizer: David Petrick (NASA - Goddard Space Flight Center), Mohamed Ibrahim (Kyushu Institute of Technology), Ian Troxel (Betrokor, Inc.)

7.0501 Memory-Aware Optimization of FPGA-Based Space Systems

Nicholas Wulf (University of Florida), Alan George (University of Florida), Ann Gordon Ross (University of Florida),

Presentation: Nicholas Wulf, Monday, March 9th, 11:25 AM, Cheyenne

Designing FPGA-based space systems that meet mission goals of high performance, low power, and high dependability is challenging. Our previous work established a framework to help designers of FPGA-based space systems to consider a wide range of designs, evaluate the power and dependability of those designs, and narrow the large design search space down to a significantly reduced Pareto-optimal set. To further improve and extend our framework's ability to evaluate and optimize increasingly complex aerospace systems, this paper details our framework's memory extension, which enables memory-aware analysis by refinements to our framework's original analysis. The memory-aware analysis more accurately predicts a system's power and dependability by modeling three memory resources: internal-memory capacity, internal-memory bandwidth, and external-memory bandwidth. We demonstrate the importance of our framework's memory extension by investigating a case study based on an enhanced version of a hyperspectral-imaging satellite mission. After analyzing 22 unique Virtex FPGA devices and optimizing each for power and then dependability, the framework selects four Pareto-optimal designs, ranging from very-low power to high dependability. Results of the framework's memory extension show that memory resources may limit the performance of an FPGA-based space-system design and contribute significantly towards power and dependability results.

7.07 Avionics for Small Satellites, Nano-Satellites, and CubeSats

Session Organizer: Jamal Haque (Honeywell), John Dickinson (Southwest Research Institute), James Lumpp (University of Kentucky),

7.0702 FPGA Hardware Nonlinear Control Design for Modular CubeSat Attitude Control System

Junquan Li (York University), Mark Post (University of Strathclyde), Regina Lee (York Univesity),
Presentation: Junquan Li, Tuesday, March 10th, 08:30 AM, Madison

This paper will focus on demonstrating the feasibility and effectiveness of a proposed nonlinear adaptive fuzzy controller implemented on a Field Programmable Gate Array as part of a highly-integrated space hardware system that is under development. Details of the attitude control system and controller are presented. We use freely-available High-Level Synthesis tools to convert C code to a logic fabric. Purely numerical simulations for the controller are done using Simulink on a host computer, and these simulations are compared with results obtained from embedded hardware-in-the-loop testing of the FPGA-based controller using simulated sensor inputs and actuator models. Evaluation of the simulation and hardware test results shows that the control performance of the FPGA hardware control system is suitable for small satellite control and can meet precise pointing requirements.

7.0703 Design and Development of 3-axis Reaction Wheel for STUDSAT-2

Saroj Kumar (Nitte Meenakshi Institute of Technology), Anik Jha (Nitte Meenakshi Institute of Technology), Divyanshu Sahay (Nitte Meenakshi Institute of Technology), Sandesh Hegde (N.M.A.M.I.T), Sandya Srinivasa Rao (Nitte Meenakshi Institute of Technology), Mahalingesh T.C (siddaganga institute of technology,Tumkur),
Presentation: Divyanshu Sahay, Tuesday, March 10th, 08:55 AM, Madison

This paper describes the designing, detailed motion and frequency analysis and brief control approach of nano reaction wheels that has to be used as an actuator for STUDSAT-2. The designing part comprises of designing a flywheel, tetrahedral configuration explanation and the motor selection. The worst case disturbance modeling is done to design the flywheel considering the four primary environmental disturbances namely aerodynamic drag, solar radiation, magnetic residual and gravity gradient. Using the design parameters a study is performed with the goal of minimizing mass of the flywheel. Furthermore, the design configuration is used to derive the relation between the torques produced on the 3 axis of the satellite. The detailed explanation of structure is done and both static and dynamic frequency analysis results are obtained. A detailed slew rate analysis is done to obtain the relation between the angular momentum gained by the satellite and the torque exerted through the reaction wheel motors. The Flat Brushless DC motor chosen for the project is modeled mathematically and open loop analysis is

done by drawing the necessary plots. Proportional Integral Derivative (PID) error control parameters are obtained for stable performance of the motor.

7.0704 Update on DM CubeSat Technology Development: ISS Flight Experiments

John Samson (Honeywell Aerospace), Benjamin Malphrus (Morehead State University),
Presentation: John Samson, Tuesday, March 10th, 09:20 AM, Madison

Following the successful SMDC (Space and Missile Defense Command) TechSat F-cubed (Form, Fit, Function) demonstration in 2012, DM CubeSat technology development continued its path to space. In March 2013, Yosemite Space, formerly known as Advanced Materials Applications, LLC, and Honeywell Aerospace were awarded a CASIS (the Center for the Advancement of Science in Space) grant to perform both ground-based and space-based radiation testing of Gumstix™ COM (Compute-On-Module) modules. Ground-based proton testing of a variety of Gumstix modules has been completed. The space-based radiation testing and performance validation will be conducted as an ISS (International Space Station) National Laboratory flight experiment. Originally scheduled for launch in late 2014, the launch of the Gumstix flight experiment has been delayed to early 2015. In September 2014, Honeywell and Morehead State University (MSU) were awarded a CASIS grant to fly a DM (Dependable Multiprocessor) CubeSat payload processor as a 2015 ISS National Laboratory flight experiment. This ISS flight experiment will culminate with the TRL7 validation of DM CubeSat technology. Following a brief overview of DM and DM CubeSat technology, the paper discusses the two ISS flight experiments and other DM CubeSat-related developments.

7.08 Power Electronics for Space Applications

Session Organizer: Peter Wilson (University of Southampton)

7.0801 High Temperature Die-attach Materials for Aerospace Power Electronics: Lifetime Tests and Modeling

Aaron Hutzler (Fraunhofer IISB),
Presentation: Aaron Hutzler, Wednesday, March 11th, 04:30 PM, Lake/Canyon

Increasing the temperature in power electronic applications usually causes a decreasing lifetime and reliability. This study shows that packaging materials and technologies, such as silver-sintering or gold germanium solders combined with silicon-carbide devices, can easily deal with temperatures above 200 °C/392 °F. Furthermore, lifetime tests (active power cycling) with 300 devices offered more cycles to failure at 120 °C/248 °F heat sink temperature than at 40 °C/104 °F (same ΔT) for silver-sintered samples and gold-germanium solders. SAC305 and tin-lead solders were also tested for comparison but could not withstand the harsh conditions. The samples were silicon carbide diodes attached to copper-ceramic-substrates (DBCs). For testing, the devices were heated up by current to achieve a 130 K temperature swing at different coolant temperatures (250 °C/482 °F maximum temperature). The reason behind the higher lifetime at elevated temperatures is the increasing ductility over temperature. The materials capability against thermo-mechanical stress is better at higher temperatures, while creep effects are not dominating. This effect can be used especially for high temperature application with extraordinary requirements on lifetime and reliability. Analytical models based on stress strain calculations can explain this material behavior. Together with an in-situ measurement of the thermal impedance the models can predict the lifetime consumption of the application and thereby upcoming maintenance. This results will be presented.

7.0802 Improving the Efficiency of 3U CubeSat EPS by Selecting Operating Conditions for Power Converters

Jesus Gonzalez Llorente (Universidad Sergio Arboleda), David Rodriguez (Universidad Sergio Arboleda), Sergio Sánchez Sanjuán , Andres Rambal Vecino (Universidad sergio Arboleda),

Presentation: Sergio Sánchez Sanjuán, Wednesday, March 11th, 04:55 PM, Lake/Canyon

CubeSat is a nanosatellite platform that provides access to space for small payloads. It is an attractive solution for space exploration missions as it reduces cost and development time. However, size constraints restrict the surface area for solar panels and thus the generated power. The efficiency of the power condition modules of the electrical power system (EPS) is a relevant feature in the design of a CubeSat. One of the parameters that defines the efficiency of the power converters is their operating input and output voltages; these voltages are given by the array configurations of solar cells and battery cells according to the number of series or parallel connected cells. Therefore, we selected four solar array and battery package combinations for a 3U CubeSat with body mounted solar cells and compared losses and efficiency of the converter by calculation and experimentation. The results reveal that the highest efficiency values for load power values between 0.7W and 7W are about 98% for input voltage of 7.5V and output voltage of 6.6V. The best array configuration is derived due to these results: two string of three serial connected solar cells and a stack of two batteries in serial connection. These results allow us to design an efficient electrical power system for a 3U CubeSat; thus, the loads and the batteries received most of the provided energy by the solar array.

7.0803 Evaluation of Gallium Nitride Transistors in Electronic Power Conditioners for TWTA

Jose Blanes (University Miguel Hernandez), Ausias Garrigos (University Miguel Hernandez),

Presentation: Jose Blanes, Wednesday, March 11th, 05:20 PM, Lake/Canyon

The aim of this paper is to evaluate the benefits of replacing Si Mosfets transistors with enhancement mode GaN transistors in a Half-Bridge Zero Voltage and Zero Current Switching Power Switching Converter (ZVZCPS). This converter is usually used as power supply of the travelling-wave tube amplifiers (TWTAs) in aerospace applications. In this paper, firstly the converter is theoretically analyzed, obtaining its operation, losses and efficiency equations, these equations are used to obtain optimizations maps based on the main system parameters. In this way, the ideal design parameters can be visually obtained. These optimization maps are the key to quantify the potential benefits of GaN transistors in this type of converters. Theoretical results show that using GaN transistors, the frequency of the converter can be pushed from 125kHz to 830kHz without sacrificing the converter efficiency. This frequency increase is directly related to reduction on the EPC size and weight.

7.0804 On the Power System of the AMALIA Moon Rover

Michele Macellari (Sapienza Universita di Roma), Giovanni Palmerini (Sapienza Universita' di Roma), Luigi Schirone (La Sapienza - DIAA),

Presentation: Giovanni Palmerini, Wednesday, March 11th, 09:00 PM, Lake/Canyon

The work deals with the Electrical Power System of a Lunar Rover, developed for the AMALIA mission, intended to compete in the Google Lunar X prize. The main subsystems are described and their operation analyzed on the basis of the observed experimental behavior. Primary generation is provided by triple-junction solar cells, arranged as four sections, each connected to a dedicated Array Power Regulator with separate Maximum Power Point Tracking. A Switch Matrix allows to rearrange the interconnections among the Solar Array sections and the APR in order to manage possible failures. During load peaks and/or with low Sun elevation the solar array is supported by

a secondary generator consisting of three redundant units with Li-Ion battery cells. Two alternate configurations of the Battery Subsystem were developed: a classical 8S Li-Ion battery, for a 28V Sun-regulated bus, and a novel approach, based on a single-cell (1S) Li-Ion battery and a high-voltage-gain Battery Charge-Discharge Regulator. A specific converter was designed for this configuration, based on the non-insulated Three Levels Neutral Point Clamped switching converter topology. Its correct operation with bus voltages up to 48V and fully discharged battery cells was demonstrated.

7.09 Electronics for Extreme Environments

Session Organizer: Elizabeth Kolawa (Jet Propulsion Laboratory), Mohammad Mojarradi (Jet Propulsion Laboratory)

7.0901 Towards Standard Component Parts in Silicon Carbide CMOS

A. Francis (Ozark Integrated Circuits, Inc.), James Holmes (Ozark Integrated Circuits, Inc.), Alan Mantooth (University of Arkansas),

Presentation: A. Francis, Thursday, March 12th, 10:35 AM, Cheyenne

A number of aerospace applications require parts capable of operation at wide temperature extremes and in the presence of ionizing radiation (extreme environments). While silicon-on-insulator technologies have met much of this demand, the selection of available components when temperatures exceed 250oC ranges is very limited. Silicon carbide, a wide-bandgap semiconductor, offers significant advantages over silicon technologies; such as high blocking voltages and fast switching in power devices, high-temperature performance, and reduced susceptibility to ionizing radiation. Presented are a series of “standard” component parts built in CMOS SiC. These parts have been designed, simulated, fabricated and tested using a unique design kit developed for the HiTSiC CMOS process. Two example parts, a general-purpose 8-bit latch and a programmable delay line will be presented. As will be demonstrated, the circuits are capable of operation at very high temperature (>300 \C) and at speeds of up to 5 MHz. The 8-bit latch supports both parallel and serial modes on input and output, and is the first demonstration of a scan-style latch in SiC. The delay unit is a 4-bit general-purpose programmable delay unit useful for multiple applications such as clock generation and PWM synthesis. The design approaches utilized as well as electrical and thermal characteristics of these devices as “catalog parts” for extreme environment applications will be covered, with emphasis on the application-specific requirements for aerospace and space.

7.0902 A Family of CMOS Analog and Mixed Signal Circuits in SiC for High Temperature Electronics

Ashfaqur Rahman (University of Arkansas), A. Francis (Ozark Integrated Circuits, Inc.), Alan Mantooth (University of Arkansas), James Holmes (Ozark Integrated Circuits, Inc.),

Presentation: Alan Mantooth, Thursday, March 12th, 11:00 AM, Cheyenne

With SiC gaining in popularity as a material for high temperature and extreme environment applications, this paper showcases the design and results of some of the first SiC CMOS analog and mixed-signal building block circuits. These include some simple current and voltage references, a pair of transconductance amplifiers and Schmitt trigger. These circuits can provide the basis for more complex mixed signal systems and controllers such data acquisition and transmission systems, and gate driver and controller circuits for power converter systems. With SiC proven as a rugged material that can withstand and operate at high temperature and high voltage conditions due its high thermal conductivity, high breakdown voltage and higher bandgap, circuits and systems designed in SiC would not need the extra protection and cooling normally required for traditional Si ICs. The circuits described in this paper were designed based on models

developed in house and were simulated over temperature and process variation bins. Each circuit was verified rigorously to ensure maximum probability of operation. While the initial models developed were in BSIM3, a more accurate family of models in BSIM4 were developed later. The circuits were tested under probe and in packaged form and the results were compared to simulated results from the BSIM4 models. The presentation will include more data than the paper itself and will highlight the ongoing work of the SiC CMOS design team. Circuits and systems designed in the second run will be highlighted and a pathway to further development will be presented.

7.0903 SiGe BiCMOS Comparator for Extreme Environment Applications

Benjamin Sissons (University of Arkansas), James Holmes (Ozark Integrated Circuits, Inc.), A. Francis (Ozark Integrated Circuits, Inc.), Alan Mantooth (University of Arkansas), Jia Di (University of Arkansas),

Presentation: Benjamin Sissons, Thursday, March 12th, 11:25 AM, Cheyenne

This paper presents a 90 nm SiGe BiCMOS comparator designed for extreme environment use. A unique circuit characteristic of this comparator topology is that it uses only one NMOS transistor in the circuit. The rest of the circuit is comprised of PMOS transistors and NPN HBTs in order to maintain radiation hardiness. The circuit was simulated across a temperature range of -195 °C to 155 °C. The circuit was simulated at cryogenic temperatures using several models developed at the University of Arkansas (UA) and at Georgia Tech. The comparator produces a maximum resolution of 500 µV with an input range of 0.05-0.6 V in a 1.2 V process. A maximum propagation delay of less than 20 ns was also achieved. These specifications were based off of its intended application in a successive approximation register analog-to-digital converter also being developed at the UA as part of a NASA Space Technology Research Opportunities-Early Stage Innovations (STRO-ESI) project.

7.0904 An Asynchronous Cell Library for Operation in Wide-Temperature & Ionizing-Radiation Environments

John Brady (University of Arkansas - Fayetteville), A. Francis (Ozark Integrated Circuits, Inc.), James Holmes (Ozark Integrated Circuits, Inc.), Jia Di (University of Arkansas), Alan Mantooth (University of Arkansas),

Presentation: A. Francis, Thursday, March 12th, 11:50 AM, Cheyenne

A delay-insensitive, NULL Convention Logic (NCL) based, asynchronous gate library is developed with the application for an extreme-temperature, radiation-exposed environment. NCL’s delay-insensitivity provides reliability in an environment where the temperature fluctuates widely, which causes a transistor's behavior to vary, and therefore affects the overall accuracy of the circuit. Since a dual-rail logic data value can only be changed if both rails are corrupted, NCL naturally increases the tolerance against errors caused by radiation-induced events. In addition, radiation-hardening techniques are applied at the transistor and gate level. These techniques are simulated in order to analyze each gate’s resistance to Single Event Upsets (SEUs). This analysis is performed on each gate’s schematic with and without parasitics extraction, which enables a high-fidelity simulation of radiation-induced behavior in each cell. The results of the radiation analysis are then used to increase each gate’s radiation tolerance. Each gate is also simulated down to -196° Celsius and up to 125° Celsius to ensure reliable behavior. To further protect the data in the circuit, an asynchronously-controlled register, utilizing the properties of a Dual Interlocked storage Cell (DICE) device, is proposed. The radiation tolerance of the asynchronous register and the DICE-based asynchronous register are compared to show the advantages of the DICE-based asynchronous register. In order to facilitate timing requirements, such as in the use of a controller, radiation-immune and temperature-stable DMIM capacitor-based delay elements, available in the IBM 9HP process, are presented as a low-cost means of tuning delays in control signals.

7.11 Fault Tolerance, Autonomy, and Evolvability in Spacecraft Avionics

Session Organizer: Didier Keymeulen (Jet Propulsion Laboratory), Tom Hoffman (Jet Propulsion Laboratory),

7.1101 Adaptive Controller for a Fourier Transform Spectrometer with Space Applications

Patrick Yiu (Caltech), Didier Keymeulen (Jet Propulsion Laboratory), Daniel Berisford (NASA Jet Propulsion Lab), Kevin Hand , Robert Carlson (Jet Propulsion Laboratory),

Presentation: Patrick Yiu, Wednesday, March 11th, 09:25 PM, Lake/Canyon

This paper presents an adaptive controller for CIRIS (Compositional InfraRed Interferometric Spectrometer) implemented on a stand-alone field programmable gate array (FPGA) architecture with emphasis on space applications in radiation environments such as Europa. CIRIS is a novel take on traditional Fourier Transform Spectrometers (FTS) and replaces linearly moving mirrors (characteristic of Michelson interferometers) with a constant-velocity rotating refractor to variably phase shift and alter the path length of incoming light. This design allows for a compact and robust device, making it ideal for spaceborne measurements in the near-IR to thermal-IR band (2-12 μm) on planetary exploration missions. The instrument's embedded microcontroller is implemented on a VIRTEX-5 FPGA and a PowerPC with the aim of sampling the instrument's detector and optical rotary encoder in order to construct an interferogram. Subsequent signal processing provides spectral immunity from the noise effects of radiation encountered during space flight to destinations such as Europa. A variety of signal processing techniques, including radiation peak removal, resampling, Fast Fourier Transform (FFT), filtering, dispersion correction, and spectral calibration processes are applied in real-time to compose the sample spectrum. The instrument's FPGA controller is demonstrated with the FTS to highlight its suitability for implementation in space systems.

7.1102 Use of Formal Modeling to Automatically Generate Correct Fault Detection and Response Methods

Meredith Lecocke (Southwest Research Institute), Justin Blount (Southwest Research Institute), Jarred Blount (Southwest Research Institute),

Presentation: Meredith Lecocke, Wednesday, March 11th, 09:50 PM, Lake/Canyon

We discuss a formal modeling approach to fault detection, isolation, and recovery (FDIR) which facilitated early communication between system engineers and stakeholders, early confidence in the fault tolerant design, full fault coverage and verification, and auto-generation of FDIR implementation in flight software. Most importantly, the model simplifies the FDIR process by abstracting the complex problem to a significantly smaller set of items requiring verification, increasing the likelihood of correctness. Using formal modeling is a great improvement in reliability, cost, and schedule compared with the traditional manual fault mode analysis (FMA) approach. This approach is sustainable throughout the system lifecycle, since changes to the system can be reflected by changes to the model, which is re-tested on a resource-rich platform and then re-downloaded to the target platform, with no changes to the embedded software.

7.12 Spacecraft Guidance, Navigation, and Control Technologies

Session Organizer: John Enright (Ryerson University), Giovanni Palmerini (Sapienza Universita' di Roma),

7.1202 Conical Scanning Approach for Sun Pointing on the CYGNSS Microsatellite

Joseph Shoer (Charles Stark Draper Laboratory), Leena Singh (Charles Stark Draper Laboratory), Timothy Henderson (Charles Stark Draper Laboratory),

Presentation: Joseph Shoer, Thursday, March 12th, 04:30 PM, Cheyenne

The small scales of area, volume, and power of small spacecraft, such as NASA's 25-kg Cyclone Global Navigation Satellite System (CYGNSS) satellites, constrain the number of independent subsystems that they can support. Consequently, small satellites often require novel approaches to execute the same mission functions that a larger satellite can easily perform with familiar sensor, actuator and algorithm options. In the case of CYGNSS, the attitude control system uses a limited actuator and sensor set consisting of three magnetic torque rods, a three-axis magnetometer, and Sun incidence-angle measurements from three solar panel faces. This paper describes the sensing and control algorithms implemented in CYGNSS flight software to acquire and maintain Sun pointing with the available measurements and actuators. The Sun acquisition process has a large convergence basin, is stable in the Lyapunov sense, and demonstrates excellent performance behavior in simulation.

7.1203 Attitude Determination and Control System Design for the CYGNSS MicroSatellite

Joseph Shoer (Charles Stark Draper Laboratory), Leena Singh (Charles Stark Draper Laboratory), Matthew Fritz (Charles Stark Draper Laboratory, Inc.), Timothy Henderson (Charles Stark Draper Laboratory), Randall Rose (Southwest Research Institute), Christopher Ruf (University of Michigan), Jacob Mc Gee (Southwest Research Institute),

Presentation: Joseph Shoer, Thursday, March 12th, 04:55 PM, Cheyenne

The Cyclone Global Navigation Satellite System (CYGNSS) mission consists of a constellation of eight 25 kg microsatellites for space-based weather monitoring of tropical cyclones. The eight microsatellites will be released from a single launch vehicle into an orbit of desired inclination. The microsatellite attitude determination and control system (ADCS) will be responsible for all spacecraft closed-loop functionality spanning stabilization, Sun acquisition and hold, pointing control, and momentum management. This paper will present the ADCS sensor & actuator suite, architecture, and algorithms required for all phases of on-orbit CYGNSS operations.

7.1204 Optimal Guidance Trajectories for a Nanosat Docking with a Non-Cooperative Resident Space Object

Parv Patel (University of Southern California), Bogdan Udrea (VisSidus Technologies, Inc.), Michael Nayak (Red Sky Research),

Presentation: Parv Patel, Thursday, March 12th, 05:20 PM, Cheyenne

There has been an increasing interest in on-orbit autonomous servicing and repair of satellites as well as controlled active debris removal (ADR) in the space industry recently. One of the most challenging tasks for servicing/repair as well as for ADR is the rendezvous and docking with a non-cooperative tumbling resident space object (RSO). This paper presents a propellant optimal maneuver profile for a servicing spacecraft to perform proximity operations and eventually dock with a non-cooperative target. The strategy is to find an optimal trajectory which will guide the servicing spacecraft to approach the tumbling satellite such that the two vehicles will eventually have no relative motion. Therefore, a subsequent docking or capture operation can be safely performed. The current work expands the scope by adding new set of linearized equations of motion that capture the effect of the J2 geopotential disturbance force.

7.1205 Methods for Estimating Spacecraft Inertia Tensor

Yeongwei Wu ,

Presentation: Yeongwei Wu, Thursday, March 12th, 08:25 PM, Cheyenne

This paper describes the methods for spacecraft inertia tensor estimates for the purpose of supporting the proposed MIMO de-coupled control design architecture. The derivations of this spacecraft inertia tensor estimator are the extension of the previous work, where a gyro-less attitude and rate determination algorithm was derived using the computed gyro data (numerical gyro data). With the obtained linearized attitude error equations and the linearized rate error equations/spacecraft inertia tensor error equations, a 12-states Extended Kalman Filter (EKF) providing spacecraft attitude estimates, rate estimates, and inertia tensor estimates is then implemented.

7.1206 On-Orbit Star Tracker Recalibration: A Case Study

John Enright (Ryerson University), Ilija Jovanovic (Ryerson University), Brendon Vaz ,
Presentation: Ilija Jovanovic, Thursday, March 12th, 08:50 PM, Cheyenne

Star trackers must be calibrated prior to flight so that they can make accurate measurements of star positions within the instrument field of view. This calibration is often performed in atmosphere and once the sensor is launched, it is not uncommon to observe a small shift in some of the calibration parameters. To maximize sensor performance, these parameter values must be corrected to better match the actual observations. In this paper, we explore the several practical strategies for on-orbit recalibration of star trackers. We consider both human-mediated batch-processing as well as autonomous, sequential algorithms. We base our results on orbital data from a number of Sinclair Interplanetary ST16 star trackers launched within the last year. Both approaches to on-orbit calibration can yield significant improvements both to sensor availability and geometric error.

7.1207 Simulation, State Determination, and Control Design for a Small Imaging Spacecraft

David Friedman (Andrews Space), Melissa Wuerl (Andrews Space),
Presentation: David Friedman, Friday, March 13th, 08:30 AM, Madison

This paper presents the design of the Attitude Determination and Control System (ADCS) for the SCOUT imaging spacecraft being developed by Andrews Space. The unique performance constraints of low-cost space vehicles present control and estimation challenges in terms of processor throughput and sensor noise. We discuss the implementation of an ADCS able to achieve sub 100m accuracy (at 450km altitude while pointing 30deg off nadir) by making use of steady-state Kalman filtering for attitude determination, low-order gravity models for orbit propagation, and an LQR-based control system. We discuss the impact of various noise sources on the satellites knowledge error as well as how processor-in-the-loop testing was performed to prove out the feasibility of running the ADCS system on the target embedded platform.

7.1209 The Attitude Control System of a Rendezvous and Docking Technology Demonstrator Mission Target

Anja Nicolai (Astro- und Feinwerktechnik Adlershof GmbH), Christian Raschke (Astro- und Feinwerktechnik Adlershof GmbH), Stephan Stoltz (Astro- und Feinwerktechnik Adlershof GmbH), Robert Eberwein (Astro- und Feinwerktechnik Adlershof GmbH),
Presentation: Anja Nicolai, Friday, March 13th, 08:55 AM, Madison

During this Phase-B study, a satellite was designed which will serve as a target / client for a rendezvous and docking technology demonstration mission. During the mission, several approaches, rendezvous, berthing and docking maneuvers by the servicing satellite are planned. To demonstrate the full capability of the approach technology, the client satellite shall simulate a cooperating as well as a non cooperating target. Therefore unusual attitude control system (ACS) modes were required, ranging from different cooperative 3-axis controlled inertial pointing modes to a 4 °/s spinning mode and a 4°/s tumbling mode with a 10° nutation angle. Typically such modes will be realized using thruster systems. But because of the mass limitations and the design constrains, thrusters are not the best solution to realize the attitude control. For this mission, a special attitude control concept is suggested utilizing a principle often used on small satellites, the reaction wheels momentum dumping using a magnetic coil system. By countering this effect an angular momentum is settled and stored in the reaction wheels in a special

configuration. Via command the stored angular momentum is redistributed from the reaction wheels to the satellite by decelerating the wheel's rotation to zero. As a result, the client will move depending on the momentum configuration prior stored in the wheel system, e.g. the client starts tumbling. The paper will give a brief overview of the client satellite and the driving design requirements and challenges.

7.13 Emerging Technologies for Space Applications

Session Organizer: Jennifer Alvarez (Southwest Research Institute), William Jackson (Sierra Nevada Corp.),

7.1301 Increasing Solar Cell Power Production on Micro and Nano Satellites Using sub-Wavelength Gratings

Hugh Podmore (York University), Regina Lee (York Univesity),

Presentation: Hugh Podmore, Friday, March 13th, 09:20 AM, Madison

Simple bio-mimetic surfaces as anti-reflective coatings are investigated for applications to commercial triple junction solar cells for pico, nano and micro satellites. Design principles for sub-wavelength anti-reflective coatings are discussed, a coating for small satellites is determined and the resultant performance is simulated by numerical analysis. It is determined that compared to commercial anti-reflective coatings an anti-reflective sub-wavelength grating will yield 3.7 to 7.1\% total increase in power production during a 24 hour orbital period for a typical earth observing 3-U CubeSat. The latest experimental results from sub-wavelength AR coating fabrication are discussed as well as the potential of the technology for CubeSats.

7.1302 Towards a Practical Cognitive Communication Network for Satellite Systems

Michael Koets (Southwest Research Institute), John Dickinson (Southwest Research Institute), Denise Varner (Southwest Research Institute), Justin Blount (Southwest Research Institute), Jarred Blount (Southwest Research Institute),

Presentation: John Dickinson, Friday, March 13th, 09:45 AM, Madison

We present progress toward the formulation of a mathematical model for a cognitive communication network with applications to satellite systems. Our model employs abstract concepts including communicators, communications channels, and demand for capacity. These model elements may be tailored to represent a wide variety of practical communication scenarios. We present a dynamic automated reasoning methodology which uses the model to find communication resource allocations for specific scenarios that are superior to static scheduling approaches. This reasoning process resolves resource dependencies, enforces communication policies, and learns from previous communication attempts. We have implemented this reasoning process using Answer Set Prolog and used it to plan communications for a constellation of 8 satellites and 3 ground stations. The example demonstrates performance improvement over a static scheduling approach and shows how solutions can be found with reasonable computational effort.

7.1303 Validation of Electroadhesion as a Docking Method for Spacecraft and Satellite Servicing

Braven Leung ,

Presentation: Braven Leung, Friday, March 13th, 10:10 AM, Madison

An electrostatic gripping force is created when a non-conducting dielectric is placed between a conducting material and a series of oppositely charged monopolar electrodes. Given the non-uniformity of satellites and their typical lack of docking structures, electrostatic gripping is a promising option for docking to satellites for servicing and refueling. This research investigates the effectiveness of a high voltage electrostatic gripper in vacuum to validate its use as a docking method in space. Five linear actuators were mounted inside a vacuum chamber to create a 5 DOF test stand to examine normal, shear, peeling, and twisting forces on various test materials. To further assess the feasibility of the gripping system in docking operations, the gripper was mounted to a robotic arm atop a free-floating frictionless base on a special flat floor in the NASA MSFC Flight Robotics Laboratory to test satellite docking and capture maneuvers utilizing electroadhesion.

7.14 Panel/Forum: Using COTS in Space -

Session Organizer: Harald Schone (Jet Propulsion Laboratory),

TRACK 8: SPACECRAFT & LAUNCH VEHICLE SYSTEMS & TECHNOLOGIES

Track Organizers: Robert Gershman (Jet Propulsion Laboratory), Tye Brady (Charles Stark Draper Laboratory)

8.01 Human Exploration Systems

Session Organizer: Bret Drake (NASA), Kevin Post (The Boeing Company)

8.0101 The Evolvable Mars Campaign – Study Status

Douglas Craig (NASA), Bret Drake (NASA),

Presentation: Douglas Craig, Sunday, March 8th, 04:30 PM, Jefferson

NASA is developing a long-term strategy for extended human missions to Mars in support of the policies outlined in the 2010 NASA Authorization Act and National Space Policy. The Authorization Act states that “A long term objective for human exploration of space should be the eventual international exploration of Mars.” Echoing this is the National Space Policy - “By 2025, begin crewed missions beyond the moon, including sending humans to an asteroid. By the mid-2030s, send humans to orbit Mars and return them safely to Earth.” NASA’s 2014 Strategic Plan states “Our long-term goal is to send humans to Mars. Over the next two decades, we will develop and demonstrate the technologies and capabilities needed to send humans to explore the red planet and safely return them to Earth.” To accomplish these goals, NASA is employing a capability-driven approach to its human spaceflight strategy. This approach is based on developing a suite of evolving capabilities that provide specific functions to solve exploration challenges. These capabilities can be leveraged and reused, enabling more complex operations over time and exploration of more distant solar system destinations. The Evolvable Mars Campaign is an ongoing study identifying potential exploration options leading to sustainable human exploration of Mars. This campaign will leverage existing activities, adapt to capability developments, scientific discovery, and ever-changing programmatic environments. The results of this study will inform NASA management on key decision options and investment priorities. This paper provides a summary of the 2014 study activities and key findings to date.

8.0102 NASA’s Asteroid Redirect Mission Concept Development Summary

Michele Gates , Daniel Mazanek (NASA - Langley Research Center), Brian Muirhead (Jet Propulsion Laboratory),

Presentation: Michele Gates, Sunday, March 8th, 04:55 PM, Jefferson

This paper summarizes key findings of Asteroid Redirect Mission pre-formulation concept development efforts, including mission architecture and design drivers, flight system concepts and trades, advanced solar electric propulsion component and system options, and asteroid capture option trades and risk reduction efforts. This paper also provides a summary of concept development findings with a focus on extensibility to future mission applications and risk reduction and early testing of astronaut extra-vehicular activities.

8.0103 Combining Solar Electric Propulsion and Chemical Propulsion for Crewed Missions to Mars

Thomas Percy (SAIC), Burton Joosten (MBO Partners, Inc.), Tara Polsgrove , Melissa Mc Guire (NASA Glenn Research Center), Bret Drake (NASA),

Presentation: Burton Joosten, Sunday, March 8th, 05:20 PM, Jefferson

This paper documents the results of an investigation of human Mars mission architectures that leverage near-term technology investments and infrastructures resulting from the planned Asteroid Redirect Robotic Mission (ARRM), including high-power Solar Electric Propulsion (SEP) and a human presence in Lunar Distant Retrograde Orbit (LDRO). The architectures investigated use a combination of SEP and chemical propulsion elements. Through this combination of propulsion technologies, these architectures take advantage of the high efficiency SEP propulsion system to deliver cargo, while maintaining the faster trip times afforded by chemical propulsion for crew transport. Evolved configurations of the Asteroid Redirect Vehicle (ARV) are considered for cargo delivery. Sensitivities to SEP system design parameters, including power level and propellant quantity, are presented. For the crew delivery, liquid oxygen and methane stages were designed using engines common to future human Mars landers. Impacts of various Earth departure orbits, Mars loiter orbits, and Earth return strategies are presented. The use of the Space Launch System for delivery of the various architecture elements was also investigated and launch vehicle manifesting, launch scheduling and mission timelines are also discussed. The study results show that viable Mars architecture can be constructed using LDRO and SEP in order to take advantage of investments made in the ARRM mission.

8.0104 Mars Conjunction Crewed Missions with a Reusable Hybrid Architecture

Raymond Merrill (NASA - Langley Research Center), Nathan Strange (Jet Propulsion Laboratory),

Presentation: Raymond Merrill, Sunday, March 8th, 09:00 PM, Jefferson

A new crew Mars architecture has been developed that provides many potential benefits for NASA-led human Mars moons and surface missions beginning in the 2030s or 2040s. By using both chemical and electric propulsion systems where they are most beneficial and maintaining as much orbital energy as possible, the size of the spaceship that carries crew round trip to Mars is minimized. This allows delivery of an integrated Mars transporation system to orbit in a single launch. The spacecraft is refueled in cis-lunar space and can transport crew round trip to Mars in less than 1100 days, with a minimum of 300 days in Mars orbit. Upon return to Earth the entire spaceship is recaptured into cis-lunar space after a mission and can be reused every other opportunity.

8.0105 Human-assisted Mars Sample Return

Robert Gershman (Jet Propulsion Laboratory), A Howe (NASA Jet Propulsion Lab), Stanley Love , Joshua Hopkins (Lockheed Martin),

Presentation: Robert Gershman, Sunday, March 8th, 09:25 PM, Jefferson

Any Mars Sample Return campaign must assure a very low probability of inadvertent release of Mars material into the Earth's biosphere in order to provide protection against the extremely unlikely possibility of biological hazards in the returned material. Containment assurance requires breaking the chain of contact with Mars: any Mars material reaching Earth must be inside a sealed sample container. And the integrity of the sample container must be maintained (with an unprecedented degree of confidence)

until delivered to a secure receiving facility on Earth. Earth entry poses a challenge to sample container integrity. In most studies this challenge is met by developing a new, highly-robust, robotic Earth entry vehicle; but NASA's plans for future human space activities offer other possibilities. These plans for the next couple of decades include options for crewed operations in lunar and Mars orbits. This paper describes the results of a study of options for having robotic spacecraft deliver samples to these locations for handoff to the crewed vehicle followed by return to Earth with the crew. Conceptual designs for several options are presented and pros and cons relative to the completely robotic campaign are discussed.

8.0106 NASA Evolvable Mars Campaign: Mars Surface Habitability Options

A Howe (NASA Jet Propulsion Lab), Matthew Simon , Larry Toups (NASA - Johnson Space Center), Stephen Hoffman (SAIC), Robert Howard (NASA Johnson Space Center),

Presentation: A Howe, Sunday, March 8th, 09:50 PM, Jefferson

This paper reports on current habitability concepts for human crews prepared by the NASA Human Architecture Team (HAT) for an Evolvable Mars Campaign (EMC). For many years NASA has investigated alternative human Mars missions, examining different mission objectives, trajectories, vehicles, and technologies, the combinations of which have been referred to as reference missions or architectures. At the highest levels, decisions regarding the timing and objectives for a human mission to Mars continue to evolve while at the lowest levels, applicable technologies continue to advance. This results in an on-going need for assessments of alternative system designs such as the habitat, a significant element in any human Mars mission scenario, to provide meaningful design sensitivity characterizations to assist decision-makers regarding timing, objectives, and technologies. As a subset of the Evolvable Mars Campaign activities, the habitability team builds upon results from past studies and recommends options for Mars surface habitability compatible with updated technologies.

8.0107 Transportation-Driven Mars Surface Operations Supporting an Evolvable Mars Campaign

Larry Toups (NASA - Johnson Space Center), Stephen Hoffman (SAIC), Kendall Brown (NASA - Marshall Space Flight Center), Bret Drake (NASA),

Presentation: Bret Drake, Monday, March 9th, 08:30 AM, Jefferson

This paper describes the results of a study evaluating options for supporting a series of human missions to a single Mars surface destination. In this scenario the infrastructure emplaced during previous visits to this site is leveraged in following missions. The goal of this single site approach to Mars surface infrastructure is to enable "Steady State" operations by at least 4 crew for up to 500 sols at this site. These characteristics, along with the transportation system used to deliver crew and equipment to and from Mars, are collectively known as the Evolvable Mars Campaign (EMC).

8.0108 Logistics Needs for Potential Deep Space Mission Scenarios Post Asteroid Redirect Crewed Mission

Pedro Lopez (NASA Johnson Space Center), Eric Schultz (NASA), Bryan Mattfeld (Binera, Inc.), Chel Stromgren (EASI), Kandyce Goodliff (NASA),

Presentation: Pedro Lopez, Monday, March 9th, 08:55 AM, Jefferson

The Asteroid Redirect Mission (ARM) is currently being explored as the next step towards deep space human exploration, with the ultimate goal of reaching Mars. NASA is currently investigating a number of potential human exploration missions, which will progressively increase the distance and duration that humans spend away from Earth. Missions include extended human exploration in cis-lunar space which, as conceived, would involve durations of around 60 days, and human missions to Mars, which are

anticipated to be as long as 1000 days. The amount of logistics required to keep the crew alive and healthy for these missions is significant. It is therefore important that the design and planning for these missions include accurate estimates of logistics requirements. This paper provides a description of a process and calculations used to estimate mass and volume requirements for crew logistics, including consumables, such as food, personal items, gasses, and liquids. Determination of logistics requirements is based on crew size, mission duration, and the degree of closure of the environmental control life support system (ECLSS). Details are provided on the consumption rates for different types of logistics and how those rates were established. Results for potential mission scenarios are presented, including a breakdown of mass and volume drivers. Opportunities for mass and volume reduction are identified, along with potential threats that could possibly increase requirements.

8.0109 Preparing for Mars: The Evolvable Mars Campaign Emerging "Proving Ground" Approach

Marianne Bobskill (NASA - Langley Research Center),
Presentation: Marianne Bobskill, Monday, March 9th, 09:20 AM, Jefferson

NASA is in the early stages of planning missions within the framework of an Evolvable Mars Campaign. Initial missions would be conducted in near-Earth cis-lunar space and would eventually culminate in extended duration crewed missions on the surface of Mars. To enable such exploration missions, critical technologies and capabilities must be identified, developed, and tested. NASA is developing a “Proving Ground” strategy wherein exploration-enabling capabilities and technologies are tested, reducing risks, and the foundation is laid for sustained human presence in space. Proving Ground missions also provide valuable experience with deep space operations and support the transition from “Earth-dependence” to “Earth-independence” required for sustainable space exploration. NASA is evaluating a number of options for Proving Ground missions. An “Asteroid Redirect Mission” could demonstrate needed capabilities and transportation systems for the crew and for cargo. NASA is considering emplacing a small pressurized module in cis-lunar space to support crewed operations of increasing duration and to serve as a platform for critical exploration capabilities testing. “Opportunistic mission operations” could demonstrate capabilities not on the Mars critical path that may, nonetheless, enhance exploration operations. The Proving Ground may also include “pathfinder” missions to test and demonstrate specific capabilities at Mars not tested in other domains. This paper describes the (1) process used to conduct an architecture-driven technology development assessment, (2) exploration mission critical and supporting capabilities, and (3) approach for addressing test and demonstration opportunities encompassing the spectrum of flight elements and destinations consistent with the Evolvable Mars Campaign.

8.0110 Developing a Crew Time Model for Human Exploration Missions to Mars Surface

Bryan Mattfeld (Binera, Inc.), Chel Stromgren (EASI), Hilary Shyface , William Cirillo (NASA - Langley Research Center), Kandyce Goodliff (NASA),
Presentation: Bryan Mattfeld, Monday, March 9th, 09:45 AM, Jefferson

Candidate human missions to Mars require mission lengths that could extend beyond those that have previously been demonstrated during crewed Lunar (Apollo) and International Space Station (ISS) missions. The nature of the architectures required for deep space human exploration will likely necessitate major changes in how crews operate and maintain the spacecraft. The uncertainties associated with these shifts in mission constructs - including changes to habitation systems, transit durations, and system operations – raise concerns as to the ability of the crew to complete required overhead activities while still having time to conduct a set of robust exploration activities. This paper will present an initial assessment of crew operational requirements for human missions to the Mars surface. The presented results integrate assessments of crew habitation, system maintenance, and utilization to present a comprehensive analysis of potential crew time usage. Destination operations were assessed for short (~50 day) and long duration (~500 day) surface habitation cases. To support this assessment, the integrated crew operations model (ICOM) was developed. ICOM was used to parse overhead, maintenance and system repair, and destination operations requirements within each mission segment – outbound transit, Mars surface duration, and return transit - to develop a comprehensive estimation of exploration crew time allocations. Overhead operational requirements included daily crew operations, health maintenance activities, and down time. Maintenance and repair operational allocations are derived using the Exploration Maintainability and Analysis Tool (EMAT) to develop a probabilistic estimation of crew repair time necessary to maintain systems functionality throughout the mission.

8.0111 Human Outer Solar System Exploration via Q-thruster Technology

Burton Joosten (MBO Partners, Inc.),
Presentation: Burton Joosten, Monday, March 9th, 10:10 AM, Jefferson

Propulsion technology development efforts at the NASA Johnson Space Center continue to advance the understanding of the quantum vacuum plasma thruster (Q-Thruster). Through the use of electric and magnetic fields, a Q-thruster pushes quantum particles (electrons/positrons) in one direction, while the Q-thruster recoils to conserve momentum. Based on laboratory results and theoretical analysis, it appears that continuous specific thrust levels of 0.4 - 4.0 N/kWe may be achievable with essentially no onboard propellant consumption. To evaluate the value proposition of this technology, a mission analysis tool was developed allowing very rapid assessments of "Q-Ship" minimum time transfers from earth to the outer planets and back utilizing parametric variations in thrust acceleration while enforcing constraints on planetary phase angles and minimum heliocentric distances. A speculative Q-Thruster specific thrust assumption (0.4 N/kWe) combined with "moderate" levels of space nuclear power and conservative vehicle specific masses results in continuous milli-g thrust acceleration, opening up realms of human spaceflight performance completely unattainable by any current systems or near-term proposed technologies. Minimum flight times to Mars are predicted to be as low as 75 days. Even more impressively, the Jovian and Saturnian systems would be opened up to human exploration with round-trip times of 21 and 32 months respectively including 6 to 12 months of exploration at the destinations. Finally, interstellar trip times are assessed at milli-g acceleration levels.

8.0112 Human Lunar Exploration Opportunities Enabled by the Space Launch System

Ben Donahue (Boeing Company),
Presentation: Ben Donahue, Monday, March 9th, 10:35 AM, Jefferson

The paper contains brief overviews of the SLS, its Upper Stages and its candidate exploration missions. SLS launched science missions / destinations presented here include Jupiter/Europa, Jupiter Trojan Asteroids, and Saturn/ Titan/ Enceladus. SLS Launch to Jupiter / Europa Europa may have an ocean underneath its icy crust; recent investigations may indicate active water geysers. The SLS, as compared to the Atlas-V, could enable a much shorter trip time and eliminate two Earth flybys and the thermal considerations of a Venus gravity assist. The Atlas-V can inject 3.6mt on a 6.5 year VEEGA trajectory to Jupiter (launch/arrival dates are Nov 2021/April 2028). The SLS Block 1b can inject a payload of 8.9mt on a 2 year direct trajectory saving 4.5 years (launch/arrival June 2022/May 2024). SLS Block 1 payload is 4.4mt. 0.48 years after intercept with Jupiter, the spacecraft will rendezvous with Europa. Total time to Europa

would be 2.48 years. Portions of three SLS launched Human Space Flight (HSF) missions are also described here: an Earth-Moon Lagrange Point (EMLP) based Cis-Lunar Crew mission, a Saturn/Apollo like direct LEO-to-the Moon Crew Mission, and a Human Mars Mission. The SLS provides unprecedented payload capability that can enable human and science missions not previously achievable. The enhanced capability of the SLS Block 1b can enable a number of human exploration missions to deep space, Cis-lunar and Mars locations. SLS Block 1b is also attractive for numerous science missions by significantly increasing payload and reducing transit time for deep space planetary missions.

8.0113 Human Exploration of Phobos

Andrew Abercromby (Wyle / NASA Johnson Space Center), Michael Gernhardt (NASA - Johnson Space Center), Steven Chappell (Wyle), A Howe (NASA Jet Propulsion Lab),
Presentation: Michael Gernhardt, Monday, March 9th, 11:00 AM, Jefferson

This study developed, analyzed, and compared mission architectures for human exploration of Mars' moons within the context of an Evolvable Mars Campaign. Detailed flight rules, extravehicular activity (EVA) timelines, and models of propellant mass, crew time, science productivity, radiation exposure, systems and consumables masses were integrated to enable quantitative comparison of different architectural options. Seven discrete mission architectures were evaluated. The driving consideration for habitat location (Phobos surface versus orbital) was radiation exposure, with an estimated reduction in cumulative mission radiation exposure of up to 34% (versus a Mars orbital mission) when the habitat is located on the Phobos surface, compared with only 3% to 6% reduction for a habitat in a 20-km DRO. Two-person pressurized excursion vehicles as well as mobile surface habitats offer significant exploration capability and operational benefits compared with unpressurized EVA mobility systems at the cost of increased system and propellant mass. Mechanical surface translation modes (ie, hopping) were modeled and offered potentially significant propellant savings and the possibility of extended exploration operations between crewed missions. Options for extending the use of the crew taxi vehicle were examined, including use as an exploration asset for Phobos surface exploration (when combined with an alternate mobility system) and as an EVA platform, both on Phobos and for contingency EVA on the Mars transit habitat. Human exploration of Phobos offers a scientifically meaningful first step towards human Mars surface missions that develops and validates transportation, habitation, and exploration systems and operations in advance of the Mars landing systems.

8.0114 Conceptual Mission Design of a Minimalistic Human Mars Flyby in the Year 2018

Paul Nizenkov (University of Stuttgart), Dan Fries (Georgia Institute of Technology),
Presentation: Dan Fries, Monday, March 9th, 11:25 AM, Jefferson

In the context of the Mars Society Student Design Competition, a comprehensive mission and spacecraft design for a human Mars flyby in 2018 is devised. The presentation summarizes critical aspects of the mission concept, which was selected from 38 participants in the final top 5. A narrow time frame combined with missing key technologies such as deep-space radiation protection, long-duration life support systems and affordable, sustainable access to space pose significant challenges to the overall system. The presented work shows how a mission to Mars could be executed realistically by 2018. The systems engineering approach, crucial technologies and programmatic issues such as cost, scheduling and risks are discussed. With only two launches to low Earth orbit, the total mass before trans-Mars injection is below 15 tons while utilizing a modified Dragon capsule and Cygnus module. Solutions to many of the critical spacecraft systems are introduced through synergies as opposed to brute force technology development. While the study covered all subsystems of the spacecraft, the presenta-

tion will focus on critical subsystems. A concept dealing with physical and psychological problems in an isolated and confined environment during the total mission duration of 501 days is presented. The total cost of the mission is estimated using current prices, heritage data and cost models, resulting in 5.2 Billion US Dollars. A realistic mission layout is accomplished with an adequate combination of existing elements, near-term available technologies and development focused on a few vital and promising aspects.

8.02 Human Exploration Systems Technology Development

Session Organizer: Dana Gould (NASA), Laurence Young (Massachusetts Institute of Technology), Robert Gershman (Jet Propulsion Laboratory)

8.0201 Understanding International GNC Hardware Trends

Adam Greenbaum (The Charles Stark Draper Laboratory), Tye Brady (Charles Stark Draper Laboratory),
Presentation: Adam Greenbaum, Monday, March 9th, 04:55 PM, Jefferson

An industry wide survey of GNC sensors, namely star trackers, gyros, and sun sensors was undertaken last year, in which size, mass, power, and various performance metrics were recorded for each category. A multidimensional analysis was performed, looking at the spectrum of available sensors, with the intent of identifying gaps in the available capability range. Mission types that are not currently well served by the available components were discussed, as well as some missions that would be enabled by filling gaps in the component space. This paper continues that study, with a focus on reaction wheels and magnetometers, as well as with updates to the listings of star trackers, gyros, and sun sensors. Additionally, a framework for making the database available to the community at large, as well as the continued maintenance of this database and the analysis of its contents, is discussed.

8.0202 Pressure Characterization between the Upper Body and Space Suit during Mission-Realistic Movements

Allison Anderson (Massachusetts Institute of Technology), Dava Newman (Massachusetts Institute of Technology),
Presentation: Allison Anderson, Monday, March 9th, 05:20 PM, Jefferson

Current space suits have an inherent stiffness, causing fatigue, unnecessary energy expenditure, and in some instances injury. Although the U.S. has studied space suit performance and improved upon system designs, relatively little is known about how the astronaut moves and interacts within the space suit, what factors lead to injury, and how to prevent injury. We quantify and evaluate human-space suit interaction with a novel pressure sensing tool. The Polipo, or octopus in Italian, is the system of 12 sensors that were developed as part of this research effort for low-pressure sensing utilized under soft goods. An experiment was performed to evaluate human-space suit interaction inside the Mark III space suit at NASA Johnson Space Center. One highly experienced male subject was asked to perform a series of mission-realistic movements: squat, prone and recover, assisted kneel, and cross-body boot tighten. These motions were performed in conjunction with an upper-body motion experiment to assess human-space suit interaction during controlled movements. The subject was asked to perform these mission-realistic tasks to assess the limits of system durability and loading under extreme conditions. After the motions were performed, qualitative information on subject comfort and noted hot spots was collected. We discuss the results of this experiment and follow-on work. We propose future improvements for the characterization of human biomechanics and injury mechanisms inside the space suit.

8.0203 Technology for a Robotic Asteroid Redirect Mission and Its Extensibility to Future Space Activities

John Brophy (Jet Propulsion Laboratory), Nathan Strange (Jet Propulsion Laboratory),
Presentation: John Brophy, Monday, March 9th, 09:00 PM, Jefferson

Three aspects of the proposed Asteroid Redirect Mission (ARM) could be extended to provide greater capability for future NASA missions: higher-power versions of the baseline asteroid redirect vehicle, in-space resource utilization, and planetary defense. The baseline ARM vehicle assumes the use of a 50 kW beginning-of-life solar array which provides a maximum of 40 kW to the electric propulsion system. Launch dates in mid to late 2020 could provide the opportunity for the development and implementation of higher-power solar arrays and electric propulsion systems that are farther along the path to the 100-kW-class systems that could be used to support human missions to Mars. The ARM robotic vehicle conceptual design provides a straightforward approach to increasing the solar array power to ~100 kW for the first asteroid redirect mission. Transportation is also a major challenge for harvesting asteroids for the use of their material resources in space. ARM addresses this issue by selecting an asteroid that naturally returns close to Earth and then redirecting it into lunar orbit. Deriving propellants from asteroids is essential to a robust utilization of asteroid material resources. Two elements, magnesium and sulfur, abundantly available in common chondrite asteroids could be used as propellants in Hall thrusters and may be the key to asteroid mining. Finally, ARM has the potential to demonstrate two different planetary defense techniques: an enhanced gravity tractor, or an ion beam deflector. High-power solar electric propulsion (SEP) is needed for both techniques. Simple analyses highlight a clear choice between these options.

8.0204 Asteroid Redirect Crewed Mission Space Suit and EVA System Maturation

Jonathan Bowie (NASA), Cody Kelly (NASA - Johnson Space Center),
Presentation: Cody Kelly, Monday, March 9th, 09:25 PM, Jefferson

The Asteroid Redirect Crewed Mission (ARCM) requires a Launch/Entry/Abort (LEA) suit capability and short duration Extra Vehicular Activity (EVA) capability from the Orion spacecraft. For this mission, the pressure garment selected for both functions is the Modified Advanced Crew Escape Suit (MACES) with EVA enhancements and the life support option that was selected is the Exploration Portable Life Support System (PLSS) currently under development for Advanced Exploration Systems (AES). The proposed architecture meets the ARCM constraints, but much more work is required to determine the details of the suit upgrades, the integration with the PLSS, and the tools and equipment necessary to accomplish the mission. This work has continued over the last year to better define the operations and hardware maturation of these systems. EVA simulations were completed in the Neutral Buoyancy Lab (NBL) and interfacing options were prototyped and analyzed with testing planned for late 2014. This paper discusses the work done over the last year on the MACES enhancements, the use of tools while using the suit, and the integration of the PLSS with the MACES.

8.03 Advanced Launch Vehicle Systems and Technologies

Session Organizer: Jon Holladay (NASA), Bernard Kutter (United Launch Alliance)

8.0301 Cellular Load Responsive MLI Development

Gary Mills (Ball Aerospace and Technologies Corp),
Presentation: Gary Mills, Tuesday, March 10th, 08:30 AM, Jefferson

Quest Thermal Group and Ball Aerospace have jointly developed a next generation family of insulation systems to meet the performance demands of future space and terrestrial applications. The new composite insulations are based on our proprietary load responsive system that provides higher thermal performance both in atmospheric and in vacuum of space conditions.

8.0303 Low-Cost, Low Mass Avionics System for a Dedicated Nano-Satellite Launch Vehicle

Austin Williams (Tyvak Nano-Satellite Systems, Inc),
Presentation: Austin Williams, Tuesday, March 10th, 08:55 AM, Jefferson

Tyvak Nano-Satellite Systems, Inc is currently developing a platform independent Nano-Launch Vehicle (NLV) avionics system by modifying and optimizing existing CubeSat products for use with this new class of launch vehicle. Previous work on a Phase I SBIR through NASA's Launch Services Program helped lay the foundation for the architecture, where key trades in Global Positioning System (GPS), Inertial Measurement Unit (IMU), and wireless communication protocols were evaluated. A recently awarded Phase II SBIR will fund the hardware and software elements to TRL 7. Tyvak is a team member on the NASA Launch Services Enabling eXploration & Technology (NEXT) program to demonstrate an orbital flight in 2016. The design allows electronics re-use, while providing straightforward tailoring for the particular launch vehicle application. This approach provides significant savings in avionics mass, and reduces cost through common hardware elements, and reduction in range assets. This presentation covers the avionics architecture, and discusses the approach used for tailoring the avionics to the particular vehicle.

8.0305 Additive Manufacturing in the Launch Vehicle Business

Gregory Schiller ,
Presentation: Gregory Schiller, Tuesday, March 10th, 09:20 AM, Jefferson

Additive Manufacturing aka 3D printing opens up a whole new era for digital design and manufacturing in the Aerospace industry. No longer is the aerospace engineering designer constrained by the ability to manufacture a component. The new philosophy is “if you can design it, we can produce it”. Yet there is a laundry list of caveats with the current state of the technology especially as it applies to aerospace applications and in particular, launch vehicles. Launch vehicle applications may prove to be the bounding arena for aerospace applications. However, given the variety of exquisite designs and low volume, aerospace applications are well suited for Additive Manufacturing. The challenges of today are already being solved and incorporated into the technology of tomorrow. It is simply a matter of time before AM finds not only a foot hold in aerospace but becomes the manufacturing tool of choice.

8.0307 Launch Vehicle Tracking Enhancement through Global Positioning System Metric Tracking

Timothy Gray (Space Vector Corporation),
Presentation: Timothy Gray, Tuesday, March 10th, 09:45 AM, Jefferson

This paper summarizes the current development status and performance capabilities of the GPS Metric Tracking (MT) System. The system is based on utilizing the Global Positioning System (GPS) satellite constellation and developed to allow Ranges to divest some of their radar assets. Successful flight testing and qualification of these systems has been conducted at Vandenberg Air Force Base (VAFB) on the Western Test Range and Cape Canaveral Air Force Station (CCAFS) on the Eastern Test Range. The GPS MT system has provided precise LV position, velocity and timing information that can replace ground radar tracking resource functionality. The GPS MT system provides an independent position/velocity S-Band telemetry downlink to support the current man-in-the-loop ground-based commanded destruct of an anomalous flight. To enhance cost effectiveness, the GPS MT System design was implemented using existing commercial

parts and common environmental and interface requirements for Launch Vehicles. The GPS MT System design is complete, successfully qualified, and has demonstrated in flight that the system performs as designed and simulated. The development of the next generation of GPS MT systems has been completed and qualification testing was successfully conducted and is discussed in this paper.

8.0308 Similarity Study on Infrared Radiation of Solid Rocket Plume of Different Reduced-scaled Size

Xuyi Chen (Sun Yat-sen University), Xiaoying Zhang (South China University of Technology),
Presentation: Xuyi Chen, Tuesday, March 10th, 10:10 AM, Jefferson

To determine the similarity of plume radiation between reduced-scale rockets and regular-sized rockets in ground-test conditions, the flow and radiation of rocket engines in the geometric reduced-scale ratios of 0.1 to 1 are investigated in this study. Our research shows that with the decreasing size of the rocket engine, the high-temperature core's area decreases with the square order of the rocket size. The infrared spectral radiation of the plume also decreases with the square order. The infrared radiation of the gaseous components show a strong spectral difference, and the infrared radiation of the Al2O3 particles show the spectral property of a gray medium with the same temperature. The integrated infrared characteristics of the solid rocket plume mainly show the spectral continuity of Al2O3 particles, which decreases in the peak radiation spectrum of gaseous components. The emission and scattering of Al2O3 particles makes the plume radiation grow up remarkably, this phenomenon increases the plume radiation in the 4.2–4.45μm band to two times of the non-particle radiation and increases the plume radiation in the 2.7–2.95μm band by 45%. The radiation intensity on the surface of the high temperature plume core increases with increasing sight angle.

8.05 Human Factors & Performance

Session Organizer: Kevin Duda (The Charles Stark Draper Laboratory, Inc.), Jessica Marquez (NASA Ames Research Center)

8.0501 Integrating Human Performance Measures into Space Operations: Beyond Our Scheduling Capabilities?

Jessica Marquez (NASA Ames Research Center),
Presentation: Jessica Marquez, Wednesday, March 11th, 10:35 AM, Jefferson

Current planning and scheduling software tools for International Space Station (ISS) support different flight controller teams as they plan daily space operations. Planning and scheduling tools capabilities include integrating digitized ISS state inputs, evaluating their expected future states, and propagating them over time. Extensive, custom-made computational models of operations, of objectives, and of operational constraints help ISS flight controllers identify where scheduled events violate constraints. Based on the current capabilities of these tools, this paper proposes how human performance measures could be better integrated into planning and scheduling tools for space mission operations. Future integration of human performance measures could be applied to state inputs (in this case, the astronaut's state) and to modeling human performance operational constraints & operational objectives (i.e., assigned activities) with parameters that are relevant to human performance measures. Gaps between the state-of-the-art for human performance modeling and planning tools for future exploration missions are identified.

8.0502 Development of an Integrated Simulation Platform for Real-Time Task Performance Assessment

Kevin Duda (The Charles Stark Draper Laboratory, Inc.), Stephen York (Draper Laboratories), Zahar Prasov (Charles Stark Draper Laboratory), Stephen Robinson (UC Davis), Patrick Handley (Draper Laboratory), John West (Charles Stark Draper Laboratory),

Presentation: Kevin Duda, Wednesday, March 11th, 11:00 AM, Jefferson

A re-configurable, portable test station was developed for integrating and testing real-time performance metrics for continuously assessing operator effectiveness in operationally-relevant spaceflight piloting tasks. The test station includes a single computer for hosting the vehicle simulation, rendering both graphical flight displays and a 3-D out-the-window view, and computing the performance metrics in real-time. The pilot interacts with the simulation using four displays (two piloting displays, one out-the-window display, and a mission summary display), a rotational hand controller, a translational hand controller, and a microphone. A fifth display provides a system status / engineering view for the experimenter. A key component of the simulation station is the real-time metrics engine and algorithms, which estimates pilot workload, situation awareness, and flight performance without interfering with the piloting task, or adding equipment or infrastructure to the flight deck. Workload and flight performance are estimated based on an analysis of the vehicle state (e.g., attitude, altitude, % fuel) and the pilot commands (e.g., hand controller movement), whereas situation awareness is estimated based on the comparison of the actual vehicle state and that spoken (and converted to text through an automatic speech recognition algorithm) by the flying pilot. This real-time simulation station development is discussed in the context of four operationally-relevant spaceflight tasks: piloted lunar landing, Orion/MPCV docking operations with the International Space Station (ISS), and manual control of the spacewalking Simplified Aid for EVA Rescue (SAFER) jet pack near the ISS.

8.0503 Survey and Assessment of Human Performance Evaluation Methods Applicable to Human Spacecraft Design

Christine Fanchiang (University of Colorado, Boulder), Jessica Marquez (NASA Ames Research Center), Brian Gore (San Jose State University @ NASA Ames), David Klaus (University of Colorado, Boulder),

Presentation: Christine Fanchiang, Wednesday, March 11th, 11:25 AM, Jefferson

This paper analyzes various human performance evaluation methods across a range of industries to assess their potential applications to human spacecraft design. A survey of more than 400 human performance evaluation methods was completed. Over twenty different attributes were identified for each method and a variety of analyses were conducted to characterize and evaluate their use as a tool for assessing human spacecraft design options. The analysis revealed a particular deficiency of quantitative evaluation methods that are applicable early in the systems engineering design phase. It also identified five existing methods that could be supplemented to achieve the needs of early design evaluations. Additional discussion describes potential issues that must be overcome when developing a method specific for use on human spacecraft design.

8.0505 Operator Evaluation of a Mobility-Augmenting Jetpack with Integrated Control-Moment Gyroscopes

Michele Carpenter , Kimberly Jackson (Charles Stark Draper Laboratory), Celena Dopart , Jared Rize , Jeffrey Hoffman (Massachusetts Institute of Technology), Babak Cohanim (Charles Stark Draper Laboratory), Kevin Duda (The Charles Stark Draper Laboratory, Inc.),

Presentation: Michele Carpenter, Wednesday, March 11th, 04:30 PM, Jefferson

While the direction for human space exploration may not be currently well-defined, there are many potential missions that could benefit from an astronaut mobility unit providing

six-degree-of-freedom control during extravehicular activities (EVAs). The attitude-control system (ACS) for the Jetpack device currently under development at NASA Johnson Space Center is based on the Simplified Aid for EVA Rescue (SAFER), which uses gas thrusters for both attitude control and translation. The proposed astronaut mobility unit incorporates control concepts optimized to support EVA tasks and adds control-moment gyroscopes (CMGs) to the current Jetpack system. The control architecture of this Mobility-Augmenting Jetpack with Integrated CMGs (MAJIC) considers a concept of operations that includes scenarios such as surface sample collection, equipment deployment, satellite servicing, crewmember rescue, and contingency EVA missions at objects lacking built-in handholds or foot restraints. Momentum desaturation logic is incorporated into the MAJIC control algorithm and the CMGs are optimally sized using a Monte-Carlo simulation approach. The resulting ACS design is evaluated by test subjects in comparison to an idealized CMG ACS and the baseline Jetpack thrusters-only design using a human-in-the-loop, real-time, virtual-reality simulation. Results demonstrate that while the initial CMG size is too small for practical use during EVA missions, a design incorporating a larger CMG array with sufficient angular-momentum capability significantly reduces undesired compensating torques on the astronaut while conserving onboard fuel and extending the length of EVA missions.

8.0506 Wearable CMG Design for the Variable Vector Countermeasure Suit

Rebecca Vasquez (The Charles Stark Draper Laboratory, Inc), Kevin Duda (The Charles Stark Draper Laboratory, Inc.),

Presentation: Rebecca Vasquez, Wednesday, March 11th, 04:55 PM, Jefferson

The Variable Vector Countermeasure Suit (V2Suit) is a countermeasure suit for sensorimotor adaptation and musculoskeletal deconditioning in microgravity. The V2Suit consists of wearable modules containing arrays of control moment gyroscopes (CMGs) that provide a viscous resistance to motions made against a specified direction. To reduce the movement coordination and sensorimotor problems seen during and following gravity level transitions, this resistance will be felt in the direction of “down” to mimic gravity. Control moment gyroscopes are commonly used for spacecraft stabilization. The V2Suit uses a miniaturized CMG array in a body-worn system to apply torque to the wearer’s musculoskeletal joints. This paper presents the selection and design of a miniature CMG array for use in the V2Suit. Various candidate CMG arrays were analyzed to determine the appropriate architecture for the array inside a V2Suit module, as well as flywheel parameters for the chosen array. A mechanical design for the V2Suit CMG array was developed using a combination of off the shelf and custom manufactured components. Minimizing the size of the array drove many design decisions; the final module design has a 6.5 inch square footprint and is 3.5 inches tall. A brassboard prototype has been fabricated based on this design.

8.0507 SimSup’s Loop: A Control Theory Approach to Spacecraft Operator Training

Brandon Owens (Stinger Ghaffarian Technologies, Inc), Alan Crocker ,

Presentation: Brandon Owens, Wednesday, March 11th, 05:20 PM, Jefferson

Immersive simulation is a staple of training for many complex system operators, including astronauts and ground operators of spacecraft. However, while much has been written about simulators, simulation facilities, and operator certification programs, the topic of how one develops simulation scenarios to train a spacecraft operator is relatively understated in the literature. In this presentation, an approach is presented for using control theory as the basis for developing the immersive simulation scenarios for a spacecraft operator training program. The operator is effectively modeled as a high level controller of lower level hardware and software control loops that affect a select set of system state variables. Simulation scenarios are derived from a hazard analysis of the operator's control loops. The immersive simulation aspect of the overall training program is characterized by selecting a set of scenarios that expose the operator to issues arising in each of the different sections of the typical control loop. Results from the application of this approach to the LADEE mission are provided through an analysis of the simulation scenarios used for operator training and the actual anomalies that occurred during the mission. The simulation scenarios and inflight anomalies are mapped to specific sections of the typical control loop to illustrate the characteristics of anomalies arising from the different sections of the typical control loop. Additionally, similarities between the simulation scenarios and inflight anomalies are highlighted to make the case that the simulation scenarios prepared the operators for the mission.

8.0508 Planning for Crew Exercise for Future Deep Space Mission Scenarios

Cherice Moore (NASA - Johnson Space Center),

Presentation: Cherice Moore, Wednesday, March 11th, 09:00 PM, Jefferson

test

8.0509 Cardiovascular Responses to Artificial Gravity Combined with Exercise

Ana Diaz (Massachusetts Institute of Technology), Laurence Young (Massachusetts Institute of Technology),

Presentation: Ana Diaz, Wednesday, March 11th, 09:25 PM, Jefferson

Astronauts experience important physiological adaptation to weightless environment, including bone loss, muscle atrophy, cardiovascular deconditioning, and vestibular disorientation. Physiological deconditioning will be even more challenging in future long-duration space missions, for example to Mars, in which astronauts will be exposed to microgravity for six to eight months before landing without external help to support egress. Artificial gravity (AG) is a comprehensive countermeasure that could prevent physiological deconditioning during extended exposure to microgravity, particularly if it is combined with exercise. Here, we are investigating the effect of short-radius centrifugation combined with ergometer exercise on human physiology, particularly on the cardiovascular system. One subject is tested under three different levels of AG: 0g (no centrifugation), 1g, and 1.4 g (g levels measured at the feet). At each AG level, the subject completes a 25 min bicycle ergometry exercise protocol with three different exercise intensities: warm-up (25W), moderate (50W), and vigorous (100W). Continuous cardiovascular variables (heart rate, blood pressure, pulse pressure, stroke volume, cardiac output, and vascular resistance) are measured at heart level using a ccNexfin system (Edward Lifescience). Preliminary results show that the extent to which the cardiovascular system responds to artificial gravity depends on the gravity level being applied, suggesting that artificial gravity combined with exercise may be effective as a countermeasure against cardiovascular deconditioning in space

8.0510 Comparing Human Skin Strain of the Elbow for Mechanical Counter Pressure Space Suit Development

Edward Obropta (Massachusetts Institute of Technology), Dava Newman (Massachusetts Institute of Technology),

Presentation: Edward Obropta, Wednesday, March 11th, 09:50 PM, Jefferson

Developing skin-tight space suits requires detailed understanding of human skin deformation at joints in order to fit and create mechanical counter pressure without restricting human mobility. A comparison of high-resolution human skin strain field data at the elbow joint measured using three-dimensional digital image correlation (3D-DIC) is presented. Previously, skin strain has been measured at 1 cm^2 resolution for one or two subjects to demonstrate the measurement technology. Now using 3D-DIC, skin strain is measured at 1 mm^2. Methodology to take these measurements and the data

analysis is explained in detail. This paper goes beyond the measurement technology and presents data from four subjects and compares skin strain fields of the elbow joint, which gives insight into patterns and differences between varying anthropometrics and other factors that affect skin strain. These results are important to develop mechanical counter pressure space suits that are sized correctly for each astronaut and do not inhibit locomotion. These results are discussed in the context of realizing a mechanical counter pressure space suit designed for planetary exploration.

8.06 Modular Bus Technologies, Components and Standardized Spacecraft

Session Organizer: Paul Graven (Cateni), Richard Martin (Air Force Research Laboratory),

8.0601 Solar Electric Propulsion on ESPA-Class Satellite

William Deininger (Ball Aerospace), Bryce Unruh (Ball Aerospace),
Presentation: William Deininger, Wednesday, March 11th, 10:10 AM, Jefferson

Ball Aerospace participated in a Space Act Agreement with NASA GRC to determine the feasibility of accommodating enough Solar Electric Propulsion (SEP) on the Ball ESPA-class bus to result in a mission of interest to Ball customers. The baseline for the study was the ESPA-class BCP-100 bus. Since the BCP-100 bus has flight heritage on USAF programs, the approach for the study was to use the existing bus design and minimize changes to only those necessary to accommodate the SEP system. This approach maintains high heritage and minimizes the amount of Non-Recurring Engineering required for the bus. High heritage components were also selected for the SEP system when available, including an off-the-shelf Xenon tank, existing cathode, HET thruster and Xenon feed control, allowing future development funding to be focused on a PPU compatible with the existing BCP-100 28 V power bus. The results of the study show that while meeting the ESPA envelope and mass requirements, the BCP-100 can accommodate enough SEP capability to allow the orbit to be raised or lowered anywhere within LEO or change the inclination up to 10° from a LEO starting point. From a GTO starting point, an elliptical orbit with apogee at GEO is also possible

8.07 Mechanical Systems, Design and Technologies

Session Organizer: Alexander Eremenko (Jet Propulsion Laboratory), Lisa May (NASA Headquarters),

8.0701 Mass Properties Analysis and Measurements of a High Altitude Supersonic Decelerator Test Vehicle

Mark Yerdon (NASA Jet Propulsion Laboratory), Brant Cook (Jet Propulsion Laboratory),
Presentation: Mark Yerdon, Wednesday, March 11th, 08:30 AM, Madison

The mass properties of the Low Density Supersonic Decelerator test vehicle were analyzed and measured to ensure a successful test flight and allow for accurate post-flight reconstruction. This paper covers the methods used for analytical estimates of the mass properties throughout the design process, balancing and ballasting design, mass trends, measurements performed to verify the analytical models, and issues found. The test vehicle analyzed and measured is a full scale 4.7 m diameter, 3085 kg, high altitude test vehicle.

8.0702 Application of Synthetic Gear-Wheels to Space Mechanisms

Ralf Purschke (Institute of Astronautics),
Presentation: Ralf Purschke, Wednesday, March 11th, 08:55 AM, Madison

The goal of this work was to evaluate the wear behavior of PEEK gear wheels in a simulated space environment and their applicability in space mechanisms. Polyetheretherketone (PEEK) is a promising material for the manufacturing of gear wheels in space applications. PEEK has high strength, high wear resistance, good behavior at extreme temperatures, and a low outgassing rate. But what makes PEEK particular interesting for the application in space mechanisms is its ability to be used without lubrication. A back-to-back gear test rig was developed in order to conduct the wear tests of a pinion made out of PEEK in a thermal-vacuum chamber. The wear tests were run in four different environments: (1) ambient lab environment, (2) vacuum at 20°C, (3) vacuum at +80°C, and (4) vacuum at -55°C. Before and after each test the contour of selected teeth were measured and, with the area difference, the wear coefficient was determined and the theoretical increase of backlash was calculated. The results show a dependency of the wear rate as a function of the test environment. But despite the wear-caused increase in backlash, the accuracy requirements of many pointing mechanisms can still be met.

8.0703 Europa Clipper Instrument Implementation in the Proposal Phase

Matthew Horner (JPL), Alexander Eremenko (Jet Propulsion Laboratory),
Presentation: Matthew Horner, Wednesday, March 11th, 09:20 AM, Madison

A look at the ambitions and challenges facing the proposed mission to Jupiter's Europa moon. The Europa Clipper proposal intends to investigate the icy moon's surface and interior to characterize the chemical processes taking place and determine the viability that Europa was or is habitable for life.

8.0704 Europa Clipper Vault Shielding Optimization Approach

Matthew Spaulding (Jet Propulsion Laboratory), Alexander Eremenko (Jet Propulsion Laboratory),
Presentation: Matthew Spaulding, Wednesday, March 11th, 09:45 AM, Madison

This paper discusses the method being utilized to analyze the potential mass savings and configuration impacts related to various radiation shielding configurations for the Europa Clipper Radiation Vault. The configurations studied incorporate either an Aluminum or Titanium structural element with additional radiation shielding incorporated in the form of Tantalum sheet. Varying the relative thicknesses of the structural and shielding materials, as well as the configuration of the Vault Panels' constituent elements results impact the overall Vault mass.

8.0706 System Design and Development of VELOX-I Nanosatellite

Vu Bui (Nanyang Technological University),
Presentation: Vu Bui, Wednesday, March 11th, 10:10 AM, Madison

This paper highlights the design approach, challenges, and solutions during the development of VELOX-I nanosatellite. VELOX-I was developed by Nanyang Technological University (NTU) for technology demonstration of in house built camera, GPS and inter-satellite communication payloads. The mission requires innovative design to miniaturize the subsystems and extend the capability of the standard 3U CubeSat. Some examples discussed in this paper include the attitude control subsystem, the deployable optics, the piggyback picosatellite VELOX-PIII and its deployment mechanism. The satellite was launched into low Earth's orbit on 30th June 2014 and various experiments have been successfully conducted.

8.09 Autonomous Space Exploration Systems and Technologies

Session Organizer: Babak Cohanim (Charles Stark Draper Laboratory), Steve Paschall (Draper Laboratory),

8.0901 Bio-inspired Engineering for the Exploration of Remote Worlds

Andrew Ketsdever (University of Colorado, Colorado Springs),

Presentation: Andrew Ketsdever, Wednesday, March 11th, 11:00 AM, Madison

The Dynamic Stereoscopic Long Range System (DSLRS) has been developed to offer an engineering perspective on the behavior of herds and flocks of animals for bio-inspired engineering applications. The system provides the relative spacing and velocity of each member within a herd or flock. The DSLRS employs two fixed cameras which simultaneously capture stereoscopic image pairs. These image pairs are analyzed using automated software algorithms developed in this work to produce spacing data up to a range of 350 meters. Eventually, the spacing and velocity data acquired by the DSLRS will aid in the development of a control algorithm for robotic swarms based on biological behavior. A control algorithm for automated robotic swarm operation will reduce or eliminate the human element in the control loop. For instance, estimates for the Global Positioning System (GPS) satellite constellation show that continuous, human-in-the-loop space operations from the ground costs up to 85 percent of the overall budget for the GPS space mission architecture. An intelligent system, with the ability to assess situations and react based on biological instincts, may address a critical need in autonomous operations. The DSLRS is a first step in understanding herd and flock behavior from an engineering perspective in an attempt to provide the necessary level of fidelity to develop bio-inspired control algorithms.

8.0902 Graph-based Terrain Relative Navigation with Optimal Landmark Database Selection

Ted Steiner , Tye Brady (Charles Stark Draper Laboratory), Jeffrey Hoffman (Massachusetts Institute of Technology),

Presentation: Ted Steiner, Wednesday, March 11th, 11:25 AM, Madison

Terrain relative navigation (TRN) offers a means to constrain absolute vehicle position and attitude without using a GPS receiver or star camera, such as for unmanned aerial vehicles or planetary landing spacecraft, using a pre-computed terrain database of distinctive landmarks in the operational environment. However, depending on the length of the planned trajectory, these terrain landmark databases may grow prohibitively large for the onboard data storage, processing, and communication capabilities of these types of vehicles. We introduce a definition of landmark utility as a measure of the value of potential line-of-sight measurements to that landmark, and an efficient algorithm to sort all potential landmarks in an environment based on their relative utility prior to flight. This enables pre-determination of a limited-size terrain landmark database containing the N-best landmarks in the environment. We additionally introduce an incremental smoothing-based approach to TRN using a Bayesian factor graph representation. This system is capable of overcoming several challenges associated with TRN systems, including relinearization of past measurements, simultaneously utilizing pre-mapped and opportunistic features in a common estimator, and efficient sensor fusion in a common, probabilistic framework.

8.0903 Software Testbed for Developing and Evaluating Integrated Autonomous Subsystems

James Ong (Stottler Henke Associates, Inc (SHAI)), Peter Robinson (NASA - Ames Research Center), Emilio Remolina , Axel Prompt (Stottler Henke Associates, Inc.), Adam Sweet (QSS Group, Inc.), David Nishikawa (NASA Ames Research Center),

Presentation: James Ong, Wednesday, March 11th, 11:50 AM, Madison

To implement fault tolerant autonomy in future space systems, it will be necessary to integrate planning, adaptive control, and state estimation subsystems. However, integrating these subsystems is difficult, time-consuming, and error-prone. This paper describes Intelliface/ADAPT, a software testbed that helps researchers develop and test alternative strategies for integrating intelligent subsystems quickly and easily. The testbed's architecture, graphical data displays, and implementations of the integrated subsystems support plug and play of alternate components to support research and development in fault-tolerant control of autonomous vehicles and operations support systems. Intelliface/ADAPT controls NASA's Advanced Diagnostics and Prognostics Testbed (ADAPT), which comprises batteries, fans, pumps, lights, relays, circuit breakers, invertors, and sensors. During execution, an experimentor can inject faults into ADAPT. The diagnostic subsystem, based on NASA's Hybrid Diagnosis Engine (HyDE), detects and isolates these faults. Intelliface/ADAPT then determines whether the current plan can be executed using the reduced resources. If not, a new plan is generated that reschedules tasks, reconfigures ADAPT, and reassigns ADAPT resources to work around the fault. The adaptive controller executes the new plan, using augmented, hierarchical finite state machines. Real-time sensor data, commands, and plans are displayed in information-dense arrays of timelines and graphs that zoom and scroll in unison. A dynamic schematic display uses color to show the real-time fault state and utilization of the system components and resources. An execution manager coordinates the activities of the other subsystems. The subsystems are integrated using the Internet Communications Engine (ICE), an object-oriented toolkit for building distributed applications.

8.10 New Technologies and Instruments for Scientific Balloon Missions

Session Organizer: Jessica Gaskin (NASA - Marshall Space Flight Center), Ira Smith (Southwest Research Institute),

8.1001 The First Balloon Flight of the Low Density Supersonic Decelerator Technology Demonstration Mission

Thomas Randolph (Jet Propulsion Laboratory), Steve Sell , Chris Schwantes (Columbia Scientific Balloon Facility), Robert Mullenax (NMSU/CSBF), Danny Ball (Columbia Scientific Balloon Facility/New Mexico State University),

Presentation: Thomas Randolph, Thursday, March 12th, 08:30 AM, Jefferson

To improve the state of the art in Mars supersonic decelerator technology, the Low Density Supersonic Decelerator (LDSD) technology demonstration mission has embarked upon a series of high altitude balloon lofted, rocket propelled, supersonic reentry tests. Similar to Mars reentry technology tests performed in the 1970s, including the Planetary Entry Parachute Program (PEPP) and the Balloon Launch Decelerator Test (BLDT), LDSD relies on a zero pressure balloon to deliver the test vehicle to its high altitude initial conditions. The test architecture was successfully demonstrated in the first test flight of the project from the Pacific Missile Range Facility (PMRF) in Kauai on June 28th, 2014. In adapting this test architecture from the 1970s to today, many new developments were made to the balloon system including: a new balloon static launch technique and new balloon trajectory predictive capabilities. Additional diagnostic tools, intended for characterization of the test vehicle flight, were also available to characterize the balloon flight including: meteorological rockets for atmospheric characterization and the test vehicle's inertial measurement unit, which was able to measure the dynamic rates of the suspended payload. These results provided the test architecture validation and data necessary for the LDSD flights planned in 2015.

8.1002 Stratospheric Balloon Missions for Planetary Science

Tibor Kremic (NASA), Andrew Cheng (JHUAPL), Charles Hibbitts (JHU-APL), Eliot Young (Southwest Research Institute), Steven Arnold (Johns Hopkins University/Applied Physics Laboratory), Pietro Bernasconi (Johns Hopkins University/Applied Physics Laboratory),

Presentation: Tibor Kremic, Thursday, March 12th, 08:55 AM, Jefferson

NASA and the planetary science community have been exploring the potential contributions of stratospheric balloons to decadal class planetary science. Previous studies of the ~200 questions raised in the Decadal Survey have identified about 45 topics that are potentially suitable for addressing by stratospheric balloon platforms. A stratospheric balloon mission was flown in the fall of 2014 called BOPPS, Balloon Observation Platform for Planetary Science. This mission observed a number of planetary targets including two Oort cloud comets. The optical system and instrumentation payload was able to provide unique measurements of the intended targets and increase our understanding of these primitive bodies and their implications for us here on Earth. This paper will discuss the mission, instrumentation and initial results and how these may contribute to the broader planetary science objectives of NASA and the scientific community. This paper will also identify how the instrument platform on BOPPS may be able to contribute to future balloon-based science. Finally the paper will address potential future enhancements and the expected science impacts should those enhancements be implemented.

8.1003 Design and Performance of the BOPPS UVVis Fine Pointing System

Jedediah Diller (Southwest Research Institute), Zachary Dischner , Kevin Dinkel , Eliot Young (Southwest Research Institute),

Presentation: Zachary Dischner, Thursday, March 12th, 09:20 AM, Jefferson

In September, 2013 the BRRISON mission suffered an anomaly resulting in a total loss of science data for the duration of flight. The Balloon Observation Platform for Planetary Science (BOPPS) mission is in essence a re-flight of the BRRISON mission. The BOPPS mission was designed to study multiple comets and other planetary bodies as well as demonstrate a fine pointing system. The performance of this fine pointing system (FPS), designed for science pointing on the 50 milliarscecond level, will be discussed along with the mission as a whole. Due to a telescope focusing issue that manifested in flight during the allocated FPS demonstration window, thorough FPS characterization could not be performed. However, a calibration dataset demonstrated stable pointing of 33 and 58 milliarcsecond (mas) RMS in instrument Azimuth and Elevation respectively. This performance is considered marginal given the conservative FPS settings it was acquired with.

8.1004 A Multi-Channel Tunable Laser Spectrometer for in Situ Measurement of Planetary Atmospheres

Scot Rafkin (Southwest Research Institute), Keith Nowicki (Southwest Research Institute),

Presentation: Scot Rafkin, Thursday, March 12th, 09:45 AM, Jefferson

A newly developed tunable laser spectrometer (TLS) capable of simultaneously measuring many of the key photochemical species in planetary atmospheres is presented. The instrument consists of a low-power (<10 mW) and low mass (<50 mg) vertical cavity emitting laser source and photodetector, a multi-pass optical cell to provide a long absorption path in a compact design, and laser driving and digital signal processing electronics. The sensor takes advantage of two key technological developments: 1) a patented multiple-pass optical cell design that uses small mirrors and dense spot patterns to give a long optical path with a small footprint; and 2) a low power and compact electronics system. Designs for Mars and Venus are mature, allowing for deployment on probe or balloon missions to either planet, and deployment on landed spacecraft at Mars. The major advantage of this system over previously developed TLS instruments is the multichannel gas measuring capability, an increase in path length and sensitivity without an increase in mirror size, a dramatic decrease in mass and power, and the robust nature of the design in a hostile environment. Current best estimates of total instrument mass and power are 750 mW and 1 kg, respectively.

8.1005 A Balloon-Borne Acousto-Optic Tunable Filter Imaging Camera for Planetary Science Investigations

Nancy Chanover (New Mexico State University), David Voelz (New Mexico State University), David Glenar (Univ. of Maryland, Baltimore County), Eliot Young (Southwest Research Institute),
Presentation: Nancy Chanover, Thursday, March 12th, 10:10 AM, Jefferson

A balloon-borne Acousto-Optic Tunable Filter (AOTF) hyperspectral imager is ideally suited to address numerous outstanding questions in planetary science. The spectral agility, narrowband wavelength selection, tolerance to the near-space environment, and spectral coverage afforded by AOTFs would enable investigations not feasible from ground-based facilities. A notional AOTF imager design includes both visible and near-infrared channels to take full advantage of the spectral coverage of an AOTF. We explore an example use case of synoptic observations of clouds on the giant planets using the visible channel of such an instrument. Although technical challenges such as detector cooling would require further performance modeling, an AOTF hyperspectral imager is a logical choice for giant planet imaging investigations from a balloon platform. The ability to rapidly acquire hyperspectral image cubes, thereby obtaining spectra of all locations on the planet that could elucidate atmospheric structure and dynamical processes, offers a unique advantage over traditional imaging techniques.

8.1006 Title: Passive Thermal Control of Balloon-Borne Telescopes

Eliot Young (Southwest Research Institute), Robert Woodruff (Retired),
Presentation: Eliot Young, Thursday, March 12th, 10:35 AM, Jefferson

Balloon-borne telescopes typically operate at altitudes of 110,000 - 127,000 ft, above 99.5% of the Earth's atmosphere. They are particularly well-suited to infrared observations in the 1 - 5 micron range, where telluric absorptions (due to water, methane, carbon dioxide, etc.) block access to important spectral regions. A key design challenge is to cool stratospheric telescopes to reduce thermal emission from the mirrors and support structure. We present modeling and vacuum chamber results which suggest that significant cooling - down to our target temperature of 180 K - can be achieved with passive thermal blankets and careful control of orientation to the Sun.

8.1007 A High-Resolution Pointing System for Continuously Scanning Platforms: The EBEX Example

Joy Didier (Columbia University),
Presentation: Joy Didier, Thursday, March 12th, 11:00 AM, Jefferson

The E and B experiment (EBEX) is a balloon-borne telescope designed to measure the polarization of the cosmic microwave background with 8' resolution employing a gondola scanning with speeds of order degree per second. In January 2013, EBEX completed 11 days of observations in a flight over Antarctica covering $\sim$6000 square degrees of the sky. The payload is equipped with two redundant star cameras and two sets of three orthogonal gyroscopes to reconstruct the telescope attitude. The EBEX science goals require the pointing to be reconstructed to approximately 10" in the map domain, and in-flight attitude control requires the real time pointing to be accurate to $\sim$0.5\ degree. The high velocity scan strategy of EBEX coupled to its float altitude only permits the star cameras to take images at scan turnarounds, every $\sim$40 seconds, and thus requires the development of a pointing system with low noise gyroscopes and carefully controlled systematic errors. Here we report on the design of the pointing system and on a simulation pipeline developed to understand and minimize the effects of systematic errors. The performance of the system is evaluated using the 2012/2013 flight data, and we show that we achieve a pointing error with RMS=25" on 40 seconds azimuth throws, corresponding to an error of $\sim$4.6" in the map domain.

8.1008 Star Camera System and New Software for Autonomous and Robust Operation in Long Duration Flights

Daniel Chapman (Columbia University),
Presentation: Daniel Chapman, Thursday, March 12th, 11:25 AM, Jefferson

The E and B Experiment (EBEX) is a balloon-borne telescope designed to probe polarization signals in the cosmic microwave background. It completed an 11 day flight over Antarctica in December 2012 / January 2013. EBEX employs two redundant star cameras to achieve its real-time and post-flight attitude determination requirements. The EBEX star cameras are designed to be robust against multiple classes of challenges that may arise in the long duration balloon-borne environment. We will report on the design, implementation, testing, and successful in-flight performance under challenging conditions of the EBEX star cameras and their associated custom-written software.

8.1009 The High Altitude Student Platform (HASP) as a Model Multi-Payload Balloon Platform

T. Guzik (Louisiana State University),
Presentation: Michael Stewart, Thursday, March 12th, 11:50 AM, Jefferson

An advantage of balloon flights is that payloads can be exposed to a near-space environment for an extended period of time, recovered, revised and then flown again. Thus, instrument and satellite component designs can be tested and refined without the need for orbital launches. This reduces development costs and reduces the time to increase the technology readiness level (TRL) of a particular component. Recently there has been increased interest in developing miniaturized satellites, with low mass, power and telemetry requirements. An inexpensive method for testing "nanosats" components, or full systems, would be to fly them on a balloon platform at 120,000 feet. These systems could be clustered onto a single balloon payload carrier that provides standardized power, telemetry and a physical interface for each experiment. Such an approach reduces the payload development overburden, so the investigator can focus exclusively on experiment, or subsystem, development and, consequently, can reduce experiment cost and improve turn-around time. Here we report on our experience with the High Altitude Student Platform (HASP), the first balloon carrier specifically designed with a standard interface to support up to 12 independent experiments per flight. Since 2006, HASP has flown nine times from Ft. Sumner, New Mexico and carried close to eighty experiments to an altitude of ~120,000 feet for an average duration of 14 hours at float. We will discuss the HASP system design, development and capabilities, the kinds of experiments that have flown on HASP, and the lessons-learned that are applicable to future multiple payload balloon platforms.

8.1010 First Flight Results of the X-ray Polarimeter X-Calibur

Matthias Beilicke (Washington University in St. Louis),
Presentation: Matthias Beilicke, Thursday, March 12th, 04:30 PM, Jefferson

X-ray polarimetry promises to give qualitatively new information about high-energy astrophysical sources, such as binary black hole systems, micro-quasars, active galactic nuclei, and gamma-ray bursts. We designed, built and tested a hard X-ray polarimeter, X-Calibur, to be used in the focal plane of the balloon-borne InFOCuS grazing incidence X-ray telescope with the goal of observing astrophysical sources. X-Calibur combines a low-Z Compton scatterer with a CZT detector assembly to measure the polarization of 20-60 keV X-rays making use of the fact that polarized photons Compton scatter preferentially perpendicular to the electric field orientation. A 1-day test flight of the instrument was performed from Ft.Sumner, NM, in fall 2014. The sensitivity, performance and first results form the flight will be presented

8.1011 Vision Algorithm for the Solar Aspect System of the HEROES Mission

Alexander Cramer , Steven Christe (NASA GSFC), Albert Shih (NASA - Goddard Space Flight Center),
Presentation: Alexander Cramer, Thursday, March 12th, 04:55 PM, Jefferson

This talk covers the design and test of a machine vision algorithm for generating high-accuracy pitch and yaw pointing solutions relative to the sun for the High Energy Replicated Optics to Explore the Sun (HEROES) balloon mission. Performance is verified on a combination of test data recorded on the ground, artificially generated images, and images from the 2013 flight.

8.1012 SuperHERO: Design of a New Hard X-Ray Focusing Telescope

Jessica Gaskin (NASA - Marshall Space Flight Center), Steven Christe (NASA GSFC), Albert Shih (NASA - Goddard Space Flight Center), Colleen Wilson Hodge ,
Presentation: Jessica Gaskin, Thursday, March 12th, 05:20 PM, Jefferson

SuperHERO is a hard x-ray (20-75 keV) balloon-borne telescope, currently in its proposal phase, that will utilize high angular-resolution grazing-incidence optics, coupled to novel CdTe multi-pixel, fine-pitch (250 μm) detectors. The high-resolution electroformed-nickel, grazing-incidence optics were developed at MSFC, and the detectors were developed at the Rutherford Appleton Laboratory in the UK, and are being readied for flight at GSFC. SuperHERO will use two active pointing systems; one for carrying out astronomical observations and another for solar observations during the same flight. The telescope will reside on a light-weight, carbon-composite structure that will integrate the Wallops Arc Second Pointer into its frame, for arcsecond or better pointing. This configuration will allow for Long Duration Balloon flights that can last up to 4 weeks. This next generation design, which is based on the High Energy Replicated Optics (HERO) and HERO to Explore the Sun (HEROES) payloads, will be discussed, with emphasis on the core telescope components.

8.1013 System Identification of a Square Parachute and Payload for the LAICAnSat

André Vinícius Santos Silva , Bruno Noronha , Renato Borges (Universidade de Brasilia), Simone Battistini (Universidade de Brasilia),
Presentation: Simone Battistini, Thursday, March 12th, 08:25 PM, Jefferson

This work is a part of the LAICAnSat project of the University of Brasília aimed at developing near-space experimental BalloonSats for scientific missions and remote sensing applications. The project is divided in two main parts: Low Altitude Part (LAP) and High Altitude Part (HIP). Regarding the LAP, which is the focus of this work, the team is currently working on the identification of the aerodynamic model parameters of a square parachute to be used in future launches. The final goal is the implementation of a suitable control system to land the payload in a predefined area. The main motivation to develop such a system is to make the payload rescue easier, avoiding areas of difficult access such as dense forests. It is important to develop a system that is capable to navigate the payload, and the first step for that is the aerodynamic model identification. In order to reach this objective, the team is using a remote controlled parachute to collect data for the identification process and also testing the proposed model. Trajectory and speed are acquired by the BeeLine GPS-2 meter in a trimmed flight and used to identify steady-state coefficients (Cl0 and Cd0) The derivatives parameters, such as Cl_alpha, Cd_alpha, and others, are estimated using biologically inspired computing and parachutes wind-tunnel data from the literature. These work represents the first step in the development of a control system to carry the payload to a predefined area, providing more possibilities for near space missions.

8.1014 The Integrated Panoramic Surveillance System Based on Tethered Balloon

Weiwei Zhang (Beijing Institute of Space Mechanics & Electricity),
Presentation: Weiwei Zhang, Thursday, March 12th, 08:50 PM, Jefferson

Tethered ball has the characteristics of the long duration, low cost, large payload, high safety performance, and it is widely applied in military and civil fields, especially in the field of various large-scale civilian activities it plays an important role on monitoring tasks. Currently, there is a suspending contradiction between the surveillance range and resolution of the tethered balloon-borne optical load. It needs urgently to be resolved that expanding the surveillance scope and enhancing the resolution. Besides, in order to improving the surveillance efficiency, panoramic surveillance images are in dire need of acquiring to increase the scope of application of the system. In order to solve these problems, an integrated panoramic surveillance system is proposed, which consists of the integrated optical sensor platform, data transmission system and ground image processing system. The whole system can get the visible 360°panoramic images, 360°cylindrical surface images, high resolution images of the interested target and the unfolding cylindrical surface images, and the system can perform the nighttime task. Integrated panoramic surveillance system can be used not only for military such as battlefield surveillance, early warning and reconnaissance, but also for the civil such as the large-scale civilian activities, public safety, geological exploration, World Expo and the Olympics. This system lay on basis for further development that the panoramic surveillance system based on the tethered balloon.

8.1015 Modifying a Scientific Flight Control System for Balloon Launched UAV Missions

Marc Schwarzbach (German Aerospace Center - DLR), Sven Wlach (German Aerospace Center - DLR), Maximilian Laiacker (German Aerospace Center - DLR),
Presentation: Marc Schwarzbach, Thursday, March 12th, 09:15 PM, Jefferson

We present our work on enabling Balloon launched high altitude UAV Missions for an autopilot system previously used only at lower levels in visual line of sight conditions. The research was performed in the context of high altitude pseudo satellites (HAPS). To gain operational experience in high altitude flying and for system and payload testing, a balloon launched small UAV (sub 10kg) system was designed including building an optimized airframe. Balloon launching was chosen because it offers fast and clearly regulated access to the desired altitudes. Hardware design was driven by the special thermal requirements resulting from flying in stratospheric conditions. In the autopilot software, several mission specific functions had to be added, which only required moderate effort due to the modular system design. Major changes included adding a flight termination manager. Extensive testing was performed to validate the design. Simulating the mission, including balloon ascend, was used to check the mission software. Thermal and pressure conditions at altitude were replicated in a thermal vacuum chamber. The simulation and control laws were verified by means of low altitude test flights.

8.11 Enabling Systems and Technologies for CubeSat/Smallsats

Session Organizer: John Enright (Ryerson University), Michael Swartwout (Saint Louis University),

8.1101 A Ground-Based Facility for Nanosatellite Systems Testing in Relevant Environments

Andrew Ketsdever (University of Colorado, Colorado Springs), Carlos Maldonado (University of Colorado at Colorado Springs),
Presentation: Andrew Ketsdever, Thursday, March 12th, 08:30 AM, Amphitheatre

There is a growing demand for a modern ground-based facility for accurate spacecraft environment simulation. The function of simulation facilities is to assist scientists and

engineers in the design and selection of materials and systems for future space missions. There are currently facilities in existence that simulate space; however they are generally limited to testing one or two environmental factors at a time. This has drawbacks in that the combined effects of multiple environmental parameters can affect materials and systems in a different manner than the singular factors alone. The Chamber for Atmospheric and Orbital Space Simulation (ChAOSS) is currently being developed to simulate multiple parameters of the orbital and inter-orbital environments that spacecraft will be exposed to. This facility will have the ability to accurately simulate multiple space environment conditions allowing for synergistic testing of materials, thermal systems, electronics, and optics. To ensure a higher rate of mission success, sensors need to be tested prior to conducting on-orbit measurements to evaluate the influence of the space environment in relation to sensor performance. The growing demand for smaller spacecraft and diagnostic equipment has been made feasible by recent advances in micro-scale manufacturing. The ChAOSS facility will have the unique ability to provide experimental validation and calibration of sensors in relevant environments during the design, development, and testing phase. In addition to these applications, the facility is of sufficient size to be a potential testbed for a completed nanosatellite system.

8.1102 An Autonomous Remote Ground Station for Reducing the Cost of LEO Satellites' Operation

Ghulam Jaffer (Institute of Space Technology (IST)), Nazish Rubab (institute of Space Technology (IST)), Tahir Mushtaq (University of Management and Technology (UMT)),

Presentation: Ghulam Jaffer, Thursday, March 12th, 08:55 AM, Amphitheatre

Cost is a major factor in satellite development at universities. This can be reduced up to 10 % by automating ground-satellite operations as these are routinely for limited times per satellite pass in LEO. The faster paradigm growing is to reduce groundstation (GS) operation cost by automating the GS and operate it remotely whenever required. Many requirements do not need personnel presence the whole day, as the communication window of LEO satellite depending on maximum elevation (MEL) is 10 - 20 minutes a satellite pass. In the course of this work it was shown that the interference from mobile radio is present but does not hinder or influence the communication with the satellite. The GS operates as a virtual GS by authenticated remote users throughout the world via internet for operating convenience. Since September 2009 the GS is working in remote user mode and up to now, there were more than 20,000 passes of many satellites over the GS. From all satellite passes with an elevation angle above 0 degree, successful communication was established with a reliability of 99 % data analyzed in real–time. Details of the software tools and their applicability to tracking, monitoring and processing are also provided as used by students and researchers performing GS operations. Among many constraints, synchronization losses and port blocking were resolved and an interface solution is worked out as a future task to avoid network latency.

8.1103 Lessons Learned - Deploying a 50 Kg Small Satellite from the International Space Station

Adam Wuerl (Andrews Space), Melissa Wuerl (Andrews Space),

Presentation: Adam Wuerl, Thursday, March 12th, 09:20 AM, Amphitheatre

Working on it.

8.1104 Optimal Power Operation of Low-cost MEMS-Based Attitude Determination System for Nano-Satellites

Mohammed Rashed (Korea Advanced Institute of Science and Technology (KAIST)),

Presentation: Mohammed Rashed, Thursday, March 12th, 09:45 AM, Amphitheatre

This paper presents a critical attempt to optimize the power operation issue within the attitude determination system especially for MEMS-Based Nano-satellites. In the recent time, Nano-satellites have been a crucial focus to enlighten the future research with miniature technology under implementation saving tremendous amount of cost and resources in balance with higher performance and enhanced reliability. For this to be achieved, a well-defined objective is an absolute necessity but for an objective to be clearly surfaced, an intensive and in-depth research and analysis of the concerns which are underlying this technology to reach its maximum performing capabilities with enriched benefits for future. Hence, taking a thorough consideration of this aspect, study and critical analysis of all the factors which affect the overall performance of a miniaturized spacecraft. while researching, of all the major parameters noted, one of them highly crucial for attitude dynamics of a satellite is keenly observed to be its power operation within assigned sensors. It is because many satellites have faced several problems or even failure due to lack of proper designing of the attitude determination system and its practical dynamics. Being most sensitive sub-system to design for Nano-satellites specifically considering low-cost MEMS sensors, a detailed study was strategized and simulated for various near space environmental conditions followed by tremendous effort was put in for attaining creative set-ups for experimenting power regular within the ADS practically. After number of tests carried out over a period of time, significant results were achieved and are demonstrated in paper.

8.1105 CubeSat Proximity Operations Demonstration (CPOD) Mission Update

John Bowen (Tyvak Nano-Satellite Systems),

Presentation: John Bowen, Thursday, March 12th, 10:10 AM, Amphitheatre

The CubeSat Proximity Operations Demonstration (CPOD) mission led by Tyvak Nano-Satellite Systems will demonstrate rendezvous, proximity operations, and docking of two 3U CubeSats. The CPOD program passed CDR in March 2014 and has since progressed to flight vehicle production and test. Tyvak developed a unique relative navigation payload that includes delta GPS, inter-satellite link with radio ranging, two infrared imagers, and two visible imagers. A cold gas propulsion system is integrated into the vehicle for translational maneuvers. A high performance attitude determination and control system was developed to enable maneuvering and relative pointing. While cost was kept low with the use of commercial off the shelf components and selective redundancy, the integration of new rendezvous and docking components necessitated a significant investment in testing and integrated performance verification. Testing included real time hardware in the loop testing of the control, maneuver planning, and image processing systems, as well as air table testing of the docking mechanism. The CPOD mission is now in the final integration and testing phase and slated for launch in 2015. This presentation presents an update on the CPOD mission including the flight vehicle configuration, concept of operations, and test data.

8.12 Federated, Fractionated, and Distributed Systems

Session Organizer: Alessandro Aliakbargolkar (Skolkovo Institute of Science and Technology), Steven Cornford (Jet Propulsion Laboratory),

8.1201 On Scalability of Fractionated Satellite Network Architectures

Inigo Del Portillo (Massachusetts Institute of Technology), Elisenda Bou Balust (UPC BarcelonaTech), Eduard Alarcon (UPC BarcelonaTech),

Presentation: Inigo Del Portillo, Friday, March 13th, 08:30 AM, Jefferson

Fractionated Satellite Networks are a popular concept in space systems. On these networks, several satellites cooperate and collaborate by exchanging resources wirelessly in order to obtain an aggregated network capability higher than the sum of the individual capabilities of the different satellites that compose it. Fractionated Satellite Networks are a generalization of Fractionated Satellites. Scalability is defined as the ability of a system to maintain its performance and function, and retain all its desired properties when its scale is increased greatly without having a corresponding increase in the systems complexity. The whole concept of fractionation (both at spacecraft level and network level) is based on the use of multiple satellites that jointly perform a function that can be further expanded by adding new satellites to the system. Because of this expandable nature of Fractionated Satellite Networks, the concept of scalability is critical on these architectures, as systems that do not scale well present a very poor performance when adding new agents, increasing costs and harming quality of service and stakeholder satisfaction. This paper presents a model and a framework for analyzing scalability of fractionated networks. Our model includes descriptions of the system at the resource, satellite, network and mission level. Connections and resource transfer among nodes are modelled using graphs whereas the study is approached from a resource allocation problem perspective. Finally, the utility and applications of the developed methodology is demonstrated through the analysis of a case study of a potential fractionated network.

8.1202 Interactive Simulation Games to Assess Federated Satellite System Concepts

Paul Grogan (Massachusetts Institute of Technology), Olivier De Weck (Space Systems Laboratory),
Presentation: Paul Grogan, Friday, March 13th, 08:55 AM, Jefferson

Federated satellite systems (FSS) consist of heterogeneous spacecraft with opportunistic data services. FSS membership is based on voluntary participation by independent actors without the centralized control required for systems engineering methods. New approaches must be developed to identify and assess mechanisms and incentives for collaborative behaviors required in a FSS. Towards this goal, this paper develops an interactive tabletop board game to demonstrate a technical simulation model integrated inside a social decision-making activity. Although simplified in technical detail, the game achieves a level of realism by basing its structure and behavior on a logical model of FSS with hierarchical federation, federate, system, and subsystem constructs. A prototype game provides a physical form using a game board, mats, tokens, counters, and cards to represent key constructs. Play-testing sessions reveal insights regarding FSS including participation based on minimizing opportunity cost, legacy hardware as a barrier to participation, partnerships to overcome the initial actor problem, and frequent under-estimation of network complexity and robustness.

8.1203 Value-Based Analysis of a Low-Earth Orbit Communications and Data Relay Infrastructure

Benjamin Putbrese (Massachusetts Institute of Technology), Paul La Tour , Michael Curry (Massachusetts Institute of Technology),
Presentation: Benjamin Putbrese, Friday, March 13th, 09:20 AM, Jefferson

This paper investigates the utility and ilities granted to participating space systems by a hypothetical publicly-available data relay and communications infrastructure. Within this analysis, all infrastructure designs are highly fractionated and make use of opportunistic sharing of on-orbit resources such as link capacity, processing power, and data storage. LEO optical imaging systems were chosen as the specific mission being serviced by the resource-sharing infrastructure, with the performance metrics and ilities of this combined system compared to one without any support infrastructure. Cost and physics-based modeling is used throughout to examine the value proposition associated with the infrastructure designs, both in terms of traditional metrics, such as global coverage and data downlink totals, as well as the ilities. As a means of identifying the best possible infrastructure designs, this paper explores a massive tradespace of infrastructure orbitology and spacecraft sizing configurations. Using the results provided by a robust physics and

cost model, this tradespace compares the utility to be gained from participation in the infrastructure with the costs of actually implementing such a project. Once candidate infrastructure designs were determined, the ilities granted to participating space systems by the infrastructure were analyzed through the use of utility functions and specified value metrics. This paper presents the results of the analysis, and then draws conclusions and makes suggestions for future work within this field.

8.1204 On Autonomous Software Architectures for Distributed Spacecraft: A Local-Global Policy

Carles Araguz , Inigo Del Portillo (Massachusetts Institute of Technology), Elisenda Bou Balust (UPC BarcelonaTech), Eduard Alarcon (UPC BarcelonaTech), Kenny Root (Google Inc.), Angel Alvaro Sanchez (Thales Alenia Space España),

Presentation: Inigo Del Portillo, Friday, March 13th, 09:45 AM, Jefferson

New trends such as satellite swarms or fractionated spacecraft have experienced a very significant growth in the last decade. Migration from monolithic satellite architectures to new mission architectures involving large constellations of collaborative spacecraft is enabled by several hardware technologies and the application of modularity-driven designs, and presents numerous benefits such as low development costs and times and high flexibility. This has forced the exploration of new techniques and designs which have been often tackled from the hardware perspective but scarcely approached from the software architecture standpoint. This paper presents an autonomous software architecture and a management policy targeted for the broad range of distributed architecture missions. The paper presents the Local-Global approach, an adaptive management policy based on the collaboration between two levels of control which is aimed at enabling distributed mission control in dynamic and changing environments with limited computational capabilities. The LocalGlobal policy establishes the behavioural model of a system composed of a master scheduler and an arbitrary number of local schedulers, and describes the parameters that can be adjusted to reduce the amount of information processed by the master node which makes it suitable for different distributed spacecraft architectures.

8.1205 DES-based F6 Cluster Analysis Tool: Optimizing the User Experience

Steven Cornford (Jet Propulsion Laboratory),

Presentation: Steven Cornford, Friday, March 13th, 10:10 AM, Jefferson

The System F6 DARPA Program has resulted in a trade study tool which analyze the various attributes (both cost and benefit) of various architectures with various degrees of fractionation. This paper describes the final processes to complete the closed-loop analytic process.

8.1206 Simulating a Proactive Ad-Hoc Network Protocol for Federated Satellite Systems

Ignasi Lluch Cruz (Skolkovo Institute of Science and Technology), Alessandro Aliakbargolkar (Skolkovo Institute of Science and Technology),

Presentation: Ignasi Lluch Cruz, Friday, March 13th, 10:35 AM, Jefferson

Communications network technologies are a key enabler of novel distributed space mission paradigms such as Federated Satellite Systems (FSS). Federated Satellite systems are a new approach to space mission architectures where participant missions, while being autonomous, trade resources such as data relay, storage, data processing, or ranging services, among others. Such an exchange of resources occurs in an opportunistic and voluntary basis through standardized Inter-Satellite Link interfaces. The underlying network concept must operate subject to frequent link disruptions, dynamic topologies, variable delays, variable traffic and heterogeneous link capabilities. This work leverages on the suite of protocols and techniques of Mobile Ad-Hoc Networking

(MANET) to propose an FSS protocol concept based upon Optimized Link State Routing (OSLR) network discovery concepts and the store-carry-forward Better Approach to Networking (BATMAN) routing approach. The performance of this protocol is tested on a dedicated Network Simulator and the FSS simulation toolkit. Results show the benefits on space data latency of using FSS for data relay under this protocol. On a contemporary 40-satellite LEO scenario, average latency of on-board data space-to-ground delivery is around 41 minutes. By using FSS, participant missions can benefit of cross-links to reduce average data latency to only 3.7 minutes if all nodes are willing to collaborate 100% of the time. More realistic scenarios such as a 40% average in time node participation yield a data latency figure of 22 minutes, showcasing the benefits of spacecraft federations.

TRACK 9: AIR VEHICLE SYSTEMS AND TECHNOLOGIES

Track Organizers: Christian Rice (Naval Air Systems Command, Patuxent River, MD.), Robin Locksley (Naval Air Warfare Center),

9.02 UAV Systems & Autonomy

Session Organizer: Kendra Cook (C2 International, LLC),

9.0201 Automatic Aerial Retrieval of a Mobile Robot Using Optical Target Tracking and Localization

Maximilian Laiacker (German Aerospace Center - DLR), Marc Schwarzbach (German Aerospace Center - DLR), Konstantin Kondak (German Aerospace Center - DLR),

Presentation: Maximilian Laiacker, Tuesday, March 10th, 08:30 AM, Lamar/Gibbon

In this paper we present a system for automatic deployment and retrieval of a mobile ground robot using a helicopter UAV. Our system allows using a mobile outdoor robot in areas that cannot be reached other than from the air and aerial measurements alone are not sufficient. For example a ground robot can perform in situ measurements and even take samples that can later be analysed when the robot is returned by the aerial system. We use a helicopter UAV with a take-off mass of 11kg as a proof-of-concept platform. The aerial system is using a high precision hover position controller and a multi-sensor fusion module which is used for detection and precise localization of the mobile ground robot. It combines GPS-based localization for obtaining an initial estimation of the ground robot location and a vision-system for its accurate localization. We use a known optical marker on the ground robot for its precise localization relative to the aerial system. All control and sensor processing and fusion are performed on board of the UAV. Results from multiple successful outdoor flight experiments will be presented and analysed.

9.0203 Dynamic Analysis of a Variable-Sweep, Variable-Span Morphing UAV

Nirmit Prabhakar (Embry Riddle Aeronautical University), Richard Prazenica (Embry-Riddle Aeronautical University), Snorri Gudmundsson (Embry-Riddle Aeronautical University),

Presentation: Richard Prazenica, Tuesday, March 10th, 08:55 AM, Lamar/Gibbon

This paperconsiders the dynamic effects of morphing for a variable-sweep, variable-span UAV. A scale model of such a morphing wing has been fabricated and tested in the low-speed wind tunnel at Embry-Riddle Aeronautical University. The focus of this thesis is the development of a dynamic model for this morphing wing UAV that accounts for not only the varying dynamics resulting from different static morphing configurations, but also the transient dynamics associated with morphing. A Vortex Lattice Method (VLM) solver is used to model the aerodynamics of the morphing wing UAV over a two-

dimensional array of static configurations corresponding to varying span and sweep. In this analysis, only symmetric morphing configurations are considered (i.e., in every configuration, both wings have the same span and sweep); therefore, the analysis focuses on the longitudinal dynamic modes (i.e., the long period and short period modes). The dynamic model of the morphing wing UAV is used to develop a simulation in which it is possible to specify different morphing configurations as well as varying rates of morphing transition. As such, the simulation provides an invaluable tool for analyzing the effects of wing morphing on the longitudinal flight dynamics of a morphing UAV.

9.0204 Sensitivity Study for Feature-Based Monocular 3D SLAM

Christopher Raabe (The University of Tokyo), Emad Saad (The Boeing Company), John Vian (Boeing Company), Niklas Bergström ,

Presentation: Niklas Bergström, Tuesday, March 10th, 09:20 AM, Lamar/Gibbon

Advances in cameras and computing hardware, both in terms of performance and miniaturization, has made vision-based localization a feasible onboard sensor for aerial vehicles. In GPS deprived environments or scenarios where the resolution of GPS is not sufficient, such a sensor presents an attractive alternative. Vision-based position sensors typically estimate their pose by tracking natural features in the environment, while at the same time creating a map of those features. This process is referred to as simultaneous localization and mapping (SLAM), and it employs several sub-processes, such as feature detection and description, map generation, feature mapping, and optimization, each of which is subject to a large number of parameters. Due to the complexity of the problem, finding a satisfactory parameter setting can be a tedious task. In this paper we investigate the effects of each parameter in the context of SLAM. As an example we use the PTAM (Parallel Tracking and Mapping) algorithm from the University of Oxford. The results of this sensitivity study indicate which parameters are most influential in achieving good tracking performance and also show suitable ranges for each parameter. This information can be used to expedite discovery of a satisfactory parameter setting for a new environment.

9.0205 Conservative Algorithms for Automated Collision Awareness for Multiple Unmanned Aerial Systems

Christopher Lum (University of Washington), Kevin Ueunten (University of Washington),

Presentation: Kevin Ueunten, Tuesday, March 10th, 09:45 AM, Lamar/Gibbon

As the Federal Aviation Administration (FAA) prepares to integrate Unmanned Aerial Systems (UAS) into the National Airspace System (NAS), developing technologies that mitigate the risk associated with UAS collisions have become a top priority. Despite advances in detect and avoid technologies, the UAS operator remains the primary controller responsible for maintaining inter-vehicle separation and ensuring conflicts do not occur. This paper examines a collision awareness system which increases the operator's situational awareness by spatially and temporally predicting conflicts between the UAS and entities such as other aviation traffic or restricted airspaces. By modeling entities as 3D point masses, the system can be implemented for various, dissimilar UASs. Furthermore, the system supports aircraft engaged in different flight modes such as free flight, following a flight path, and orbit/loiter behavior. Mixed Gaussian distributions model each entity's future position, where the mean is determined by 3D kinematic motion and the covariance is determined by a continuous time error propagation model. Convolving these mixed distribution with another entity or airspace yields mathematically conservative future conflict estimates. Scenarios are presented to demonstrate the algorithm's capabilities.

9.0206 Proving Your Safety Case - Commonalities in FAA CoA Decisions

Harrison Wolf (University of Southern California),
Presentation: Harrison Wolf, Tuesday, March 10th, 10:10 AM, Lamar/Gibbon

This paper examines over 100 CoA approvals for UAS operations in the United to determine the extent of Safety Management System inclusion. Safety cases have been the main focus by the FAA for UAS operations, however the process for approval is rather opaque in their requirements. This paper seeks to compare the requirements for manned aviation SMS framework as described by ICAO and FAA to CoA applications that have been approved.

9.0208 Carbon Nanotube Based Airfoil Heating System for In-Flight Anti-Icing and De-Icing of UAVs

Kim Sørensen (Norwegian University of Science and Technology), Tor Johansen (Norwegian University of Science and Technology), Andreas Helland (NTNU),
Presentation: Kim Sørensen, Tuesday, March 10th, 10:35 AM, Lamar/Gibbon

The presentation will revolve around the work completed and summarised in the paper submitted. It will primarily focus on the development of the described ice protection system.

9.0209 Net Recovery of UAV with Single-Frequency RTK GPS

Tor Johansen (Norwegian University of Science and Technology), Robert Skulstad , Christoffer Syversen , Mariann Merz (Norwegian University of Science and Technology), Nadezda Sokolova (SINTEF), Thor Fossen (Norwegian University of Science and Technology),
Presentation: Nadezda Sokolova, Wednesday, March 11th, 08:30 AM, Elbow 1

A system for autonomous precision recovery of fixed-wing unmanned aerial vehicles (UAVs) using low-cost GPS L1 C/A based RTK (Real-Time Kinematic) solution utilizing locally generated corrections is described and field tested. We present a system architecture which includes the setup of the hardware and software for the onboard GPS receiver, base-station, differential link, computers running open-source carrier-phase positioning software, roll-stabilized GPS-antenna, dedicated flight control algorithms for the final approach, and their integration with the ArduPilot open-source autopilot in the small X8 UAV (flying-wing). Experimental results show proof-of-concept field tests where the prototype implementation has been used for recovery in a stationary recovery net.

9.0210 Unmanned Aircraft Sense and Avoid - Leveraging ATC Infrastructure

Robert Stamm (Raytheon), Jason Glaneuski (US DOT / RITA / Volpe Center),
Presentation: Robert Stamm, Wednesday, March 11th, 08:55 AM, Elbow 1

To ensure safe unmanned aircraft (UA) operations in US National Airspace, Ground Based Sense and Avoid (GBSAA) capabilities were added to the Standard Terminal Automation Replacement System (STARS) for the USAF at Cannon Air Force Base (AFB) to support Predator and Reaper UA operations. The GBSAA system allows ground-based flight crews to visualize the sensor data provided by ground radars to build an awareness of the locations of other airborne traffic near the UA. A DOD, DOT and industry team has developed the first USAF operational GBSAA system for use during transits of civil airspace. The capabilities described include the use of 3D geospatial static threat volumes that define an alerting environment for tracks considered possible threats to safe access through civil airspace. Also a moving dynamic protection zone defines alert thresholds for close encounters by the UA with other traffic. GBSAA alerts and fused track data are displayed along with map and weather data to provide a shared situational awareness between air traffic control and the UA flight crew. By modifying an existing DOD and FAA STARS system for GBSAA, the cost of requirements,

safety analysis and testing was reduced, since much of the system's capabilities are already certified by the FAA for operational use. Furthermore training and maintenance support was also reduced as FAA and DoD personnel existed that support the existing ATC system.

9.0211 Design and Flight Testing of an Integrated Solar Powered UAV and WSN for Remote Gas Sensing

Jairo Malaver Rojas (QUT), Luis Gonzalez (Queensland University of Technology), Nunzio Motta (QUT), Tommaso Villa (Queensland University of Technology (QUT)),

Presentation: Luis Gonzalez, Wednesday, March 11th, 09:20 AM, Elbow 1

Remote monitoring of gases is useful to develop important tasks such the analysis of Greenhouse gases affecting the environment; study of natural phenomena such volcanos and monitoring of harmful gases from natural and manmade sources. Unmanned Aerial Systems (UAVs) and Wireless Sensor Networks (WSNs) represent the best alternatives to monitor large areas. However, the cost-benefit of these technologies reduces their availability and applications. This paper describes the architecture and integration of a low cost solar powered UAV and a WSN for remote monitoring. The paper describes the use of MoX nano-sensos as a promising and an inexpensive technology to track environmental gases such as CH4. CO2 concentrations were estimated by an off-the-shelf Non-dispersive Infrared module. The sensing technologies were adapted for aerial sampling on-board the UAV and the analysis of the UAV weight-energy is fully described and discussed. The integrated UAV and WSN were successfully tested on the field, collecting, storing and transmitting data in real time to a central node for analysis and 3D mapping of the samples. The system can be used in a wide range of outdoor applications, especially in agriculture, bushfires, mining studies, opening the way to a ubiquitous low cost environmental monitoring. A video of the bench and flight test performed can be seen in the following link https://www.youtube.com/watch?v=Bwas7stYIxQ.

9.0213 Automatic Detection and Tracking of Objects at the Ocean Surface from UAVs Using a Thermal Camera

Frederik Leira (Norwegian University of Science and Technology), Tor Johansen (Norwegian University of Science and Technology), Thor Fossen (Norwegian University of Science and Technology),

Presentation: Frederik Leira, Wednesday, March 11th, 09:45 AM, Elbow 1

The use of unmanned aerial vehicles (UAVs) that can operate autonomously in dynamic and dangerous operational environments are becoming increasingly more common. In such operations, object detection and tracking can often be one of the main goals. In recent years there has been an increased focus on embedded hardware that is both small and powerful, making UAV on-board data processing more viable. Being able to process the video feed on-board the UAV calls for fast and robust real-time algorithms for object identification and tracking. This paper discusses the development and implementation of a machine vision system for a low-cost fixed-wing UAV with a total flying weight of under 4kg. The machine vision system incorporates the use of a thermal imaging camera and onboard processing power to perform real-time object detection, classification and tracking of objects at the ocean surface. The system is tested on thermal video data from a test flight, and is found to be able to detect 99; 6% of objects of interest located in the ocean surface, having a false positive rate of 5%. Furthermore, it classifies 93; 3% of the object types it is trained to classify correctly. The classifier is highly agile, allowing the user to quickly define which object characteristics that should be considered during classification, and what types of objects to classify. Finally, the system is found to successfully track 85% of the object types it is actively searching for in a real-time simulation test.

9.0215 An Intuitive, Aggressive Control Architecture for an Unmanned Helicopter in Near-Hover Flight

Christopher Fourie (Stellenbosch University), Thomas Jones (Stellenbosch University),
Presentation: Christopher Fourie, Wednesday, March 11th, 10:10 AM, Elbow 1

Control system design for unmanned helicopters has become a widely studied topic, resulting in numerous design techniques with varying qualities. Many control designs rely on precise knowledge of the highly non-linear system dynamics inherent in a helicopter, and as a result, general techniques suffer from both modelled and un-modelled gain margin issues associated with the effect of the designed control laws on the variable system modes. We propose a robust and heuristically defined control system structure that can be theoretically designed and empirically tuned in the field based on observed responses, as well as providing a platform that can be used to alleviate unexpected system dynamics in practical control system testing and design. The philosophy behind the design is structured according to the dynamic response of a human operator, and is implemented as a successively closed system with four tiers of control loops to ensure stability and ease of design. The control structure presented in this paper illustrates a theoretically robust system that when used with analytic models and low control gains provides implicit system controllability and stability open to optimization by means of various control techniques. The structure is intended for operation at near-hover flight. This control structure has been practically tested for hover and near hover flight and will soon be tested for its application to autonomous landing on a moving platform, representative of a translating, pitching, rolling and heaving ship deck.

9.03 Aircraft Systems & Avionics

Session Organizer: Warren Jones (AMERICAN SYSTEMS),

9.0301 Improving Mode Awareness of the VNAV Function with a Multiple Hypotheses Prediction Method

Pengfei Duan (Ohio University), Maarten Uijt De Haag (Ohio University),
Presentation: Pengfei Duan, Sunday, March 8th, 04:30 PM, Elbow 1

This paper describes a Multiple Hypothesis Prediction (MHP) method that is used to improve aircraft state (energy and attitude) and automation mode awareness. The paper specifically focuses on its application for mode awareness during the use of the Vertical Navigation (VNAV) function. VNAV is used during the majority of the flight phases to govern vertical motion of aircraft and it is essential for flight constraint compliance and flight performance optimization. The existence of the VNAV sub-modes (i.e., VNAV SPD, VNAV PTH, and VNAV ALT), however, has often been confusing to the flight crew and the mode transition logic between these sub-modes is very complex. A previous survey has shown that VNAV is considered to be “the most disliked feature of automated cockpit systems” by many pilots. The MHP method presented in this paper reduces the occurrence of VNAV mode confusion by predicting aircraft trajectory and mode transitions with multiple hypotheses and alerting the flight crew of the hazardous situations when necessary. Violation of a waypoint altitude restriction is used as the example to evaluate the effectiveness of the MHP method, and both simulation and Human-In-The-Loop (HITL) study results show that this method increases the mode awareness of VNAV considerably and reduces the possibility of a potential waypoint altitude violation.

9.0302 Sampling-based Collision Avoidance for Commercial Airliners with Intruder Aircraft and Terrain

William Van Den Aardweg (Stellenbosch university), Jacobus Engelbrecht (Stellenbosch University), Corné Van Daalen (Stellenbosch University),
Presentation: William Van Den Aardweg, Sunday, March 8th, 04:55 PM, Elbow 1

This paper presents a robust, sampling-based path- planning algorithm for commercial airliners that simultaneously performs collision avoidance for both aircraft and terrain. The current resolution systems implemented on commercial airliners are effective and efficient, but have certain limitations; the algorithm proposed in this paper attempts to rectify some of these. Recent advances in automatic dependent surveillance-broadcast (ADS-B) and GPS technology provides the information required to resolve complex conflict scenarios that simultaneously involve multiple intruder aircraft and terrain. The proposed algorithm applies an incremental sampling-based technique to determine a safe path quickly and reliably. As the number of samples increase, the algorithm strives towards an optimal solution; this results in a safe, near-optimal path that avoids the conflict region. Simulation results show that the proposed algorithm is able to successfully resolve various conflict scenarios, including the generic two aircraft scenario, terrain only scenario and a multiple aircraft with terrain scenario. A statistical analysis of the simulation results shows that the algorithm finds near- optimal paths quickly and reliably.

9.0305 Dynamics and Control of the Hose Whipping Phenomenon in Aerial Refueling

Haitao Wang (Air Force Engineering University),
Presentation: Haitao Wang, Sunday, March 8th, 05:20 PM, Elbow 1

Dynamic modeling of a hose-drogue aerial refueling system, derivation of a new set equations of motion of the time- varying inertia receiver, and a command filtered backstepping- sliding mode controller design for the hose whipping phenomenon during coupling are studied. To analyze dynamics of the hose whipping phenomenon, a dynamic model of the variable-length hose-drogue assembly is built with the hose restoring force due to bending. The hose is modeled by a sequence of variable-length links connected with frictionless joints. A set of iterative equations of motion of the hose is derived subject to hose reeling in/out, tanker motion, hose restoring force due to bending, gravity, and aerodynamic loads. Based on a fixed weight aircraft, a set equations of motion of the time-varying inertia receiver is derived. Then, an active control strategy based on the permanent magnet synchronous motor angular control for the hose whipping phenomenon is proposed. Command Filtered Backstepping is used to eliminate the analytic computation of command derivatives, and exponential sliding mode reaching laws of d/q axis current error are applied to enhance convergence speed, control accuracy, and robustness. Finally, dynamics of the hose whipping phenomenon and effectiveness of the control laws are analyzed by simulations.

9.0306 Different Approaches of Actuator Placement for Active Vibration Control in the Aircraft Engine

Xiaonan Zhao (TECHNISCHE UNIVERSITÄT DARMSTADT),
Presentation: Xiaonan Zhao, Monday, March 9th, 09:00 PM, Amphitheatre

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9.0307 An Adaptive Middleware Approach for Fault-tolerant Avionic Systems

Oliver Marquardt (University of Stuttgart),
Presentation: Oliver Marquardt, Monday, March 9th, 09:25 PM, Amphitheatre

Intricate system functionality, the tight dependency between different system functions and the consideration of non-functional aspects are attributes, characterizing complex avionic systems. The distributed nature of many of these avionic systems is hidden by the system architecture, containing a middleware which abstracts the communication and the system management. For the middleware in complex avionic systems the configuration knowledge comprises a great number of parameters. Additionally, these systems are faced with the increasing demand for more flexibility and modifiability - systems should be adaptive. To manage these systems reasonably, adaptive mechanisms have to replace the still common manual configuration and parameterization of the middleware. Therefore the middleware design needs to be rethought, enabling autonomous adaption during the initial middleware configuration. Here, an adaptive middleware approach which aims to push future avionics systems further towards adaptivity is outlined. Presented is a procedure how unconfigured modules are transferred to a fault-tolerant avionic system, autonomously. Especially the adaptation of the communication middleware is of interest.

9.04 Air Vehicle Flight Controls

Session Organizer: Tom Mc Ateer (NAVAIR), Thomas Post (AVIAN LLC)

9.0402 Utilization of Differential Thrust for Directional Stability with a Damaged Vertical Stabilizer

Kamran Turkoglu (San Jose State University), Long Lu (San Jose State University),
Presentation: Kamran Turkoglu, Thursday, March 12th, 08:25 PM, Lake/Canyon

This paper studies the utilization of differential thrust to help a commercial aircraft with a damaged vertical stabilizer regain its lateral/directional stability. The vertical stabilizer is the key aerodynamic surface that provides an aircraft with its directional stability characteristic while the ailerons and rudder are the primary control surfaces that give the pilots the control authority of the yawing and banking maneuvers. In the event of an aircraft losing its entire vertical stabilizer, the consequential loss of the lateral/directional stability and control is likely to cause a fatal crash. In this paper, lateral/directional equations of motion are revisited to incorporate differential thrust as a control input. The engine dynamics of the jet aircraft is modeled as a system of differential equations with engine time constant and time delay terms to study the engine response time with respect to a differential thrust input. The novel differential thrust control module is then presented to map rudder input to differential thrust input. The investigation of the aircraft's open loop system response is also presented. Finally, model reference adaptive control based on the Lyapunov stability approach is implemented to test the ability of the damaged aircraft to track the undamaged aircraft's (reference) response in an extreme scenario.

9.0404 Design and Development of an Air Supply Unit for Circulation Control Wing-Based UAVs

Konstantinos Kanistras (University of Denver), Pranith Chander Saka (University of Denver), Matthew Rutherford , Nikolaos Vitzilaios (University of Denver), Kimon Valavanis (University of Denver),
Presentation: Konstantinos Kanistras, Thursday, March 12th, 08:50 PM, Lake/Canyon

The main contribution of this paper is the design, development and evaluation of a light-weight Air Supply Unit (ASU) and its associated speed controller, suitable for use in Circulation Control Wings (CCW) of small scale Unmanned Aerial Vehicles (UAVs). An iterative process, presented here, is used to optimize the design of the centrifugal compressor for the ASU through extensive simulation. The implemented speed controller provides the necessary mass flow rate on-demand by maintaining a fixed velocity ratio thereby reducing the power penalties associated with operating the ASU continuously.

9.0405 Multi-rotor with Suspended Load: System Dynamics and Control Toolbox

Jan Trachte (University of Stuttgart), Luis Gonzalez (Queensland University of Technology), Aaron Mcfadyen (Queensland University of Technology),
Presentation: Luis Gonzalez, Thursday, March 12th, 09:15 PM, Lake/Canyon

A Nonlinear Model Predictive Control (NMPC) for safe and precise operation of multi-rotors with heavy slung load in three dimensions is presented. The paper describes a System Dynamics and Control Simulation Toolbox for use with MATLAB/SIMULINK which includes a detailed simulation of a multi-rotor with slung load as well as the pre-

dictive controller to manage the nonlinear dynamics whilst accounting for system constraints. It is demonstrated that the controller simultaneously tracks specified waypoints and actively damps large slung load oscillations. A linear-quadratic regulator (LQR) is derived and control performance is compared. Results show the improved performance of the predictive controller for a larger flight envelope, including aggressive manoeuvres and large slung load displacements. The computational cost remains relatively small, amenable to practical implementations.

9.05 Guidance Strategies in Presence of Wind

Session Organizer: Kamran Turkoglu (San Jose State University),

9.0501 Virtual Structure UAV Formations Using Wind-Compensation and Generalized Velocity Obstacles

Jeffrey Barton (Johns Hopkins University), Cammy Peterson ,
Presentation: Cammy Peterson, Friday, March 13th, 08:30 AM, Lake/Canyon

This paper describes two algorithms that can be utilized in tandem to direct a group of cooperating vehicles into time-varying formations using virtual structures as reference trajectories. The first algorithm is a command generation method to achieve high-precision position control in the presence of wind, and the second algorithm provides flight command overrides to avoid collisions. The command generation algorithm, which was verified in UAV flight demonstrations, is a wind-compensating flight control method wherein roll and airspeed commands are generated to steer each UAV toward a future position within the virtual structure. This algorithm provides a geometrically exact solution to achieve a desired location in the future in the presence of a spatially-uniform, time-invariant wind. In flight demonstrations, four vehicles were shown to achieve tight virtual structure formations despite the presence of significant winds. The second algorithm, demonstrated using a numerical simulation, provides active collision avoidance between members of the virtual structure using flight command overrides based on generalized velocity obstacles.

9.0503 Flow Sensing, Estimation and Feedback Control for Rotorcraft Landing in Ground Effect

Chin Gian Hooi , Francis Lagor (University of Maryland), Derek Paley (University of Maryland),
Presentation: Chin Gian Hooi, Friday, March 13th, 08:55 AM, Lake/Canyon

This paper describes a dynamic controller for rotorcraft landing and hovering in ground effect using feedback control based on flowfield estimation. The rotor downwash in ground effect is represented using a potential flow model selected for real-time use. A nonlinear dynamic model of the rotorcraft in ground effect is presented with open-loop analysis and closed-loop control simulation. Flowfield velocity measurements are assimilated into a grid-based recursive Bayesian filter to estimate height above ground. Height tracking in ground effect and landing are implemented with a dynamic linear controller. The overall framework is applicable for rotorcraft operation in ground effect and landing.

TRACK 10: SOFTWARE AND COMPUTING

Track Organizers: Jeff Norris (NASA Jet Propulsion Laboratory), Sanda Mandutianu (Jet Propulsion Laboratory)

10.01 Computational Modeling

Session Organizer: Virgil Adumitroaie (Jet Propulsion Laboratory), Darrell Terry (The Mitre Corporation),

10.0101 Rapid Calculation of Missile Aerodynamic Coefficients Using Artificial Neural Networks

Steven Ritz (Simulations Plus, Inc.), Jeffrey Dahlen (Simulations Plus, Inc.), Roy Hartfield (Auburn University), John Burkhalter (Auburn University), Walter Woltosz (Simulations Plus, Inc.),

Presentation: Steven Ritz, Sunday, March 8th, 04:30 PM, Madison

Determining aerodynamic coefficients for a range of prospective missiles during preliminary design is a numerically intensive computation, when considering multiple design variables at multiple flight Mach numbers and angles of attack. The use of computational fluid dynamics (CFD) can usually lead to accurate solutions that characterize the flow around a missile in flight. However, when many designs need to be considered, CFD calculations can be computationally costly and inefficient. This has led to the development of various estimation methods that can produce results more rapidly than a full CFD calculation. One such program, AERODSN, has been utilized successfully in a range of optimization programs. These approaches are substantially faster than CFD calculations and provide reasonably accurate results for missiles over a wide range of Mach numbers and configurations. However, they are created based on a variety of approximations and data-fitting algorithms pieced together to cover the required data ranges. Such results can be enhanced through the use of surrogate modeling techniques that utilize high-fidelity data. The approach investigated in this study has given promising results through work with ensembles of artificial neural networks (ANNEs). The results obtained in this study show this method can be viable for an iterative and rapid design of missile systems. Once fully trained, each of the models for the corresponding flow regimes was able to predict aerodynamic coefficients with high accuracy (Q2>.99) and extremely fast computational times.

10.0102 Collision Detection of Two Fast Moving Objects

Sang Yang , Kristin Wortman (Johns Hopkins University/Applied Physics Laboratory),

Presentation: Sang Yang, Sunday, March 8th, 04:55 PM, Madison

To model status of collision of two fast moving objects in the field of space science and computer aided geometric design, one approach is to perform high-precision orbit and forward propagations, compare the distance between the objects at closely spaced instants of time to determine the moment of closest approach, and compute the minimum distance. Mathematical and physical formulation of two fast moving objects is the corresponding position covariance ellipsoids. Assuming fast moving object's positional uncertainty is along its moving direction and three principal axes of covariance ellipsoid are mutually orthogonal, a physics based simulation was developed to detect three different stages of the two objects collision. To detect status of collision, a new analytical method is used to compute eigenvalues and compare the analytical solution with well-known numerical computation approach. This analytical approach shows that if the characteristic equation has at least two negative real solutions, the ellipsoids are separated. If ellipsoids share a common point, or touch one another, the characteristic equation has a positive double real solution and discriminant of the quadratic equations is zero. Two or more complex eigenvalues are obtained when complete penetration of one ellipsoid by another. Eigenvalues prescreening method is used to reduce comput-

ing time and detect collision of two fast moving objects. The symbolic manipulation tool provides the capability to prescreen results and solves a system of four simultaneous non-linear equations. The prescreening methodology, in conjunction with the analytical approach, provides the detection of collision tool for the fast moving objects.

10.0103 Characteristics Boundary Conditions to Treat Adjoint Block Interfaces

Nidhi Sikarwar (Penn State University),
Presentation: Nidhi Sikarwar, Sunday, March 8th, 05:20 PM, Madison

This paper presents a methodology to deal with complex geometries when using adjoint-based optimization technique. In a multi block approach complex geometries are meshed in a fashion such that the whole domain is divided in multiple blocks and each simple block is considered independently. An issue at the block boundaries arises when the communication of the information at the interfaces of these blocks is considered. A method is provided here to ensure correct communication based on the direction of the propagation of information. The direction of propagation of information and the required treatment at these interfaces is determined based on the characteristics of the flow and adjoint field. Adjoint boundary conditions for the treatment of multi-block grids for complex geometries are developed. Two examples are given where there are grid singularities in the domain and characteristics-based boundary conditions have been used to rectify the numerical errors that could arise due to these grid singularities.

10.0104 Near Real-time Characterization of Unknown Missiles in Flight Using Computational Intelligence

Steven Ritz (Simulations Plus, Inc.), Jeffrey Dahlen (Simulations Plus, Inc.), Roy Hartfield (Auburn University), John Burkhalter (Auburn University), Walter Woltosz (Simulations Plus, Inc.),
Presentation: Steven Ritz, Sunday, March 8th, 09:00 PM, Madison

This paper focuses on the rapid characterization and identification of missiles of both known and unknown types early in their trajectories. Many physical relationships in the field of aerospace can be used to create computational models to calculate characteristics of an aerodynamic system. In such cases, the models created are generally more computationally intensive for problems of higher complexity. For example, computational fluid dynamics (CFD) yields high-fidelity solutions at the expense of long computation times. In a missile defense scenario, computations must be performed much more rapidly than CFD while maintaining a high level of accuracy. In the event that an adversarial missile system of an unknown type is launched, there is an even greater need for rapid characterization. The computational cost of training for computational intelligence methods can reduce the calculation time per new solution to the order of milliseconds, enabling near real-time applications. In this study, an artificial neural network ensemble method was used to accurately predict the diameter of missiles based on critical points of their ballistic trajectories. The results show that it is feasible to determine geometric parameters, such as missile diameter, based on sparse telemetry data while a missile is still in flight. We expect that additional independent models can be trained for fineness ratio and other geometric measures. With further enhancement, this methodology could serve as an additional input to current missile defense algorithms, and is particularly well-suited as a supplementary process for characterizing previously unknown missiles.

10.0105 Coupled Analysis of Film-Cooling and Infrared Characteristics of a Vectored Axis-symmetric Nozzle

Xuyi Chen (Sun Yat-sen University), Xiaoying Zhang (South China University of Technology),
Presentation: Xuyi Chen, Sunday, March 8th, 09:25 PM, Madison

The film-cooling and infrared radiation analysis of a high-performance aero-engine nozzle wall is the key problem in developing a vector propulsion technology. In this work, a simulation program is developed, and the expansion part of an experimental nozzle in NASA TN D-1988 is investigated for verification. Another vectoring nozzle with a multi-row of film cooling is also investigated. Results of temperature distribution under deflection and non-deflection conditions are presented, as well as the infrared radiation observed from the rear hemisphere of the nozzle outlet. This study shows that the film in the heat shield remarkably cools the convergent part of the nozzle, thereby increase the temperature on the expansion part of the nozzle. The deflection of the nozzle can change the distribution of the wall temperature and the radiation on the expansion part, which is lower on the deflection side than on the opposite side. The radiation from the nozzle outlet is high, particularly along the deflection direction in the rear hemisphere.

10.0106 Numerical Analysis and Optimization of Different Ventilation Systems for Commercial Aircraft Cabins

Ahmed Farag , Essam E. Khalil (Cairo University, Faculty of Engineering),
Presentation: Walid Attia, Sunday, March 8th, 09:50 PM, Madison

The ventilation systems in commercial aircraft cabins are important for providing a healthy and comfortable environment for the passengers and crew. The high density and close proximity of passengers in the modern aircraft cabin exposes them to the risk of contracting airborne diseases such as flu, severe acute respiratory syndrome (SARS), chickenpox and tuberculosis. Current aircraft personalized ventilation (PV) systems still cannot ensure a constant circulation of fresh humidified air around each passenger’s breathing zone to shield them from airborne contaminants. The components of the framework consists of the age of air, predicted mean vote (PMV), predicted percentile dissatisfied (PPD), draught risk (PD), contaminant aerosol transport model and a humidity model. Three case studies using novel PV designs have been assessed based on the analysis. The objective of the present investigation is to study the potential for both the under-floor displacement and personalized ventilation systems to improve air quality in the aircraft cabin of the economy section of a Boeing 767 airplane during cruise, and how to reach to the optimum design to protect passengers from pollution air if it happened inside cabin. The CFD modelling techniques using ANSYS FLUENT 15 package solved the continuity, momentum, energy, and species transport equations in addition to k-ε model equations for turbulence closure. The SIMPLEC algorithm is used for the pressure-velocity coupling and a second order upwind scheme was used for discretization of the governing equations. Mesh sizes used in the present work exceeded 8,000,000 mesh volumes in one case.

10.0107 Aero-Thermodynamic Analysis of Space Shuttle Vehicle at Re-Entry

Swapnil Jagtap (Georgia Institute of Technology),
Presentation: Swapnil Jagtap, Monday, March 9th, 08:30 AM, Madison

Since the last two decades, aerospace agencies around the world have started planning Space-based Solar Power Systems (SSPS) as an alternative power source. The use of Space Shuttle Orbiter type re-usable launch vehicles will enable the completion of this project in a limited time span with economic feasibility. This would leave less time between successive launches, making it imperative that the aero-thermodynamic analysis of these vehicles be fast and accurate. Currently, aero-thermodynamic analysis is done by high fidelity Computational Fluid Dynamics (CFD) solvers which are accurate but take significantly more time to give necessary results. Therefore, the present CFD solvers might not be useful tools for this mission to be completed in limited time. In this work a low cost, quick and reasonably accurate model is developed when compared with the results from the CFD solver of ‘Air Force Research Lab, Wright-Patterson’. Pressure coefficients and surface temperatures from this code are compared with results from the

CFD solver mentioned above. The model developed in this work is based on hypersonic theories which meet the requirements of this mission.

10.0108 Simulation for Risk Assessment of Diode Single Event Burnout

Jesse Theiss (The Aerospace Corporation), Bob Moision (The Aerospace Corporation), Brendan Foran (The Aerospace Corporation), Brent Morgan (The Aerospace Corporation),

Presentation: Jesse Theiss, Monday, March 9th, 08:55 AM, Madison

High voltage Schottky diodes used in DC-to-DC converters are susceptible to radiation single event burnout (SEB), posing a concern for use in space components. Prior to recent reports, diode SEB had not been considered a risk to space programs despite the phenomenon having been studied in high power terrestrial PN diodes in the 1990s. Schottky diodes have been engineered to prevent premature breakdown under high reverse bias voltage. Graded passivation structures, p+ doped guard rings, and metallization field plates with thick field oxide help to mitigate failures due to high electric fields resulting from edge effects at the contact electrode. Recent radiation strike data indicate a tendency of failure along the guard ring structure under heavy ion bombardment, where an effective drop in failure rate of two orders of magnitude has been observed after protective masking of the diode edge. Due to the lack of comprehensive test data and understanding of the exact physics of failure, SEB in Schottky diodes has an uncertain impact on reliability. Existing derating guidelines may already be sufficient to mitigate this failure but with an uncertain margin that could further depend on the diode type, design, and implementation. We investigate the observed preferential SEB through physics-based computer modeling using Silvaco TCAD. We perform transient electro-thermal simulations on three-dimensional structures derived from destructive physical analysis (DPA) of failed diodes and failure sites. This effort should better the understanding of the risk of diode SEB by coupling numerical modeling with direct observations of failure.

10.0110 Reynolds Stress on SWBLI in Isolator Using Different Turbulent Models

Jinfeng Dang (Harbin Engineering University),

Presentation: Jinfeng Dang, Monday, March 9th, 09:20 AM, Madison

Shock wave/boundary layer interactions (SWBLI) is an unavoidable problem in supersonic and hypersonic flow. The inherent defects caused by Reynolds-averaged method make the RANS (Reynolds-averaged Navier-Stokes) turbulent models unable to reveal the impact of small-scale recirculation zone on shock wave. Meanwhile, the LES (Large Eddy Simulation) turbulent model is still unaffordable for engineering since a huge amount of calculation. Therefore, the DES (Detached Eddy Simulation) turbulent model is a more economical choice. In this paper, the study of Reynolds stress on SWBLI in isolator is conducted using four different commonly used RANS turbulent models. The results could be used as a guide to choosing the RANS in the core flow of the DES model. It was found that, in the boundary layer, the normal Reynolds Stress is usually under predicted and the shear Reynolds Stress is over predicted. The maximum difference was more than 50%. Averaged velocity in y direction was far more over predicted, and the maximum difference was about 500%. In the main flow area, the SST model and the Standard k-ε model were more accurate. Analysis suggests that shear Reynolds stress difference caused its difference in averaged velocity, especially velocity in the y direction. Comparing the four turbulent models simulation results, it was suggested that, in the main flow, the SST model had enough accuracy in Reynolds averaged velocity, Reynolds stress and the shock wave intermittent resolution. It is most suitable main flow area turbulent model in the DES model.

10.0111 Reducing Runtime for Monte Carlo Estimates to Partial Differential Equations

Matthew Ward (NAVSEA),
Presentation: Matthew Ward, Monday, March 9th, 09:45 AM, Madison

This paper discusses multiple methods available for reducing the run time for Monte Carlo estimates to Partial Differential Equations (PDEs). PDEs appear extensively in mathematical modeling across the sciences, but they are often very difficult to solve analytically. Monte Carlo approaches provide a robust approach for generating estimates for the solutions of PDEs by simulating many random walks that travel through the domain of the specific problem. These random walks can be performed using a discrete time Markov Chain transition matrix. Two specific properties of Markov Chains can then be used to reduce the computation time, namely raising the matrix to a higher power and the independence of the random walk. When combined with parallel processing, dramatic reductions in runtime for a simulation can be achieved. This paper uses the 2D Laplace equation on a square domain as an example problem and implements all three of the techniques to reduce the computation time by a factor of nearly 150. The techniques described can be applied to other PDEs and allow researchers to either obtain results faster than the baseline, or achieve a higher accuracy in a given amount of time.

10.02 Software Engineering

Session Organizer: Kristin Wortman (Johns Hopkins University/Applied Physics Laboratory)

10.0201 Contrasting Factors for Reuse Success and Failure in Aerospace: Semistructured Interviews

Julia Varnell Sarjeant (University of Denver), Anneliese Andrews (University of Denver),
Presentation: Julia Varnell Sarjeant, Monday, March 9th, 04:30 PM, Madison

We present the results of a set of semistructured interviews of experts in aerospace companies. These experts were asked about reuse practices, successes and failures, and the reasons why these happened. We were particularly interested in learning about differences and similarities in reuse approaches for embedded vs. nonembedded systems. In addition, since modern development approaches enable reuse of a wide variety of artifacts, we wanted to know whether artifact reuse was different between embedded and nonembedded systems and whether the experts thought certain development strategies worked better for one type of system than another, and why. Experts were from a variety of corporate cultures. Results indicate that there are important differences. For example, component reuse is more common with embedded systems experts, whereas architecture reuse is more common among nonembedded systems experts. Unlike nonembedded systems experts, embedded systems experts preferred platform standardization over platform independence. Embedded systems experts prefer to use code already developed for the platform intact due to the difficulty of modifying optimized code.

10.0202 Visualization of a Spacecraft Mission Software System

Kristin Wortman (Johns Hopkins University/Applied Physics Laboratory),
Presentation: Kristin Wortman, Monday, March 9th, 04:55 PM, Madison

A Spacecraft Mission Software System (SMSS) consists of both ground and flight software working cohesively to perform failure-free and reliable spacecraft operations in order to meet critical NASA or Department of Defense mission objectives. Visualization of all inter-dependencies of system components provides a means for assessment and detection of problems that can lead to a potential failure of the SMSS. When a spacecraft operation anomaly does occur, a quick assessment and isolation of the problem (software or hardware) and its impact on the mission are necessary to form a strategy to keep the spacecraft safe and to meet mission objectives. An interactive approach to drill down the visualization of spacecraft operations to the subsystem and component level yields an efficient way to determine the root cause. The visualization of the spacecraft operations can determine if the root cause is due to an actual failure in the flight or ground software system, or if the root cause is related to a system-level component contributing to a software failure. Discussion will center around the layered visualization design implemented in the System Insight software developed by the Embedded Applications Group at the Johns Hopkins University Applied Physics Laboratory. Elaboration on the Van Allen Probes SMSS will be presented along with examples of how System Insight can be used by software engineers and mission operators to visually identify functional problems in the SMSS.

10.0203 Model-based Product Line Engineering - Enabling Product Families with Variants

James Hummell (PTC), Matthew Hause (Atego),
Presentation: James Hummell, Monday, March 9th, 09:00 PM, Madison

Product Lines are a group of related products manufactured or produced by a single organization. To effectively manage a product line, one needs to understand both the similarities and differences between the different products and optimize the development lifecycle to leverage the similarities, and concentrate development on the differences. ISO 26550:2013 Software & Systems Engineering – Reference Model for Product Line Management & Engineering provides a standard for defining these similarities and differences as well as the choices between them. Model-Based Systems and Software Engineering (MBSE) using the Systems Modeling Language (SysML) and the Unified Modeling Language (UML) provide a means of modeling systems and software. Bringing the two together allows users to model product lines in industry standard formats. Combining these with an execution engine means that product models can be created for specific products, whilst maintaining the original product line model. This provides significant ROI for aerospace related products.

10.0204 Testing Proper Mitigation in Safet-Critical Systems: An Aerospace Launch Application

Anneliese Andrews (University of Denver), Salwa Elakeili (University of Denver), Seana Hagerman (University of Denver), Ahmed Gario (University of Denver),
Presentation: Anneliese Andrews, Monday, March 9th, 09:25 PM, Madison

This paper presents a method to test proper failure mitigation in safety-critical systems. It uses a behavioral test suite, applies failures, and creates a mitigation test suite by weaving required mitigation steps at selected points of failure into the test suite. Testing criteria are also presented.The approach is illustrated using an aerospace launch vehicle.

10.0205 Collaborative Pentesting and Analysis Toolkit (CPAT)

Ihssan Alkadi (Southeastern Louisiana University), Jason Guidry (Performance Contractors, Inc.), Darrien Rushing ,
Presentation: Darrien Rushing, Monday, March 9th, 09:50 PM, Madison

This presentation describes a software project surrounding network penetration testing and the problems associated with team-based efforts utilizing present network analysis tools and technologies. Often each responsibility that needs to be taken care of during network analysis requires several tools. Each of these tools produces a report containing data and results which then can be saved to a file on the analyst’s computer. The nature of these individual reports gives rise to a problem once several reports have been created. Though the large number of reports to review may only pose a minor inconvenience to the analyst running the tools and creating the reports, the magnitude of the issue compounds once multiple people need to review all reported data. This is a major concern since the data needs to be reviewed to determine what is applicable to the penetration test. The issue could again be exacerbated if the target has a large area of vulnerability. This is the problem this software project intends to remediate. By utilizing a web framework which synchronizes data between the client and the server in real time, we will be able to implement a system that organizes data given by a few prominent tools and allows for multiple users to simultaneously collaborate on a network penetration test while ensuring the security of all collected data. The extremely limited availability of a similar solution on the market well justifies the necessity of such a system. The software project will be further explained during the presentation.

10.03 Software Architecture and Design

Session Organizer: Sanda Mandutianu (Jet Propulsion Laboratory), Charles Lee (ASML),

10.0301 Security Testing of an Aerospace Launch System

Seana Hagerman (University of Denver), Anneliese Andrews (University of Denver), Salwa Elakeili (University of Denver), Ahmed Gario (University of Denver),

Presentation: Seana Hagerman, Monday, March 9th, 10:10 AM, Madison

Many aerospace vehicles are vulnerable to security attacks that not only can cause loss of the vehicle, but also loss of life or compromise national security. This paper proposes an approach for security testing an aerospace launch system. Our approach is based on building a security test suite from a behavioral model, an attack type and a mitigation model. The behavioral and attack model determine where specific attacks can occur. We then build the security test based on a required mitigation from the mitigation model.

10.0303 Utilizing Artificial Intelligence for Achieving a Robust Architecture for Future Robotic Spacecraft

Steffen Jaekel (German Aerospace Center - DLR), Bastian Scholz ,

Presentation: Steffen Jaekel, Monday, March 9th, 10:35 AM, Madison

This paper presents a novel failure-tolerant architecture for future robotic spacecraft. It is based on the Time and Space Partitioning (TSP) principle as well as a combination of Artificial Intelligence (AI) and traditional concepts for system failure detection, isolation and recovery (FDIR). Combining, and partly replacing traditional methods with flexible AI approaches aims to yield a control environment that features increased robustness, safety and reliability for space robots. The developed architecture is based on a modular on-board operational framework that features deterministic partition scheduling, an OS abstraction layer and a middleware for standardized inter-component and external communication. The supervisor (SUV) concept is utilized for exception and health management as well as deterministic system control and error management. In addition, a Kohonen self-organizing map (SOM) approach was implemented yielding a real-time robot sensor confidence analysis and failure detection. The SOM features non-supervized training given a typical set of defined world states. By compiling a set of reviewable three-dimensional maps, alternative strategies in case of a failure can be found, increasing operational robustness. As demonstrator, a satellite simulator was set up featuring a client satellite that is to be captured by a servicing satellite with a 7-DoF dexterous manipulator. The avionics and robot control was integrated on an embedded, space-qualified Airbus e.Cube on-board computer. The experiments showed that the integration of SOM for robot failure detection successfully allows complementing the capabilities of traditional FDIR methods.

10.04 Model-based Systems and Software Engineering

Session Organizer: Alexander Murray (Jet Propulsion Laboratory)

10.0401 The Use of UML for Software Requirements Expression and Management

Alexander Murray (Jet Propulsion Laboratory), Ken Clark (Jet Propulsion Laboratory),
Presentation: Alexander Murray, Thursday, March 12th, 04:30 PM, Lamar/Gibbon

It is common practice to write English-language "shall" statements to embody detailed software requirements in aerospace software applications. This paper explores the use of the UML language as a replacement for the English language for this purpose. Among the advantages offered by the Unified Modeling Language (UML) is a high degree of clarity and precision in the expression of domain concepts as well as architecture and design. Can this quality of UML be exploited for the definition of software requirements? While expressing logical behavior, interface characteristics, timeliness constraints, and other constraints on software using UML is commonly done and relatively straight-forward, achieving the additional aspects of the expression and management of software requirements that stakeholders expect, especially traceability, is far less so. These other characteristics, concerned with auditing and quality control, include the ability to trace a requirement to a parent requirement (which may well be an English "shall" statement), to trace a requirement to verification activities or scenarios which verify that requirement, and to trace a requirement to elements of the software design which implement that requirement. Our approach uses the Stereotype construct of UML to precisely identify elements of UML constructs, especially behaviors such as State Machines and Activities, as requirements, and also to achieve the necessary mapping capabilities. We describe this approach in the context of a space-based software application currently under development at the Jet Propulsion Laboratory.

10.0402 Developing a CubeSat Model-Based System Engineering (MBSE) Reference Model – Interim Status

David Kaslow , Louise Anderson (JPL), Sharanabasaweshwara Asundi (Tuskegee University), Bradley Ayres , Curtis Iwata (The Aerospace Corporation), Bungo Shiotani (University of Florida), Robert Thompson (US Air Force),
Presentation: David Kaslow, Thursday, March 12th, 04:55 PM, Lamar/Gibbon

Model-Based Systems Engineering (MBSE) is a key practice to advance systems engineering that can benefit CubeSat missions. MBSE creates a system model that helps integrate other discipline specific engineering models and simulations. The system level model is initiated at the start of a project and evolves throughout development. It provides a cohesive and consistent source of system requirements, design, analysis, and verification. The International Council on Systems Engineering (INCOSE) Space Systems Working Group (SSWG) established the Space Systems MBSE Challenge team in 2007. The SSWG Challenge team has been investigating the applicability of MBSE for designing CubeSats since 2011. Our application of MBSE uses System Modeling Language (SysML), a graphical modeling language, to model all aspects of a system either directly or through an interface with another model. SysML diagrams are used to describe requirements, structures, behaviors, and parametrics from the system down to the component level. The current modeling effort and has two objectives: 1) Develop a CubeSat Reference Model that other projects can use as a starting point for their mission specific CubeSat model and 2) Develop a CubeSat Project Model that models how design and development are to be accomplished. The effort to date has been focused on establishing nomenclature; the incorporation of the stakeholders and their needs, objectives, measures of effectiveness; and the architecture down to the logical subsystems. The next step is to create models for the concept and development phases.

10.0403 Multipurpose Spacecraft Simulator for LADEE

Nathaniel Benz ,
Presentation: Nathaniel Benz, Thursday, March 12th, 05:20 PM, Lamar/Gibbon

The Lunar Atmosphere Dust Environment Explorer (LADEE) was a small explorer class spacecraft that was launched on Sept 7, 2013. After completing all of the mission objectives, LADEE was de-orbited and successfully impacted the moon's surface on April 17, 2014. In order to reduce costs and leverage previous research and development, a model-based multipurpose simulator was created of the LADEE spacecraft and its mission environment. The spacecraft simulator was designed to have sufficient fidelity that it could be used to test the required modes and responses of the onboard flight software. A faster-than-real-time Workstation SIMulator (WSIM) version of the LADEE simulator was used to develop and test the software control algorithms in the Simulink environment. The automatic code generation feature in Simulink was used to port the simulation to several real-time environments to support Processor-in-the-Loop (PIL) and Hardware-in-the-Loop (HIL) testing, verification and validation. Since the simulation interface was designed to be compatible with the command interface employed by the LADEE mission operation team, the WSIM, PIL and HIL simulators were used for both personnel training (nominal and off-nominal operations) prior to the mission and to perform command sequence verification during the mission. This approach resulted in time and budget savings, and allowed changes to the model to be quickly propagated through all the simulation target environments. The mode- based design approach also allows the simulation framework to be generalized and reused to model future spacecraft missions.

10.0404 Model Driven Language Framework to Automate Command and Data Handling Code Generation

Meenakshi Deshmukh (German Aerospace Center - DLR), Benjamin Weps (German Aerospace Center - DLR), Pedro Isidro (German Aerospace Center - DLR), Andreas Gerndt (German Aerospace Center),

Presentation: Benjamin Weps, Thursday, March 12th, 08:25 PM, Lamar/Gibbon

On-board computer software (OBSW) is an integral part of every space mission. It has been continuously growing in size and complexity. The insufficient level of automation in the development process of such software leads to low software re-usability and drives up the costs. This paper presents a generic approach to describe and model the on-board software in terms of data that is processed by it. Domain Specific Language (DSL) based framework is developed using which provides a DSL editor, a model validator, and a code generator. Using the framework, a system data model is created. The C++ code is generated from it which is then customized to implement low-level behavior. As a proof of concept, the telecommand handling functionality of OBSW is developed to prove the feasibility of applying the solution to the whole system. Based on the analysis conducted on the source code of the TET-1 satellite of the German Aerospace Center (DLR), a DSL is designed and implemented. The resulting DSL-based framework is tested with an example model and target code customization, showing its ease of use and proving that it behaves as expected.

10.0405 A Model-Driven Approach for the Development of an IDE for Spacecraft On-Board Software

Luigi Pomante (Università degli Studi del'Aquila), Emilio Incerto (Gran Sasso Science Institute (GSSI) Center of advanced studies L'Aquila), Sante Candia ,

Presentation: Luigi Pomante, Thursday, March 12th, 08:50 PM, Lamar/Gibbon

This paper presents the application of a Model-Driven Engineering (MDE) approach to the aerospace domain. Specifically, it shows the Model-Driven Development (MDD) of an Integrated Development Environment (IDE) for a Domain-Specific Language (DSL) targeted to the achievement of the so called “Spacecraft on-board software flexibility”. In fact, the goal of the presented work has been to deploy a full-featured IDE to be used as a complete development environment of the On-board Command Procedures (OBCP).

The OBCPs specification is done by using the “OBCP Definition Language” (ODL), specified by Thales Alenia Space Italy (TASI) on the basis of the requirements stated in the “Space Engineering: Spacecraft On-board Control Procedures” ECSS standard (ECSS-E-ST-70-01, 16 April 2010). By following such guidelines and by exploiting some MDE technologies and tools it has been possible to realize an Eclipse-based IDE able to provide to the ODL developer all the features essential in a modern environment for the development of software. Moreover, by means of the adopted MDE approach, a very large part of the IDE code has been automatically generated starting from the EBNF specification of the ODL grammar so allowing for the IDE developers to be more focused on the quality of product than on the coding activity. The obtained result is a professional product that satisfies all the expected requirements but this would be just a starting point since the final goal of this work is to contribute to fostering the adoption of MDE approaches in the spacecraft software domain.

10.0406 Model-based Spacecraft Fault Management Design & Formal Validation

Corrina Gibson (NASA Jet Propulsion Lab), Michael Bonnici (Jet Propulsion Laboratory), Jean Francois Castet (NASA Jet Propulsion Lab),

Presentation: Corrina Gibson, Thursday, March 12th, 09:15 PM, Lamar/Gibbon

Fault management system behavior design, verification, and formal validation were accomplished using model-based systems engineering tools. The process we developed is meant to be used throughout the entire project lifecycle and works with an integrated system model or as a stand-alone fault management model. We have demonstrated that when modeling fault protection system behaviors during the design phases of a project, the expected behavior can be verified early on by executing the model. Correctly capturing the expected behavior in the model improves the system design so that is better defined and complete upon implementation. Prior to transforming the model to flight code, it should be run through a model checker to formally validate the behavior model against properties of correctness (assertions). We use Java Pathfinder to check the model against assertions derived from requirements and the design description. The big challenges in model checking are to decide when you have adequate assertion coverage and to configure the model checker to search interesting areas of the model before state space explosion occurs.

10.05 Implementing Artificial Intelligence for Aerospace

Session Organizer: Jeremy Straub (University of North Dakota), Christopher Bridges (Surrey Space Centre),

10.0501 Unsupervised Anomaly Detection for Aircraft Condition Monitoring System

Mohamed Cherif Dani (Airbus),

Presentation: Mohamed Cherif Dani, Thursday, March 12th, 08:30 AM, Lake/Canyon

Anomaly detection is an important field for the anticipation of aircraft maintenance operations, working as an enabler of diagnostic and prognostic functions. A method has been implemented to detect abnormal data in Aircraft Condition Monitoring System (ACMS) records. Rather than using already known and usual detection triggers which are partial detectors and insensitive to new flight and system conditions,this method automatically extracts abnormal data points with-out requiring any a priori information about the system and its conditions. To accomplish this objective, we propose to combine a segmentation based and density clustering approaches for detecting and filtering anomalies. This method was applied onA340 ACMS data recordings. The detection logics associated with the new anomalies can be used as new detection conditionsto be potentially implemented on board, further extending legacy detection capabilities

10.0502 A Risk-Aware Architecture for Resilient Spacecraft Operations

Catharine Mc Ghan (California Institute of Technology), Richard Murray (California Institute of Technology), Romain Serra (CNRS), Michel Ingham (Jet Propulsion Laboratory), Masahiro Ono (JPL), Tara Estlin (NASA Jet Propulsion Laboratory), Brian Williams (MIT),

Presentation: Catharine Mc Ghan, Thursday, March 12th, 08:55 AM, Lake/Canyon

In this paper we discuss a resilient, risk-aware software architecture for onboard, real-time autonomous operations that is intended to robustly handle uncertainty in spacecraft behavior within hazardous and unconstrained environments, without unnecessarily increasing complexity. This architecture, the Resilient Spacecraft Executive (RSE), serves three main functions: (1) adapting to component failures to allow graceful degradation, (2) accommodating environments, science observations, and spacecraft capabilities that are not fully known in advance, and (3) making risk-aware decisions without waiting for slow ground-based reactions. This RSE is made up of four main parts: deliberative, habitual, and reflexive layers, and a state estimator that interfaces with all three. We use a risk-aware goal-directed executive within the deliberative layer to perform risk-informed planning, to satisfy the mission goals (specified by mission control) within the specified priorities and constraints. Other state-of-the-art algorithms to be integrated into the RSE include correct-by-construction control synthesis and model-based estimation and diagnosis. We demonstrate the feasibility of the architecture in a simple implementation of the RSE for a simulated Mars rover scenario.

10.0503 Swarm Intelligence, a Blackboard Architecture and Local Decision Making for Spacecraft Command

Jeremy Straub (University of North Dakota),

Presentation: Jeremy Straub, Thursday, March 12th, 09:20 AM, Lake/Canyon

Control of a multi-spacecraft constellation is a topic of significant inquiry, at present. Prior work has suggested that spacecraft can be combined to create synergistic outcomes. This is particularly true in the case of small spacecraft which can provide increased temporal coverage, at the expense of individual craft capabilities. This paper presents and evaluates a command architecture for a multi-spacecraft mission. It combines swarm techniques with a decentralized / local decision making architecture and demonstrates, via comparison to centralized and non-swarm approaches, the efficacy of this approach. Under this approach, the Blackboard software architecture is used to facilitate data sharing between craft as part of a resilient hierarchy and the swarm techniques are used to coordinate activity. This approach has two key benefits. First, the use of swarm techniques (specifically derivatives of the Intelligent Water Drops approach), reduces communications requirements for control. Second, it allows a constellation to continue operating for an extended period of time in a communications denied environment. The paper begins with an overview of prior work on the precursor command technologies. Then, it presents five command architectures for comparison purposes. Next, the paper presents a qualitative analysis of the strengths and weaknesses of these techniques. Then, a quantitative analysis is performed which characterizes the constellation's performance across multiple prospective scenarios including normal operations, several mission scenarios which limit communications, operations in an intentionally communications-denied environment and operations across a variety of craft failure scenarios. From performance analysis, the utility of the various techniques is analyzed.

10.0504 Planning Views to Model Planetary Pits under Transient Illumination

Heather Jones (Carnegie Mellon University), Wennie Tabib (Carnegie Mellon University), William Whittaker (Carnegie Mellon University),

Presentation: Heather Jones, Thursday, March 12th, 09:45 AM, Lake/Canyon

This paper addresses the problem of planning views for modeling large, local, substantially 3D terrain features at long range from surface rovers. These include building-size and stadium size pits with vertical walls. Pits have been identified in recent high-resolution images of the Moon and Mars. Planetary pits are interesting scientific targets created by collapse, often exposing layers of bare rock in their walls, hinting at past volcanism and other subsurface processes with their morphology. Some offer glimpses into caves. This paper presents a pipeline for view trajectory planning that enables detailed modeling of planetary pits from surface rovers. Techniques for converting prior terrain knowledge into a planning problem are developed, methods for planning rover images are discussed, and a comparison of different image-based reconstruction methods for pit modeling is presented. Results from preliminary field experiments for the end-to-end view trajectory planning pipeline are presented.

10.0505 Robust Fixed Interval Satellite Range Scheduling

Antonio Jose Vazquez Alvarez (University of New Mexico), Richard Erwin ,
Presentation: Antonio Jose Vazquez Alvarez, Thursday, March 12th, 10:10 AM, Lake/Canyon

The Satellite Range Scheduling problem has been solved in previous work by the authors. However, real scenarios may involve contingencies on the satellites, the ground stations or the communication link, which in practice can be translated as communication requests eventually being dropped from the schedule with a certain probability. Compared to existing suboptimal approaches which add back-up passes to a nominal schedule, robust scheduling finds the schedule with maximal expected performance. Robust schedules are not necessarily free of conflicts, conversely to optimal schedules, and thus finding the robust schedule poses increased complexity. The authors investigate the tractability bounds for the case where these requests have fixed start and end times, different priorities, and different failure probabilities, and provide a linear time algorithm for obtaining the robust schedule in scenarios with a single scheduling entity, laying the foundations for studying more complex cases.

10.0506 Noncooperative Satellite Range Scheduling with Perfect Information

Antonio Jose Vazquez Alvarez (University of New Mexico), Richard Erwin ,
Presentation: Antonio Jose Vazquez Alvarez, Thursday, March 12th, 10:35 AM, Lake/Canyon

The Satellite Range Scheduling problem has been traditionally approached in a centralized manner. Existing literature provides a wide variety of sub-optimal algorithms for allocating communication times between a list of satellites and a network of ground stations. The authors have provided an optimal solution for this problem in previous work. But regardless of the optimality, the application of a centralized solution in a distributed system raises the question: could a selfish party improve its schedule by unilaterally deviating from the precomputed centralized solution? Through a game theoretic approach where all the parties act selfishly, the authors show that the system converges to an Stackelberg equilibrium which can be computed in polynomial time for a fixed number of players. Results are illustrated via simple numerical example.

10.0507 An Overview of the OpenOrbiter Autonomous Operating Software

Dayln Limesand , Jeremy Straub (University of North Dakota), Ronald Marsh (University of North Dakota),
Presentation: Scott Kerlin, Thursday, March 12th, 11:00 AM, Lake/Canyon

The OpenOrbiter spacecraft aims to demonstrate the efficacy of the Open Prototype for Educational Nanosats (OPEN) framework. Software is an important part of this framework. This paper discusses the operating software for the spacecraft (which runs on top of the Linux operating system to command spacecraft operations). It presents an overview of this software and then pays particular attention to the aspects of software design that enable onboard autonomy. It also discusses the messaging scheme that is used onboard and the testing and validation plan. Finally, it discusses system extensibility, before concluding.

10.0508 Nanosatellite Scheduling Using a Dictionary Module and a Useful Trick with Integers

Monilito Castro (University of North Dakota), Jeremy Straub (University of North Dakota),
Presentation: Monilito Castro, Thursday, March 12th, 11:25 AM, Lake/Canyon

Schedulers for small spacecraft must satisfy the dual requirement of generating very efficient schedules while concurrently minimizing the resources required to create the schedule. This paper proposes a technique for searching for tasks that can be utilized to fill particular schedule locations. This approach is based on a modular system for storing important variables. This modular system has three important variables: t0, x0 and y0. The variable y is latitude and x is longitude. Time variable t is an integer and each unit represents a time quantum. They are related to each other by three functions Ft, Fx, and Fy. These functions are derived from a space time function where x0 and y0 are the normalized ground trace. These three variables can define a prospective instance of any task on an Earth-orbiting spacecraft. Similarly, this same approach could be used for planetary missions by making the ground trace references in relation to the local body. This approach is based on a 'useful trick' that can be performed with integers that facilitates the encoding of conditional statements using these three variables. This trick helps define the life cycle of a task. This approach can also, if needed, be expanded to allow the incorporation of other variables. This paper considers the limits of using integers in this way. It presents and considers several example problems and demonstrates the efficacy of using this algorithm to generate a solution.

10.06 Human-Systems Interaction

Session Organizer: Robin Wolff (German Aerospace Center - DLR), Jeff Norris (NASA Jet Propulsion Laboratory),

10.0601 Virtual Hand-Button Interaction in a Generic Virtual Reality Flight Simulator

Turgay Aslandere (German Aerospace Center - DLR), Daniel Dreyer (EADS Deutschland GmbH), Frieder Pankratz (Technische Universität München),
Presentation: Turgay Aslandere, Wednesday, March 11th, 04:30 PM, Lamar/Gibbon

In this talk, we give information about our virtual reality flight simulator and we introduce virtual hand-button interaction. We start our talk describing the methods and the algorithms to implement the virtual hand-button interaction. Afterwards, we examine the virtual hand-button interaction in the generic virtual reality flight simulator. To achieve this, we explain the user studies. Firstly, we show the effects of the virtual hand avatar and the buttons' collision volume. We demonstrate that a change in the collision volume within aircraft design limits does not have a significant impact on the interaction. Secondly, we demonstrate that the accuracy of the hand-button interaction depends on the hand avatar rather than the collision volume. At the end of the talk, we demonstrate that our finding with regard to the hand avatars contributes to the various virtual reality applications which exploit the virtual hand metaphor.

10.0602 FORROST: Advances in On-Orbit Robotic Technologies

Roberto Lampariello (German Aerospace Center - DLR), Jordi Artigas Esclusa (German Aerospace Center - DLR), Nassir Oumer (German Aerospace Center - DLR, Robotics and Mechatronics), Giorgio Panin , Wolfgang Rackl (German Aerospace Center - DLR), Ralf Purschke (Institute of Astronautics), Jan Harder (Technical University Munich), Ulrich Walter (Technical University Munich), Jürgen Frickel (Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU)), Ismar Masic (SpaceTech GmbH), Karthik Ravandoor (University of Wuerzburg), Julian Scharnagl (Universität Würzburg), Klaus Schilling (Univer-

sity Wuerzburg), Klaus Landzettel (DLR-RMC), Gerhard Hirzinger (DLR (German Aerospace Center)),
Presentation: Roberto Lampariello, Wednesday, March 11th, 04:55 PM, Lamar/Gibbon

Orbital robotics is receiving growing attention worldwide for applications in servicing and repositioning of partially or fully defective satellites. In this paper, we present the scope and main results of a four-year research project, which aimed at developing necessary robotic technologies for such applications. The scope is two-fold, since we address both the human-operated robotic operational mode, referred to in robotics as force-feedback teleoperation, as well as the alternative autonomous mode, for the specific task of approaching and grasping a free-tumbling target satellite. We present methodological developments and experimental as well as numerical validations in the fields of telecommunications, computer vision, robot and spacecraft control and system identification. The results of this work constitute important advances in the fundamental building blocks necessary for the orbital applications of interest.

10.0603 The Neural Basis of Decision-Making during Sensemaking: Implications for Human-System Interactions

Michael Howard (HRL Laboratories, LLC), Rajan Bhattacharyya (HRL Laboratories, LLC), Suhas Chelian (HRL Laboratories, LLC), Matthew Phillips , Praveen Pilly (HRL Laboratories, LLC), Yanlong Sun (Texas A&M University), Hongbin Wang , Matthias Ziegler (HRL Laboratories, LLCs),
Presentation: Michael Howard, Wednesday, March 11th, 05:20 PM, Lamar/Gibbon

We have created a high-fidelity model of 9 regions of the brain involved in making sense of complex and uncertain situations. The MINDS model (Mirroring Intelligence in a Neural Description of Sensemaking) was designed to reveal the neural principles and cognitive tradeoffs that explain weaknesses in human reasoning and decision-making. The challenge problems – geospatial reasoning for counter-insurgency operations – focus on aspects such as: selecting which type of available information to request next, deciding how much to review older information before making a decision, adapting probabilities over hypotheses as new information comes in, and spatial reasoning including configural or distance judgments. We will give a high level overview of how the human brain makes sense of the world, and describe how our model simulates this. We will briefly describe five studies on different aspects of the sensemaking process, each with a high-level background in the neurobiological justification for our mechanistic explanations, and comparison with the results of a pool of human subjects. Our model is distinguished not only by simulating individual brain regions in depth, but also by detailing their interactions. Cognitive biases in decision-making emerge from both. We will conclude with implications for the design of human-system interaction systems.

10.0604 A Collaborative Workspace Architecture for Strengthening Collaboration among Space Scientists

Arturo Garcia (University of Salford), Robin Wolff (German Aerospace Center - DLR), David Roberts (University of Salford), Terrence Fernando (University of Salford), Christian Bar , Wito Engelke (German Aerospace Center (DLR)), Janki Dodiya (German Aerospace Centre), Andreas Gerndt (German Aerospace Center),
Presentation: Robin Wolff, Wednesday, March 11th, 09:00 PM, Lamar/Gibbon

Space exploration missions have produced large data of immense value, to both research and the planning and operating of future missions. However, current datasets and simulation tools fragment teamwork, especially across disciplines and geographical location. The aerospace community already exploits virtual reality for purposes including space tele-robotics, interactive 3D visualization, simulation and training. However, collaborative virtual environments are yet to be widely deployed or routinely used in space projects. Advanced immersive and collaborative visualization systems have the potential for enhancing the efficiency and efficacy of data analysis, simplifying visual benchmarking, presentations and discussions. We present preliminary results of the EU funded international project CROSS DRIVE, which develops an infrastructure for collaborative workspaces for space science and missions. The aim is to allow remote scientific and engineering experts to collectively analyze and interpret combined datasets using shared simulation tools. The approach is to combine advanced 3D visualization techniques and interactive tools in conjunction with immersive virtuality telepresence. This will give scientists and engineers the impression of teleportation from their respective buildings across Europe, to stand together on a planetary surface, surrounded by the information and tools to use it, that they need. The conceptual architecture and proposed realization of the collaborative workspace are described. ESA's planned ExoMars mission provides the use-case for deriving user requirements and evaluating our implementation

10.0605 VR-OOS: The DLR's Virtual Reality Simulator for Telerobotic On-Orbit Servicing with Haptic Feedback

Mikel Sagardia (German Aerospace Center (DLR)), Robin Wolff (German Aerospace Center - DLR), Katharina Hertkorn , Thomas Hulin , Johannes Hummel (German Aerospace Center - DLR), Andreas Gerndt (German Aerospace Center), Janki Dodiya (German Aerospace Centre), Simon Schätzle (German Aerospace Center - DLR),

Presentation: Mikel Sagardia, Wednesday, March 11th, 09:25 PM, Lamar/Gibbon

In order to reduce costs and risks, telerobotic on-orbit servicing (OOS) becomes more and more important for maintenance and life extension of future spacecraft missions. However, space systems and service robots have to fit together so that servicing operations are possible at all. One of the most feasible approaches is to carry out design development and training with Virtual Reality (VR) simulators. In this work, the distributed architecture which has been developed at the German Aerospace Center (DLR) is described. Many aspects are crucial to improve confidence in VR simulators. Besides photo-realistic visualization of the on-orbit servicing scenario, fast and accurate collision detection, as well as physically correct multi-object behavior are prerequisites for high user acceptance. Furthermore, only very precise input devices with realistic haptic feedback lead to full immersion. This is the reason why DLR investigates human computer interfaces already for a long time, from robotic-supported bimanual haptic systems for telepresence to vibro- and electrotactile feedback devices for enhanced sensation in virtual environments. All mentioned system components and interfaces are addressed by this paper. The implementations are presented in detail and the performance of the overall system is validated. Eventually, a preliminary user study in which the virtual system is compared to a physical test bed shows the suitability of the VR-OOS framework for training purposes.

10.07 Cloud Computing

Session Organizer: Kapil Bakshi (Cisco Systems Inc),

10.0701 Comparative Analysis of Current Security Algorithms and the "MIST" Algorithm in Cloud Computing

Ihssan Alkadi (Southeastern Louisiana University),

Presentation: Ihssan Alkadi, Monday, March 9th, 11:00 AM, Madison

The need for simple security mechanisms for cloud computing systems that are being used by non-technical users is increasing in importance as cloud systems are becoming more widely accepted by these users. With cloud computing, data is stored on and delivered across the Internet infrastructure. The owner of the data has no knowledge of the where this data exists on the network nor geographically. The owner, therefore, does not have control or even know where their data is being stored. Additionally, in a multi-tenant environment, it may be very difficult for a cloud service provider to provide the level of isolation and associated guarantees that are possible with an environment dedicated to a single customer. Unfortunately, to develop a security algorithm that outlines and maps out the enforcement of a security policy and procedure can be a daunting task. We present a new security mechanism that will enforce cloud computing services against breaches and intrusions. Existing techniques for securing servers used for cloud computing and storage of data will be surveyed. Due to the relevance of cloud systems in gathering sensitive information in aerospace platforms, the techniques will also need to prevent common attacks through weak password recovery, retrieval, authentication and hardening systems, otherwise hackers will be able to compromise even the protected systems. In case of security breaches, it would be advantageous to include the capabilities of the MIST algorithm (Alkadi). The MIST algorithm is named after the condensation from clouds that forms a layer before entering the cloud.

10.0702 Networking Considerations for Open Source Based Clouds

Kapil Bakshi (Cisco Systems Inc),

Presentation: Kapil Bakshi, Monday, March 9th, 11:25 AM, Madison

Cloud-based services are being consumed and developed at an unprecedented rate and cloud architects are looking for open-source options to architect and deploy next generation clouds. There are several use cases that can be explored for the aerospace industry. This paper will focus on the networking aspects of cloud architecture, which can be built via select open source technologies. This paper reviews, the three open source technologies, namely OpenStack, OpenDaylight and Open vSwitch and their corresponding networking sub components for cloud architectures. The benefits of adopting open source technologies vary from the standpoints of cost, flexibility, customizability, and auditability factors. OpenStack is an open source software that consists of interrelated projects for cloud processing, storage, and networking resources in a cloud data center. OpenDaylight is an open platform for network programmability to enable Software Defined Network (SDN) and Network Function Virtualization (NFV). OpenDaylight (ODL) software is a combination of components including a network controller, interfaces, protocol plug-ins and Application Programmable Interfaces (APIs). Open vSwitch (OVS), is an open source implementation of a distributed virtual multilayer switch. The purpose of Open vSwitch is to provide a switching stack for hardware virtualization environments. This paper will review the networking considerations of OpenStack design and implementation, the cloud-related functions and applicability for OpenDayLight in cloud designs, and the details of Open vSwitch and its consideration for a virtualized cloud architecture. The paper will explore aerospace industry cloud use cases and intersection of these open source with these components.

10.0703 Scalable Human in the Loop Decision Support

Ramona Georgescu ,

Presentation: Ramona Georgescu, Monday, March 9th, 11:50 AM, Madison

A scalable human-in-the-loop decision support system has been built around an active learning algorithm operating on aircraft engine time series data. The system integrates hierarchical clustering and active learning algorithms backed by a big data analytics ecosystem with a browser-based user interface. This combination enables multiple expert users to efficiently train a model to classify aircraft engine behavior by prioritizing the segments of flight for human analysis. This system lowers the time required from human experts by eliminating unnecessary labeling effort and supporting the aircraft maintenance industry’s service technicians.

10.08 PANEL: Software Architecture

Session Organizer: Kristin Wortman (Johns Hopkins University/Applied Physics Laboratory),

TRACK 11: DIAGNOSTICS, PROGNOSTICS AND HEALTH MANAGEMENT (PHM)

Track Organizers: Wolfgang Fink (University of Arizona), Andrew Hess (The Hess PHM Group, Inc.)

11.01 PHM for Aerospace Subsystems, Components and Structures

Session Organizer: Andrew Hess (The Hess PHM Group, Inc.)

11.0101 Robust Passive Fault Tolerant Control Applied to the Fuel Metering Valve of a Jet Engine

Yani Souami (Arts et Métiers ParisTech),
Presentation: Yani Souami, Sunday, March 8th, 04:30 PM, Lake/Canyon

—In this paper, we propose to monitor the Fuel Metering Valve (FMV) of a jet engine, subsystem controlling the fuel flow. The proposed control strategy aims to design a virtual sensor based on robust on-line estimation for LPV systems using Takagi-Sugeno formalism. The purpose of the original approach is to provide performances required in the specifications in spite of occurrence of an unexpected fault during the operation. The robustness is guaranteed by a Neural Kalman Filter accommodating, in real time, the model prediction. In the proposed methodology, an off-line closed-loop identification scheme is first used to elaborate multi local linear state space models, after that a multi-model observer based on Linear Matrix Inequalities (LMI) optimization is used to build the virtual sensor. The NEKF is added to circumvent online model accuracy problems. The efficiency and limit of the approach are shown and discussed through simulations on a complete numerical engine test bench.

11.0102 Towards a Physics Based Prognostic Model for Bearing – Spall Initiation and Propagation

Dmitri Gazizulin (Ben-Gurion),
Presentation: Dmitri Gazizulin, Sunday, March 8th, 04:55 PM, Lake/Canyon

One of the common reasons for rolling element bearings failure is the rolling contact fatigue (RCF). RCF occurs when two bodies roll/slide with respect to each other, producing alternating stresses over a very small volume beneath the contact surface. Complete understanding of the fatigue process is critical for estimation of the bearing remaining useful life and allows planning maintenance actions. In the current work, it is assumed that the spall generation, on the surface of the raceway, is a result of RCF. This process is modeled based on continuum damage mechanics and later implemented using ABAQUS Finite Element software. Different meshes were constructed for simulation purposes. An ideal line contact, representing the cylindrical roller bearing, is used to simulate rolling contact conditions. The geometry and initiation time of the simulated spalls are in good agreement with published simulated and experimental data.

11.0103 Aircraft Corrosion Monitoring and Data Visualization Techniques for Condition Based Maintenance

Jeff Demo (Luna Innovations), Fritz Friedersdorf ,
Presentation: Jeff Demo, Sunday, March 8th, 05:20 PM, Lake/Canyon

Exposure to harsh, corrosive environments during operational and on-ground activities can have significant negative effects on aircraft, presenting large contributions to aging and structural deterioration. To support maintenance exposure tracking, autonomous data analysis techniques are being developed to track and visualize environmental severity within airframes for clear, intuitive, and informative presentation of long-term environmental exposure. Development of this process involves collection of data from sensor nodes installed in a variety of locations on multiple aircraft located in disparate geographical locations. Following collection, the data is evaluated against local NOAA weather station data to determine correlations between conditions monitored within the airframe versus external ambient conditions. Environmental severity within the airframe is determined based on the collected data and graphically presented against sensor exposure time. The visual representation of the collected data provides maintainers with a method of determining locations where corrosion mitigation is required, and daily and seasonal periods of time when environmental exposure is most severe.

11.0104 A Physical Model for Fatigue Crack Growth Prediction under Constant and Variable Amplitude Loadings

Shan Jiang (Beihang University), Wei Zhang (Clarkson University),
Presentation: Shan Jiang, Sunday, March 8th, 09:00 PM, Lake/Canyon

11.0105 Impact of Uncertainty on the Diagnostics and Prognostics of a Current-Pressure Transducer

Shankar Sankararaman (SGT, Inc., NASA Ames Research Center), Christopher Teubert ,
Presentation: Shankar Sankararaman, Sunday, March 8th, 09:25 PM, Lake/Canyon

Current-Pressure (I/P) transducers are effective pressure regulators that can vary the output pressure depending on the supplied electrical current signal, and are commonly used in pneumatic actuators and valves. Faults in current-pressure transducers have a significant impact on the regulation mechanism; therefore, it is important to perform diagnosis to identify such faults and estimate their effect on the remaining useful life of the transducer. However, there are different sources of uncertainty that significantly affect the diagnostics procedure, and therefore, it may not be possible to perform fault diagnosis and prognosis accurately, with complete confidence. These sources of uncertainty include natural variability, sensor errors (gain, bias, noise), model uncertainty, etc. This paper presents a computational methodology to quantify the uncertainty and thereby estimate the confidence in the fault diagnosis of a current-pressure transducer. Further, the effect of diagnostic uncertainty on prognostics is also quantified.

11.0106 Hybrid Prognostic Approach for Micro-Electro-Mechanical Systems

Haithem Skima (FEMTO-ST institute),
Presentation: Haithem Skima, Sunday, March 8th, 09:50 PM, Lake/Canyon

A hybrid prognostic approach which is applied on electro-thermally actuated MEMS valve will be presented. Firstly, we present a brief literature review related to MEMS reliability and how we can address the reliability limitations by applying PHM approaches. The proposed method will be described in details. This method consists of combining both degradation and nominal behavior models in order to estimate current and future MEMS health states. A test bed which is designed to acquire data in relation with the health state of the MEMS will be presented. The data processing obtained with this platform lead us to propose a degradation model. Then, a detailed modeling of the electro-thermal actuator used in the MEMS valve will be presented to derive the nominal behavior model of the valve. Finally, and to show the effectiveness of the proposed

method and in order to validate the implementation of PHM models on MEMS, we present two simulated degradations of the MEMS valve.

11.03 Algorithms and Advanced Concepts for Diagnostics and PHM

Session Organizer: Matthew Daigle (NASA Ames Research Center), Chetan Kulkarni (SGT. Inc NASA Ames Research Center),

11.0301 An Integrated Framework for Distributed Diagnosis of Process and Sensor Faults

Anibal Bregon (University of Valladolid), Matthew Daigle (NASA Ames Research Center), Indranil Roychoudhury (SGT, Inc.),

Presentation: Matthew Daigle, Monday, March 9th, 08:30 AM, Lake/Canyon

Complex engineering systems require efficient on-line fault diagnosis methodologies to improve safety and reduce maintenance costs. In complex systems, faults may occur in the process itself but also in the sensors monitoring the system, which makes the fault diagnosis task difficult, because the signals from which diagnostic reasoning takes place may be corrupted by faulty sensors. As such, many diagnosis solutions focus on either process or sensor faults, but not both. When considering both types of faults, additional diagnostic information is needed because of the additional ambiguity introduced by potentially faulted sensors. As such, traditional centralized diagnosis approaches, which already do not scale well, scale even worse. To address these issues, this paper presents a distributed diagnosis framework for physical systems applied to diagnosis of both sensor and process faults. Using a structural model decomposition method, we develop a distributed diagnoser design algorithm to build local fault diagnosers. These diagnosers are constructed based on global diagnosability analysis of the system, determining the minimal number of residuals required to have the maximum possible diagnosability in the system. We evaluate the design approach on a diagnostic benchmark system that is functionally representative of a spacecraft electrical power distribution system. Results demonstrate that the proposed distributed approach scales significantly better than a centralized approach.

11.0302 Methodology for Quantifying the Effect of Mission Profiles on Aircraft Engine's Life

Manzar Abbas (National University of Sciences and Technology), George Vachtsevanos (Georgia Tech),

Presentation: Manzar Abbas, Monday, March 9th, 08:55 AM, Lake/Canyon

Prediction of Effects of Mission Profiles of Commercial Aircraft on Creep Life of Turbine Blades using Response Surface Methodology: Complex engineering systems, such as aircraft engines, consist of several subsystems, each of which is composed of large number of components. Faults, while being originatedat component level, their effects are manifested at subsystem and system level. In the field of prognostics and health management (PHM), diagnostics and prognostics activities in complex systems have been mostly limited to the component level, primarily due to the complexity of these large-scale engineering systems. However, the output of these prognostic algorithms can be practically useful for the system managers, operators, or maintenance personnel, only if it helps them in making decisions, which are based on system-level parameters. Therefore, there is a growing need to develop algorithms that can produce system-level assessment results while utilizing the component-level diagnostics / prognostics results. This paper presents a methodology of developing a hierarchical framework that connects component-level prognostic models to system-level health assessment. This framework allows for capturing and representing the effects of system usage pattern on the system level health, thus helping the mission planners and system managers in taking appropriate decisions.

11.0303 An Efficient Way to Embed Analytics for Prognostics in an on Board System

Sreerupa Das (EASI),

Presentation: Sreerupa Das, Monday, March 9th, 09:20 AM, Lake/Canyon

Prognostics and Health Management (PHM) systems are becoming increasingly important for monitoring and maintaining high value assets. In order to enable real time on board diagnostic and prognostic capabilities, mechanisms for reading, manipulating and analyzing the data need to be built into the on board system. Machine learning and statistical algorithms provide tools to develop data models for enabling prognostics that are typically developed off-board by mining historical data. Once trained, the logic of processing real time data is then embedded on a real time on board system. A straightforward approach for incorporating the knowledge and intelligence for real time data processing is to add the needed logic and algorithms as an integral part of the on board software. While this method can serve the purpose of enabling real time health assessment and analysis, it is very restrictive in nature. Every time the analytics need to be updated or algorithms need refinement, it requires a refresh of the complete on board software. The ability to fine tune on board embedded logic for the purpose of making the analysis smarter is crucial for creating a successful and sound health monitoring system. This paper discusses an approach to build algorithms and logic into an on board system such that they are programmatically decoupled from the on board software. The approach described in this paper allows users the ease of use and flexibility in building knowledge into the system.

11.0304 Subspace-based Fault Detection – Multiplicative and Additive Fault

Young Man Kim (Saginaw Valley State University),

Presentation: Young Man Kim, Monday, March 9th, 09:45 AM, Lake/Canyon

In this research, a technique is developed to separate an additive fault from a multiplicative fault of a system which is disturbed by integrated white noise. First, Predictor-based System Identification (PBSID) is formulated in a differenced form (DPBSID) in order to filter out the integrated white noise. Second, the differenced PBSID is reformulated in a recursive form (DRPBSID) which is for separating an additive fault from a multiplicative fault. If the fault type is multiplicative, the Frobenius norm of the difference between the identified system matrix and a changed one becomes greater than a threshold. By recursively updating the system matrix, the difference goes below the threshold hence, a multiplicative fault is separated from an additive one. This technique is applied to a complex system and its effectiveness is demonstrated using Matlab simulation.

11.0305 Random Forests for Industrial Device Functioning Diagnostics Using Wireless Sensor Networks

Wiem Elghazel ,

Presentation: Wiem Elghazel, Monday, March 9th, 10:10 AM, Lake/Canyon

In this paper, random forests are proposed for operating devices diagnostics in the presence of a variable number of features. In various contexts, like large or difficult-to-access monitored areas, wired sensor networks providing features to achieve diagnostics are either very costly to use or totally impossible to spread out. Using a wireless sensor network can solve this problem, but this latter is more subjected to flaws. Furthermore, the networks' topology often changes, leading to a variability in quality of coverage in the targeted area. Diagnostics at the sink level must take into consideration that both the number and the quality of the provided features are not constant, and that some politics like scheduling or data aggregation may be developed across the network. The aim of this article is (1) to show that random forests are relevant in this context, due to

their flexibility and robustness, and (2) to provide first examples of use of this method for diagnostics based on data provided by a wireless sensor network.

11.05 Systems Health Management for Space Systems and Operations

Session Organizer: Shankar Sankararaman (SGT, Inc., NASA Ames Research Center), Indranil Roychoudhury (SGT, Inc.),

11.0501 State-of-Health Analysis Applied to Spacecraft Telemetry Based on a New PLS-DA Algorithm

Bassem Nassar (MTC), Wessam Hussein (MTC),

Presentation: Bassem Nassar, Monday, March 9th, 10:35 AM, Lake/Canyon

The potential for space mission operations and the supporting ground infrastructure is growing dramatically, fueled by new technologies, but with that growth comes increased complexity, and daunting reliability and security challenges. In order to deliver cost-effective space operations services, researchers must explore novel ways to build and operate systems under study. Statistical multivariate latent techniques are one of the vital learning tools that are used to tackle the aforementioned problem coherently. In this paper, we present a supervised learning algorithm based on projection to latent structure discriminant analysis technique (PLS-DA). The algorithm is particularly uses to model, analyze and classify telemetry data while simultaneously measuring several predictor and response variables. The performance of the algorithm using the telemetry acquired from of attitude determination and control system (ADCS) of actual remote sensing spacecraft was presented. Finally, the algorithm provides competent information in modelling, classifying, diagnosis and prediction as well as adding more insight and physical interpretation to the ADCS state of health (SOH).

11.0502 LADEE Preparations for Contingency Operations for the Lunar Orbit Insertion Maneuver

Howard Cannon (NASA Ames Research Center), Anupa Bajwa (NASA Ames Research Center), Peter Berg (SGT, Inc.), Alan Crocker ,

Presentation: Howard Cannon, Monday, March 9th, 11:00 AM, Lake/Canyon

The Lunar Atmosphere and Dust Environment Explorer (LADEE) spacecraft was launched on September 7, 2013, and completed its mission on April 17, 2014 UTC with a directed impact to the Lunar Surface. Its primary goals were to examine the lunar atmosphere, measure lunar dust, and to demonstrate high rate laser communications. The LADEE mission was a resounding success, achieving all mission objectives, much of which can be attributed to careful planning and preparation. To get to the Moon, the spacecraft traversed multiple phasing loops around the Earth, and then executed a breaking maneuver to achieve lunar orbit. This Lunar Orbit Insertion (LOI) maneuver was perhaps the most time-critical phase of the entire mission. To achieve lunar orbit and meet minimum science objectives, the maneuver had to occur within a twenty minute window. Missing this window due to an untimely fault or errant fault management response would have resulted in loss of mission. To prevent this from occurring, careful planning and preparation was undertaken. This paper describes the LADEE fault management design and contingency preparation for the LOI maneuver, and offers recommendations for other missions in similar circumstances.

11.08 Probabilistic Design for Reliability of Aerospace Electronics

Session Organizer: Laurent Bechou (IMS Laboratory, University Bordeaux 1), Ephraim Suhir (University of California, Santa Cruz),

11.0801 Keynote: Aerospace Electronics Reliability: Could It Be Predicted in a Cost-Effective Fashion?

Joseph Bernstein (Ariel University),

Presentation: Joseph Bernstein, Wednesday, March 11th, 08:30 AM, Lake/Canyon

We present a method for predicting the failure rate, and thus the reliability of an electronic system by summing the failure rate of each known failure mechanism. We use a competing acceleration factor methodology by combining the physics of failure for each mechanism with their effects as observed by High/Low temperature and High/Low voltage stresses. Our method assumes that lifetime of each of its failure mechanisms follows constant rate distribution and each mechanism is independently accelerated by the stress factors, which include also frequency, current, and other factors that can be entered into a reliability model. The overall failure rate is thus, also follows an exponential distribution and is described in the standard FIT (Failure unIT or Failure in Time). The method combines mathematical models for known failure mechanism and solves them simultaneously at a multiplicity of accelerated life tests to find a consistent set of weighting factors for each mechanism. The result of solving the system of equations is a more accurate and a unique combination for each system model by proportional summation of each of the contributing failure mechanisms. We show that this methodology can be used to qualify avionics and other electronic systems for reliability in an accurate and cost effective manner.

11.0802 Advantagers of Using Aluminum Substrates for Aerospace Electronics

Joseph Fjelstad (Verdant Electronics),

Presentation: Joseph Fjelstad, Wednesday, March 11th, 08:55 AM, Lake/Canyon

Aluminum has many attractive qualities in terms of its physical, mechanical, thermal and processing properties and it widely used in aerospace applications as a result. However as a substrate for electronics, it is normally limited to use as an add-on thermal spreader after the electronics assembly has been built. This paper illustrates how aluminum can be used as an integral part of an electronic assembly bypassing completely the soldering process and the formation of solder joints, which are known to be an "Achilles Heel" in electronic assemblies. Assemblies produced in accordance with the methods described in this paper offer numerous prospective benefits and improvement potential in a wide range of areas including: cost, performance, size reduction, design security and reliability improvement through the elimination of solder and the deleterious effects the process is known to have on electronic assemblies of all types, but most especially in the area of high temperature lead-free soldering.

11.0803 Assessment of a Product’s Degradation Rate from the Measured Bathtub Curve Data

Ephraim Suhir (University of California, Santa Cruz),

Presentation: Ephraim Suhir, Wednesday, March 11th, 09:20 AM, Lake/Canyon

An experimental bathtub curve (BC) exhibits the combined effect of the statistics-related and reliability-physics-related processes. The first process results in a decreased failure rate with time, while the second one leads to an increased failure rate, especially at the wear-out portion of the BC. In this analysis a simple and physically meaningful analytical probabilistic predictive model is developed for the evaluation of the failure rates and the probabilities of non-failure of a product at the given time of its operation. It is assumed that the product underwent burn-in and its BC does not contain therefore an infant mortality portion, that the probability of the product failure could be treated as a random variable itself, and that the two processes of interest are statistically independent. Then the reliability-physics-failure rate can be obtained by simply deducting the theoretically evaluated statistical rate from the experimentally obtained (BC) failure rate. The numeri-

cal example is carried out for the situation, when the statistical failure rate is distributed in accordance with the Rayleigh law, and that its most likely value is the one determined by the BC in its steady-state operation portion.

11.0805 Modified Dynamic Reliability Model for Damage Accumulation

Yair Shai (Technion),
Presentation: Yair Shai, Wednesday, March 11th, 09:45 AM, Lake/Canyon

The earlier suggested model for the dynamics of element reliability distribution over a generalized strength (capacity) space [D. Ingman and L. A. Reznik, "A dynamic model for element reliability", Nuclear Engineering and Design, 1982, 70 , pp. 209-213.] reflects the roles of both strength deterioration and failure processes. A modification of the dynamic reliability model for damage accumulation is demonstrated. The present model is a modification of the previously suggested model and considers the interaction of the instantaneous stress (demand) with the instantaneous strength (capacity). The kernel of the RDF dynamics, i.e. Smoluchowski's transition probability from strength state x to a lower state x', is redefined as part of the integro-differential model for RDF. The modification combines the material's physical characteristics, the environmental conditions and the induced stress, into a generalized system governed by a probabilistic strength deterioration process. A simulative solution is demonstrated offering traceability for the full dynamic probabilistic process of strength deterioration under given stress. The solution reveals new features previously unfamiliar due to the absence of general analytic solutions. The RDF tends to follow a three parameters Weibull distribution after departing from the original strength value, where all three parameters change in time in, paths unique to each case. At the same time, the model is flexible for a variety of materials and conditions for which empirical data may be fitted by the model parameters. The calculated data show physically meaningful effect of the particular material parameters and environmental conditions.

11.0806 Reliability Issues in Optical Emitters

Giovanna Mura (university of cagliari), Massimo Vanzi (University of Cagliari),
Presentation: Giovanna Mura, Wednesday, March 11th, 10:10 AM, Lake/Canyon

Device reliability is performed by following procedures. Procedures are based on Failure Physics and Probability. When one forget that link , Reliability can become unreliable. Four cases are considered for Photonics.

11.0807 Monte-Carlo Computations for Predicted Degradation of Photonic Devices in Space Environment

Laurent Bechou (IMS Laboratory, University Bordeaux 1),
Presentation: Laurent Bechou, Wednesday, March 11th, 10:35 AM, Lake/Canyon

Photonic systems are more and more used for aerospace applications and most of these systems require reliable optoelectronic emitters or photodetectors such as Laser diodes or phototransistors. Examples of satellite applications including such devices consist in time reference (atomic clock), attitude control (Fiber Optic Gyroscope) and telecommunications (inter-satellite links and satellite-downlinks). In order to ensure reliability of photonic devices for space applications, a critical issue requires to correctly evaluate their degradation with respect to the constraints of various mission profiles. In this paper, we demonstrate the relevance of Monte-Carlo based computations to predict degradation, extrapolate lifetime distribution and failure rates in operating conditions of specific photonic devices for space applications mixing physical parameters of experimental degradation laws and statistic tools. We also show that Monte-Carlo approach can be associated with a dedicated Design of Experiments (DoE) methodology in order to predict End-Of-Life performance of silicon based phototransistors arrays used in optical encoders to monitor the angular position, speed and acceleration of mechanisms by means of CMGs (Control Moment Gyroscope) controlling the orientation of spacecrafts and exposed to a wide range of space environments. Our approach does not need any accurate physical modeling of the device degradation that would be very complex to obtain anyway. In addition it does not require any specific knowledge regarding the device technology which makes it very useful for the definition of qualification strategies.

11.0808 Effect of Power Cycling Parameters on Predicted IGBT Lifetime

Zoltan Sarkany (Budapest University of Technology and Economics), Marta Rencz (BME),
Presentation: Zoltan Sarkany, Wednesday, March 11th, 11:00 AM, Lake/Canyon

In power electronics there is an increasing need for accurate lifetime prediction. The results of power cycling tests are widely used as input data for the lifetime calculation. The general method of power cycling is described in the JESD22-A122 JEDEC standard, however as the industry has made significant progress in power module design and reliability testing ever since the standard was published. Based on the latest considerations and published data, in this paper we try to collect and discuss some important factors, namely the electrical setup, cycle time and power cycling strategy, which can significantly affect the final test results, and allow the reliability engineers to make more focused testing definitions.

11.0809 Predicted Stresses in an Optoelectronics Tri-component Bow-free Assembly

Ephraim Suhir (University of California, Santa Cruz), Laurent Bechou (IMS Laboratory, University Bordeaux 1), Johann Nicolics (Vienna University Vienna), Sung Kang (Korea Advanced Institute of Science and Technology),
Presentation: Ephraim Suhir, Wednesday, March 11th, 11:25 AM, Lake/Canyon

Analytical thermal stress modeling enables one to better understand the possible physics of failure and to design a viable and reliable assembly experiencing thermal stresses and deformations [1-5]. There is an obvious incentive for using bow-free (temperature change insensitive) assemblies in various areas of applied science, especially in aerospace optoelectronics, when excessive thermally induced bow might lead to the loss in the coupling efficiency of the opto-electronic or a photonic device. A bi-material assembly cannot be made bow-free: the total thermally induced bending moment is never zero in such an assembly. A bow-free assembly should contain at least three components able to produce forces that could lead to a zero resultant bending moment [6]. The induced stresses in such an assembly could be, however, rather high and could possibly generate inelastic stresses and strains. If this happens, the bow-free condition could be compromised. Accordingly, the previously suggested model for a tri-material adhesively bonded assembly [7] is modified, with an objective to obtain a bow-free condition for it and to develop easy-to-use and physically meaningful analytical (mathematical) predictive stress models. The addressed models include the normal stresses acting in the cross-sections of the assembly components, as well as the interfacial shearing and peeling stresses. The numerical example has indicated that all the stress categories are on the same order of magnitude and could be rather high indeed.

11.09 PHM for UAVs and Autonomous Systems

Session Organizer: Karl Reichard (Applied Research Laboratory), Wolfgang Fink (University of Arizona),

11.0901 Stochastic Prediction of Remaining Driving Time and Distance for a Planetary Rover

Matthew Daigle (NASA Ames Research Center), Shankar Sankararaman (SGT, Inc., NASA Ames Research Center), Chetan Kulkarni (SGT. Inc NASA Ames Research Center),
Presentation: Matthew Daigle, Thursday, March 12th, 04:30 PM, Lake/Canyon

The operations of a planetary rover depend critically upon the amount of power that can be delivered by its batteries. In order to plan the future operation of the rover, it is important to make reliable predictions regarding the end-of-discharge time, which, in turn, can be used to estimate the remaining driving time and distance of the rover. In addition, quantifying the uncertainty in these predictions is critical to making risk-informed decisions regarding the operations of the rover. This paper presents a computational methodology to stochastically predict end-of-discharge time, remaining driving time, and remaining driving distance for a planetary rover, based on monitoring the batteries that power the rover. We utilize a model-based prognostics framework that characterizes and incorporates the various sources of uncertainty into these predictions, thereby assisting operational decision-making. We consider two different types of driving scenarios, structured and unstructured driving, and characterize the uncertainty they create in the future usage of the rover. In structured driving, the rover navigates among a set of known waypoints, and in unstructured driving, the rover performs a sequence of unplanned maneuvers. Results from a set of field experiments illustrate these computational methods and demonstrate their applicability.

11.11 PHM for Astronauts and Pilots

Session Organizer: Wolfgang Fink (University of Arizona), Alexandre Popov (AIAA SETC),

11.1102 Personal Health Care and Corresponding Technology with Prognostic Capability. Issues and Challenges.

Olha Kevorkova (UQAM),

Presentation: Alexandre Popov, Thursday, March 12th, 05:20 PM, Lake/Canyon

Unlike conventional medicine, the systems biology seeks to utilize the engineer's familiarity with complex artificial systems and "reverse engineering" concepts to facilitate the difficult process of recognition of the structure, function, and precise method of operation of complex biological systems. It has appeared that properly collected and structured Electronic Health Records (EHR) is the key component of any healthcare technology. The expected growth of EHR is the fierce emergence of technologies and tools for self-diagnosis and autonomous preventive health maintenance based on predictive capabilities. Yet it is clear that the technologies combine advanced improvements with new risks. Although electronic medical records and EHR have been in existence for quite a while, the self-diagnostics and autonomous health maintenance technologies still haven’t been widely adopted. Patients should have the assurance that they properly interpret and understand the received recommendations as well as the way how to implement them. So they proceed the recommendations correctly and safely in order to have the best chance possible of achieving the desired outcome. But most importantly, safety considerations should be always a part of system design. Given limited medical support, personal health-tracking and health-management tools are required to predict future health condition if no preventive measures are taken. The proposed approach could be a viable health-care solution for astronauts during long-duration space missions.

11.14 Panel: PHM from the Practitioner’s Perspective – a Potpourri of Requirements, Experiences, and Lessons Learned

Session Organizer: Michael Houck (NAVAIR 4.4.2, Propulsion & Power), Andrew Hess (The Hess PHM Group, Inc.), Richard Friend (Rolls-Royce), Track Organizers: Jonathan Gal Edd (Goddard Space Flight Center), Manfred Bester (University of California, Berkeley SSL)

12.01 Spacecraft Development and Flight Operations: Challenges, Successes, Failures and Lessons Learned

Session Organizer: Allan Cheuvront (General Dynamics C4 Systems), Mona Witkowski (Jet Propulsion Laboratory),

12.0101 Verification of Mars Odyssey All Stellar Attitude Determination Ten Years after Launch

Dave Gingerich (lockheed martin),

Presentation: Dave Gingerich, Monday, March 9th, 04:30 PM, Elbow 1

This paper describes the process used in 2012 by a combined mission Operations Team from the Jet Propulsion Lab and Lockheed Martin Civil Space to successfully upgrade and certify all-stellar attitude determination flight software first included in the as-launched, flight software image of Mars Odyssey 2001. It provides background on why this attitude determination flight software was not completely verified prior to launch and yet had prudently been included in the as-launched FSW image. All-stellar attitude determination was re-considered in 2012 as an alternative to gyro-based attitude determination after the A-side inertial measurement unit's laser intensity monitor exhibited a typical, near-end-of-life signature. This paper also relates how that while completing the previously de-scoped system verification tests of all-stellar AD, the Operations Team discovered a design defect in the original flight software as well as limitations with the star camera which is the primary component for All-Stellar. It describes the rigorous process followed by the Operations Team to build and test a patch to the Odyssey flight software that enabled the successful transition from gyro-based to all-stellar attitude determination. Subsequently, the A-side inertial measurement unit was powered off, prolonging the life of this spacecraft component. The paper concludes with a discussion of how the operations model employed by the combined mission Operations Teams enabled the successful, albeit unorthodox, correction and verification of previously de-scoped flight software included in an as-launched, but never completely verified flight software image

12.0102 Operating LADEE: Mission Architecture, Challenges, Anomalies, and Successes

Matthew D'ortenzio (NASA - Ames Research Center), John Bresina (NASA Ames Research Center), Alan Crocker , Richard Elphic (Los Alamos National Laboratory), Ken Galal , Brandon Owens (Stinger Ghaffarian Technologies, Inc), Laura Plice (Metis Technology Solutions), Alisa Hawkins (Aerospace Corporation), Lisa Policastri (Applied Defense Solutions Inc.), David Hunt (NASA Ames Research Center),

Presentation: Matthew D'ortenzio, Monday, March 9th, 04:55 PM, Elbow 1

NASA's Lunar Atmosphere and Dust Environment Explorer (LADEE) mission was both a lunar science and a technology demonstration mission. The LADEE spacecraft, with its three science instruments and one laser communications demonstration, launched in September of 2013 from Wallops Island, VA. The spacecraft successfully entered lunar orbit in October of 2013, and spent 188 days at the Moon, making measurements of the tenuous lunar atmosphere and dust exosphere while breaking high-speed data communications records in the process. This presentation summarizes the LADEE mission architecture and describes the operational phase of the LADEE mission. The combination of an aggressive science campaign, the demonstration of a new optical communications payload, and the first-use of a new low-cost spacecraft bus resulted in an operational phase filled with challenges, both planned and unplanned. As such, LADEE's approach to orbit determination, maneuver planning, attitude planning, activity planning and command sequencing, will be discussed as well as a summary of several anomalies that occurred while in flight.

12.0103 Cassini Spacecraft's Command & Data Subsystem: Preparations for the End-of-Mission Proximal Orbits

Paula Morgan (Jet Propulsion Laboratory),
Presentation: Paula Morgan, Monday, March 9th, 05:20 PM, Elbow 1

The Cassini Mission-to-Saturn spacecraft will enter its end-of-mission phase in November 2016; a unique segment which will require the vehicle to fly at very high speeds in a ballistic trajectory. Called the "F-Ring/D-Ring Proximal Orbit" phase, the spacecraft will enter the outside edge of Saturn's F-Ring for 20 orbits, followed by 22 final orbits between the innermost D-Ring and Saturn, ending the spacecraft's very successful 20-year mission on September 15, 2017 with a plunge into the planet. Environmental assessments indicate that the D-Ring contains high dust levels; a condition known to cause numerous "bit flips" within the Solid State Recorder memory devices where computer & instrument flight software (FSW) and recorded science data are stored. Corruption of the data within the FSW region triggers autonomous repairs, interrupting science data collection and inhibiting instrument FSW load retrieval from the SSR when required by the onboard sequence. These bit flips also contribute to the likelihood of SSR memory sub-module failures as well. Also, bit flips can occur on uplinked commands; a condition which will activate the Spacecraft's Safing Response fault protection, consuming a portion of Cassini's carefully budgeted propellant residual. Additionally, possible higher radiation levels will contribute to Solid State Power Switch trip-offs (192 switches). In the presence of this adverse D-Ring environment where very short orbits require minimized fault recovery time to maximize science capture, preparatory measures are being taken to address anomalous events quickly and are detailed in this presentation, in addition to an overview of the Cassini mission.

12.0104 Successes and Challenges of Operating the Van Allen Probes Mission in the Radiation Belts.

Karen Kirby (JHU-APL), Kristin Fretz (Johns Hopkins University/Applied Physics Laboratory),
Presentation: Karen Kirby, Monday, March 9th, 09:00 PM, Elbow 1

Performance of the two Van Allen probes spacecraft while in operation for 2.5 years in the Van Allen radiation belts is presented. The spacecraft have demonstrated successful operating with mostly single string electronics in this high radiation environment. Science data return has been enhanced on orbit to twice the pre-launch prediction. Spacecraft and instrument trending, environmental monitoring sensors and high activity events including SEEs are discussed, along with investigation of on-board anomalies and correlation to environment. The on-board mitigations put in place to protect the spacecraft and instruments from the harsh radiation belt environment have proven successful. There have been very few anomalies due to the environment and the spacecraft has recovered from these with almost no impact on science data return. The Van Allen probes are prepared to support continued operations in the Van Allen radiation belts and have the capacity to make further contributions to studies of the Earth-Sun system.

12.0105 Essentials for Team Based Rehearsals and the Differences between Low Earth and Deep Space Missions

Juan Cifuentes (General Dynamics - NASA), Francis Wasiak (General Dynamics-C4S), Carlos Gomez Rosa (NASA - Goddard Space Flight Center), Agustin Alfonzo (General Dynamics C4 Systems),
Presentation: Juan Cifuentes, Monday, March 9th, 09:25 PM, Elbow 1

Ever wonder how NASA train their flight teams for non-manned missions? And does the methodology change between NASA centers? As part of the pre-launhc maturation process, a mission rehearsal program is introduced to focus on team processes within the final flight system, in a more realistic operational environment. The overall goal for a mission rehearsal program is to: 1) ensure all flight system elements are able to meet mission objectives as a cohesive team; 2) reduce the risk in space based operations due to deficiencies in people, processes, procedures, or systems; and 3) instill confidence in the teams that will execute these first time flight activities. A good rehearsal program ensures critical events are exercised, discovers team or flight system nuances whose impact were previously unknown, and provides a real-time environment in which to interact with the various teams and systems. For flight team members, the rehearsal program provides experience and training in the event of planned (or unplanned) flight contingencies.

12.0106 Getting Back on the Road: Reformatting Flash Memory On-board the Mars Exploration Rover Opportunity

Rebekah Sosland (NASA Jet Propulsion Lab), Michael Seibert (Jet Propulsion Laboratory), Eric Ferguson (Jet Propulsion Laboratory), Robert Steele , Kyle Zittle (NASA Jet Propulsion Lab),
Presentation: Rebekah Sosland, Monday, March 9th, 09:50 PM, Elbow 1

In early 2011, NASA's Mars Exploration Rover (MER) Opportunity began experiencing intermittent errors when writing data products to Flash memory. Similar errors occurred with increasing frequency in early 2013 and many were accompanied by unexpected resets of the rover's flight computer (warm reboots). Depending on timing, warm reboots occasionally caused communication faults. Although these errors subsided in mid-2013, they returned at an increasing rate in mid-2014. The MER team developed techniques to mitigate the effects of infrequent warm reboots but these became ineffective as the rate and severity of the errors increased. Faced with these more frequent errors, the MER team decided to reformat the Flash memory. Using lessons learned from reformatting the Flash file system on the Spirit rover and implementing some new techniques, the MER team was able to reformat Flash and resume science operations much more quickly than anticipated. This paper will discuss the history of Flash related anomalies, suspect cause, initial operational mitigations, and the ultimate Flash reformat strategy and rover recovery activities.

12.02 Flight/Ground Systems, Mission Planning and Operations

Session Organizer: Judith Furman (Southwest Research Institute), Manfred Bester (University of California, Berkeley SSL),

12.0201 The OSIRIS-REX ASTEROID SAMPLE RETURN –Mision Operations Trades and Design

Jonathan Gal Edd (Goddard Space Flight Center),
Presentation: Jonathan Gal Edd, Tuesday, March 10th, 08:30 AM, Elbow 2

OSIRIS-REx will thoroughly characterize near-Earth asteroid Bennu (previously known as 1019551999 RQ36). The OSIRIS-REx Asteroid Sample Return Mission delivers its science using five instruments and radio science along with the Touch-and-Go Sample Acquisition Mechanism (TAGSAM). All of the instruments and data analysis techniques have direct heritage from flown planetary missions. The OSIRIS-REx mission employs a methodical, phased approach to ensure success in meeting the mission's science requirements. OSIRIS-REx launches in September 2016, with a backup launch period occurring one year later. Sampling occurs in 2019. The departure burn from Bennu occurs in March 2021. On September 24, 2023, the Sample Return Capsule (SRC) lands at the Utah Test and Training Range (UTTR). Traveling to and returning samples from

an asteroid that has not been explored before requires unique operations consideration. The Design Reference Mission (DRM) ties together spacecraft, instrument, and operation scenarios. Asteroid Touch-and-Go (TAG) has various options varying from ground only to fully automated (natural feature tracking). Spacecraft constraints such as thermodynamics and high gain antenna pointing impact the timeline. The mission is sensitive to navigation errors, so a late command update has been implemented. The project implemented lessons learned from other “small body” missions. The key lesson learned was “expect the unexpected” and implement planning tools early in the lifecycle.

12.0202 Laying down Tracks: DSN Planning for Cassini’s Final Mission Phase

Erick Sturm (Jet Propulsion Laboratory), Emily Manor Chapman (Jet Propulsion Laboratory),
Presentation: Erick Sturm, Tuesday, March 10th, 08:55 AM, Elbow 2

The Cassini Mission is in the final years of its second extension, the Cassini Solstice Mission (CSM). Nine months prior to the end-of-mission, the spacecraft will embark on its final mission phase, the F-ring and Proximal Orbits (FRPO). These orbits will bring the spacecraft closer to Saturn than ever before, allowing for the collection of some of the most unprecedented, imperative, and profuse science of the entire mission. A key challenge during this phase is identifying viable spacecraft downlink opportunities given the reduced orbital period and the temporal ‘balancing act’ that must be maintained between science data acquisition, orbit trim maneuvers (OTMs), orbital geometry, other missions’ events, and Deep Space Network (DSN) downtimes. This paper describes the development of the DSN straw-man for the FRPO phase of the Cassini mission, starting with the constraints identified from the above sources, then the process followed to select DSN passes given those constraints, and finally the products produced to summarize the selected passes and verify their compliance with the constraints. Ultimately, the DSN straw-man included 286 selected passes, of which only 44 had conflicts with constraints.

12.0204 LARES Mission Operations

Giampiero Sindoni (sapienza), Claudio Paris (University of Rome, La Sapienza),
Presentation: Claudio Paris, Tuesday, March 10th, 09:20 AM, Elbow 2

LAser RElativity Satellite (LARES) is an Italian Space Agency mission that started operations on February 2012 after a successful launch on ESA’s VEGA qualification flight. The satellite is covered with retroreflectors that allow accurate laser ranging tracking from the stations of the International Laser Ranging Service. Data of laser ranged satellites are publicly available for scientific analysis and in the case of LARES are being used mainly for testing general relativity and in particular the Lense-Thirring effect due to the rotation of Earth. Although designed for fundamental physics, the LARES mission is also very useful for geodesy and geodynamics and it will provide, among other things, improvement of the International Terrestrial Reference Frame. After a description of the scientific objectives and of the satellite, we will focus on the operations required to run the mission.

12.0205 SPACE OUTREACH INITIATIVES through ONLINE & REAL-TIME SPACE OPERATIONS USING VIRTUAL GROUND STATION

Nazish Rubab (institute of Space Technology (IST)), Ghulam Jaffer (Institute of Space Technology (IST)),
Presentation: Nazish Rubab, Tuesday, March 10th, 09:45 AM, Elbow 2

12.0206 TDRSS Demand Access System Augmentation

Haleh Safavi (NASA - Goddard Space Flight Center), Keith Hogie (Computer Sciences Corp.), Edward Criscuolo (Computer Sciences Corp), Jeffrey Lubelczyk (NASA - Goddard Space Flight Center), Asoka

Dissanayake (Exelis), Xun Yang ,

Presentation: Keith Hogie, Tuesday, March 10th, 10:35 AM, Elbow 2

The Demand Access System (DAS) of the Tracking and Data Relay Satellite System (TDRSS) enables space borne and ground based Space Network (SN) customers to send their telemetry and science data 24 hours a day without having to schedule network services. DAS uses Tracking and Data Relay Satellite (TDRS) Multiple Access (MA) antennas and spread spectrum modulation. The current DAS system, installed in 2004, is limited in several ways and becoming obsolete due to outdated technology. A new DAS concept that takes advantage of newer technologies and low-cost components to provide enhanced customer service has been developed as a potential replacement of the existing system. The new concept does away with the hardware resource limitations of the previous system, and its performance is limited only by the selfinterference generated by the MA users. In contrast to the previous system, which is largely a custom design, the new system makes use of Commercial-Off-The-Shelf (COTS) products and offers additional features such as seamless TDRS handovers and TDRS arraying. The system is self-contained in terms of handling all user interactions, and can be updated easily without impacting the rest of the SN infrastructure; backward compatibility is also maintained. Plans are underway to demonstrate the initial concept at the White Sands Complex (WSC) ground terminal by shadowing several orbiting DAS customers. Details of the system architecture, and design approach are presented.

12.0207 Rover Traverse-Optimizing Planner for Multi-Objective Deployment Scenarios

Wolfgang Fink (University of Arizona), Victor Baker (University of Arizona), Michael Flammia (University of Arizona), Mark Tarbell (California Institute of Technology),

Presentation: Wolfgang Fink, Tuesday, March 10th, 10:10 AM, Elbow 2

Currently, traverse/mission planning for deployed rovers (e.g., on Mars) requires planetary scientists to spend many hours in laborious surface terrain analysis, with the goal of minimizing some traverse aspects (e.g., distance) and maximizing others (e.g., smoothness). This is a largely manual process, and the results are at best functional compromises balancing the various potentially mutually exclusive optimization goals. The Rover Traverse Optimizing Planner (RTOP) introduced here is an automated system which generates optimized traverses using a multivariate stochastic optimization algorithm based on terrain data. RTOP makes it possible to quickly and accurately generate traverses optimized in numerous simultaneous constraints, such as: lowest number of deployment segments, shortest traverse based on 3D Euclidian distance measure, smoothest traverse with respect to terrain roughness, least altitude change, or any combination of these. Additional constraints which are supported by the terrain data can be added directly to the system. Waypoints (as well as avoidance points) can be assigned to each traverse, and numerous alternate (Pareto-optimal) traverses can be generated for each deployment scenario. Depending on ground-truth in-situ assessment of terrain data traversability by a deployed rover (e.g., Curiosity), RTOP allows for frequent replanning of traverses/missions.

12.04 Human Space Flight Development, Operations and Processing

Session Organizer: Michael Lee (NASA),

12.0401 Information Flow Model of Human Extravehicular Activity Operations

Matthew Miller (Georgia Institute of Technology), Karen Feigh (Georgia Tech), Kerry Mc Guire (NASA - Johnson Space Center),

Presentation: Matthew Miller, Monday, March 9th, 11:50 AM, Elbow 2

Future human spaceflight missions will face the complex challenge of performing human extravehicular activity (EVA) beyond the low Earth orbit (LEO) environment. Astronauts will become increasingly isolated from Earth-based mission support and thus will rely heavily on their own decision-making capabilities and onboard tools to accomplish proposed EVA mission objectives. To better address time delay communication issues, EVA characters, e.g. flight controllers, astronauts, etc., and their respective work practices and roles need to be better characterized and understood. This paper presents the results of a study examining the EVA work domain and the personnel that operate within it. The goal is to characterize current and historical roles of ground support, intravehicular (IV) crew and EV crew, their communication patterns and information needs. This work provides a description of EVA operations and identifies issues to be used as a basis for future investigation.

12.05 Payload and Instrument Operations and Processing

Session Organizer: David La Vallee (Johns Hopkins University APL), Radu Popescu (Laboratory for Atmospheric and Space Physics),

12.0501 Development of Science Data System for the International Space Station Cold Atom Lab

Melissa Soriano (Jet Propulsion Laboratory), Christopher Van Harmelen (JPL),

Presentation: Melissa Soriano, Monday, March 9th, 11:25 AM, Elbow 2

Cold Atom Laboratory (CAL) is a facility that will enable scientists to study ultra-cold quantum gases in a microgravity environment on the International Space Station (ISS) beginning in 2016. The primary science data for each experiment consists of two images taken in quick succession. The first image is of the trapped cold atoms and the second image is of the background. The two images are subtracted to obtain optical density. The Science Data System is responsible for processing the raw Level 0 atom and background images into the Level 1 optical density data product, as well as computing the Level 2 data products: atom number, Magneto-Optical Trap (MOT) lifetime, magnetic chip-trap atom lifetime, and condensate fraction. With experiments being conducted for 8 hours every day, the amount of data being generated poses many technical challenges, such as downlinking and managing the required data volume. A parallel processing design is described, implemented, and benchmarked. In addition to optimizing the data pipeline, accuracy in producing the Level 1 and 2 data products is key. Algorithms for feature recognition are explored, facilitating image cropping and accurate atom number calculations.

12.06 Cyber Security in Aerospace Operations

Session Organizer: Jon Handiboe (JHU/APL), David La Vallee (Johns Hopkins University APL),

12.0601 The Weak Point: A Framework to Enhance Operational Ground Systems Security

Tom Leclerc (Telindus S.A), Daniel Fischer (European Space Agency), Mariella Spada (European Space Agency), Jean Francois Job (Telindus Luxembourg S.A.), Jeremy Thimont (Telindus S.A.), Cedric Mauny (Telindus S.A.),

Presentation: Tom Leclerc, Monday, March 9th, 10:10 AM, Elbow 2

ESA and other space agencies operate assets of very high tangible and intangible value. These embed and are operated through a large number of data systems. The security and robustness of these data systems are becoming more and more important. In our presentation, we present the results of the Generic Application Security Framework (GASF) study. The GASF enables the efficient development of security enhanced operational mission data systems by introducing a secure software development lifecycle based on the European ECSS engineering standards and provides an easy-to-use tool for security requirements specification. The tool supports the specification of templates

to select the right requirements from a baseline requirements database for the deployment environment in which the data system will be operated. Finally, the GASF provides a certification/assurance and governance concept that ensures all elements of the GASF and security are maintained properly. The presentation will also contain a live demonstration of the tool that focuses on the complex requirements specification alleviated by the use of templates.

12.0602 Information Security Considerations for Protecting NASA Mission Operations Centers (MOCs)

Eduardo Takamura , Kevin Mangum (General Dynamics), Carlos Gomez Rosa (NASA - Goddard Space Flight Center), Francis Wasiak (General Dynamics-C4S),

Presentation: Eduardo Takamura, Monday, March 9th, 10:35 AM, Elbow 2

In NASA space flight missions, the Mission Operations Center (MOC) is often considered "the center of the (ground segment) universe," at least by those involved with ground system operations. It is at and through the MOC that spacecraft is commanded and controlled, and science data acquired. This critical element of the ground system must be protected to ensure the confidentiality, integrity and availability of the information and information systems supporting mission operations. This paper identifies and highlights key information security aspects affecting MOCs that should be taken into consideration when reviewing and/or implementing protecting measures in and around MOCs. It stresses the need for compliance with information security regulation and mandates, and the need for the reduction of IT security risks that can potentially have a negative impact to the mission if not addressed. This compilation of key security aspects was derived from numerous observations, findings, and issues discovered by IT security audits the authors have conducted on NASA mission operations centers in the past few years. It is not a recipe on how to secure MOCs, but rather an insight into key areas that must be secured to strengthen the MOC, and enable mission assurance. Most concepts and recommendations in the paper can be applied to non-NASA organizations as well. Finally, the paper emphasizes the importance of integrating information security into the MOC development life cycle as configuration, risk and other management processes are tailored to support the delicate environment in which mission operations take place.

12.0603 Mission-level Space Situational Awareness

David La Vallee (Johns Hopkins University APL),

Presentation: David La Vallee, Monday, March 9th, 11:00 AM, Elbow 2

Abstract—Complex space systems typically provide the operator a means to understand the current state of system components. The operator often has to manually determine whether the system is able to perform a given set of high level objectives based on this information. The operations team needs a way for the system to quantify its capability to successfully complete a mission objective and convey that information in a clear, concise way. A mission-level space cyber situational awareness tool suite integrates the data into a complete picture to display the current state of the mission. The Johns Hopkins University Applied Physics Laboratory developed the Spyder tool suite for such a purpose. The Spyder space cyber situation awareness tool suite allows operators to understand the current state of their systems, allows them to determine whether their mission objectives can be completed given the current state, and provides insight into any anomalies in the system. Spacecraft telemetry, spacecraft position, ground system data, ground computer hardware, ground computer software processes, network connections, and network data flows are all combined into a system model service that serves the data to various display tools. Spyder monitors network connections, port scanning, and data exfiltration to determine if there is a cyber attack. The Spyder Tool Suite provides multiple ways of understanding what is going on in a system. Spyder

bridges the gap between infrastructure and mission and provides situational awareness at the mission level.

12.07 PANEL -OSIRIS-REx Asteroid sample retrieval 2:00pm - 4:00pm

Session Organizer: Jonathan Gal Edd (Goddard Space Flight Center),

TRACK 13: MANAGEMENT, SYSTEMS ENGINEERING AND COST

Track Organizers: Robert Kellogg (Aerospace Corporation), Jeffery Webster (Jet Propulsion Laboratory)

13.03 Cost and Schedule Tools, Methods and Processes

Session Organizer: Robert Bitten (Aerospace Corporation), Stephen Shinn (NASA - Goddard Space Flight Center),

13.0301 Managing Cost, Schedule, and Technical Performance through a Sustained Change Framework

Stephen Shinn (NASA - Goddard Space Flight Center), Val Lunz (NASA - Goddard Space Flight Center),
Presentation: Val Lunz, Monday, March 9th, 04:30 PM, Lamar/Gibbon

Operating a world-renowned space flight mission portfolio under rigid policy, fiscal scrutiny, and increased competition makes open communication, visible performance data, and streamlined processes challenging. This paper summarizes an integrated approach developed by Goddard Space Flight Center's Flight Projects Directorate. The Business Change Initiative (BCI) was created to infuse a series of activities coordinated to drive process improvement across Goddard's missions. A sustaining change framework model is presented and a long-term strategy to maintain organizational responsiveness and to is described. This paper also recommends how similar adoption in government and industry can support the collaboration across boundaries and build strategic relationships to achieve common goals in aerospace.

13.0302 Implementing Quantitative Schedule Performance Metrics at NASA Goddard Space Flight Center

Stephen Shinn (NASA - Goddard Space Flight Center), Walter Majerowicz (Walter Majerowicz Consulting), Jonathan Little (ASRC),
Presentation: Stephen Shinn, Monday, March 9th, 04:55 PM, Lamar/Gibbon

This paper summarizes the implementation of new tools and techniques for quantitative schedule performance measurement at NASA's Goddard Space Flight Center, and examines how key metrics from a project's integrated master schedule can be used to monitor project schedule performance. The Baseline Execution Index (BEI), Hit or Miss Index (HMI), and Current Execution Index (CEI) are metrics which provide performance insight through trend reporting against both the schedule baseline and current forecast. To enable Goddard's project teams to generate and report these performance metrics, the Flight Projects Directorate designed and developed the Goddard Schedule Analysis Tool (GSAT), which when added to MS Project, can calculate BEI, HMI, and CEI, and produce their associated trend and variance reports at the total project level, while also providing a "drill capability" to lower levels of the work breakdown structure. Additionally, this paper highlights the programmatic, technical strengths, and challenges of using these indices, while also examining the cultural implications of the metrics within the organization. The business change and stakeholder engagement activities used to put the metrics and GSAT into practice at Goddard will also be discussed along with the results of some initial “back-testing” of the metrics on completed projects including actual GSAT report examples.

13.0303 Beyond Cost Tools: Spacecraft Net Present Value and the Hosted Payload Paradigm

Joseph Saleh (Georgia Institute of Technology),
Presentation: Fan Geng, Monday, March 9th, 05:20 PM, Lamar/Gibbon

This work is at the intersection of and integrates two broad considerations in the space industry, namely the emergence of the hosted payload paradigm on the one hand, and the increased emphasis for the acquisition of space systems to be value-driven on the other hand. Spacecraft, and hosted payloads, are value delivery artifacts; their value derives from the flow of service they provide to different stakeholders. Their design and acquisition should be value-centric or at a minimum value-informed. In this work, we first provide a value model and analysis for a spacecraft, which includes its lifecycle cost as well as its revenue model. The revenue model accounts for the services provided by the primary payload and their lease price, the loading dynamics, and various provisions for its obsolescence. When integrated, these two models allow us to calculate the spacecraft Net Present Value (NPV) and its return on investment. A sensitivity analysis helps us to identify the effectiveness of the different value levers of a spacecraft. Second, after a brief review of the hosted payload paradigm, and having developed a baseline spacecraft NPV model, we integrate considerations of the hosted payload into the value analysis, and in the process, we develop a pricing standard (and model) for hosted payloads. We propose that the pricing of the hosted payload should be at a minimum ΔNPV neutral. This condition helps us calculate the lower bound for either an upfront payment from the guest, an annuity or rent-like payment, or a combination of both.

13.0304 Calculating Reserves on Schedule-to-Go (STG) Based on Historical Data

Marc Hayhurst (The Aerospace Corporation), Robert Bitten (Aerospace Corporation), Stephen Shinn (NASA - Goddard Space Flight Center), Robert Kellogg (Aerospace Corporation),
Presentation: Marc Hayhurst, Monday, March 9th, 09:00 PM, Lamar/Gibbon

NASA Center guidance typically requires that a mission hold increasing schedule reserves on schedule-to-go (STG) as the project matures. This approach makes intuitive sense as history has shown that project development schedules typically grow beyond their initial planned schedule. This fact begs the question, are the schedule reserve guidelines adequate relative to the experience of historical missions? This study examines current schedule guidelines and actual historical mission data. Additionally external factors that have caused schedule growth are considered and adjustments are made for them. The results can potentially be used to inform NASA Center and Headquarters guidelines for reserves on STG to set more robust guidance for future missions.

13.0305 Calibrating the Technology Readiness Level (TRL) Scale Using NASA Mission Data

Richard Terrile (Jet Propulsion Laboratory),
Presentation: Richard Terrile, Monday, March 9th, 09:25 PM, Lamar/Gibbon

This paper seeks to assess the qualitative and quantitative aspects of the Technology Readiness Level (TRL) scale in order to understand its ability to provide estimates of the forward costs of developing a new technology to a state of flight readiness. TRLs are in common use throughout NASA, industry and military organizations and are characterized by being easy to determine using a set of well-defined parameters. However, the TRL scale is not calibrated to any consistent unit and the relative size of TRL steps are not linear and can vary for different technologies. We use archived cost data from a variety of recent NASA flight missions and from several technology-heavy instrument suites on the Mars Science Laboratory (MSL). Development costs are extracted at the time of several NASA life cycle review milestones. We relate the project requirements associated with these defined milestones with approximate TRL steps and use the cost data as a proxy for TRL step costs. When corrected for programmatic variations in time spent at each TRL step, the NASA mission data demonstrated a 30% reduction in variability, illustrating how unexpected events mask a more stable progression of technology development. A calibrated TRL scale is determined with an “S-curve” shape to TRL growth. The steepest step sizes are in the TRL 6 to 8 range, matching the region of technology maturation known to be a difficult barrier to traverse.

13.0306 Software Cost Estimation for the LADEE Mission

Karen Gundy Burlet (NASA-Ames Research Center), Howard Cannon (NASA Ames Research Center),
Presentation: Howard Cannon, Monday, March 9th, 09:50 PM, Lamar/Gibbon

The purpose of the Lunar Atmosphere Dust Environment Explorer (LADEE) mission was to measure the density, composition and time variability of the lunar dust environment. The ground-support and onboard flight software for the mission was developed using a “Model-Based Software” methodology. In this technique, models of the spacecraft and flight software are developed in a graphical dynamics modeling package. Flight Software requirements are prototyped and refined using the simulated models. After the model is shown to work as desired in this simulation framework, C-code software is automatically generated from the models. The auto-generated code is then integrated with the Core Flight Executive and Core Flight Services (cFE/cFS) packages, VxWorks and appropriate board support packages. The generated software is then tested in real time Processor-in-the-Loop and Hardware-in-the-Loop test beds. Software cost estimation for the mission was performed 3 ways: 1) Extrapolated from development of a earth-based prototype hover-test vehicle, 2) Estimated through the Goddard Space Flight Center “mission design center” 3) Through the use of COCOMO based estimation spreadsheets. In this paper, we will discuss the characteristics of each of the cost estimation methods, and how they were tuned for a model-based development effort rather than a traditional effort. The estimates are also compared with actual costing and trend data for the LADEE Flight Software effort.

13.04 Management Tools, Methods and Processes

Session Organizer: Robin Dillon Merrill (Georgetown University), Jeremiah Finnigan (Johns Hopkins University/Applied Physics Laboratory),

13.0401 Leveraging Design Principles to Optimize Technology Portfolio Prioritization

Brett Depenbrock (Booz Allen Hamilton), Tibor Balint (Royal College of Art), Jeffrey Sheehy (NASA),
Presentation: Brett Depenbrock, Monday, March 9th, 08:30 AM, Lamar/Gibbon

Research and development organizations frequently encounter challenges when attempting to identify an investment strategy. Fast moving and complex environments require managers to analyze quickly and to diagnose the value of returns on innovation investments versus allocated resources. In the government framework our Project Assessment Framework Through Design (PAFTD) tool facilitates decision making for NASA senior leadership to optimize technology portfolio prioritization. The framework has been employed to assess system level technology development investments across the high technology readiness levels of the NASA Space Technology Mission Directorate. It leverages design principles of usability, feasibility, and viability and aligns them with methods employed by NASA’s Independent Program Assessment Office for project performance assessment. The need exists for senior managers to continually evaluate the justification and prioritization of technology development investments as environmental changes occur over project life cycles. The framework informs management rapidly and comprehensively about diagnosed internal and external root causes of project performance. PAFTD offers an evidence based means to measure and quantify key aspects of different projects to enable consistent comparisons between projects in a loosely coupled investment portfolio. The model allows senior leadership to quickly diagnose project performance strengths and weaknesses to further improve project and portfolio investment decisions. In this paper we provide an overview of the framework, its capabilities, and its utility as demonstrated through example cases at NASA.

13.0402 Lessons from the GEO Communicastions Satellite Commercial Sector on Acquisition Practices

Susan Hastings (The Aerospace Corporation), William Tosney ,
Presentation: Susan Hastings, Monday, March 9th, 08:55 AM, Lamar/Gibbon

The geostationary orbit (GEO) communications satellite commercial sector delivers reliable satellites at competitive prices, in short turnaround times, with cutting-edge performance. The authors have examined the evolving commercial satellite market, both from the perspective of established US satellite manufacturers and from that of experienced fleet operators (commercial buyers), with the goal of identifying commercial best practices that could be effectively applied to government space acquisitions. Wholesale adoption of all of these commercial best practices in many government satellite acquisitions does not necessarily produce the desired results because of differences between the government and commercial acquisition environments. Recommended best practices for government acquisitions are distilled. The selective application of commercial best practices to select government acquisitions can result in more predictable program performance and lower program costs.

13.0403 New Ways to Learn from the Challenger Disaster: Almost 30 Years Later

Robin Dillon Merrill (Georgetown University),
Presentation: Robin Dillon Merrill, Monday, March 9th, 09:20 AM, Lamar/Gibbon

As we approach the thirtieth anniversary of the Challenger Disaster (January 28, 2016), how do we continue to educate current and future leaders on how to make decisions that involve significant risk and uncertainty with the lessons of Challenger in mind?
To address this challenge we have created a case that places decision makers in a situation of risky choice. The case uses but masks the facts of the Challenger launch decision in the premise of a Coast Guard response to a wrecked cruise ship that is leaking oil. We will discuss insights for organizational learning that can be gained from a case discussion of a decision similar to that faced by the Challenger managers but in a context different than Challenger.

13.0404 Managing Technical Risk

Paul Collopy (University of Alabama in Huntsville),
Presentation: Paul Collopy, Monday, March 9th, 09:45 AM, Lamar/Gibbon

The current accepted process for managing technical risk addresses only a tiny fraction of the relevant risks, looks for consequences in the wrong places, and assesses risk and consequence in a way that offends mathematical rigor and confounds very serious problems with trivial ones. This paper lays out a more solid probabilistic approach that goes a long way toward explaining the cost and schedule overruns that afflict large system developments. It shows that technical risk exists in almost every system design throughout a large system development program. Rather than managing ten or twenty risks, a program faces thousands of risks, and they are interrelated. A general stochastic solution is presented, grounded in subjective expected utility theory. However, a stochastic solution may not be sufficient for a problem that is fundamentally social and organizational. The future of risk management may be in applied game theory, which might swing the pendulum back toward today's methods, focusing more on management attention and the perception of problems rather than carefully balanced solutions.

13.0405 Risk Aversion and Optimal Satellite Systems

Matthew Daniels (Stanford University), Elisabeth Paté Cornell (Stanford University),

Presentation: Matthew Daniels, Monday, March 9th, 10:10 AM, Lamar/Gibbon

Long-term, multiple-payload satellites in Earth orbit can be designed either as consolidated or distributed satellite systems. A consolidated satellite architecture aggregates multiple payload capabilities onto individual large satellites. A distributed (or 'disaggregated') satellite architecture allocates payloads across multiple smaller, heterogeneous satellites. Each system type has certain advantages and disadvantages. A consolidated system often has highly-reliable individual satellites and may offer a lower initial deployment cost. The advantages of a distributed system include the ability to replace a failed unit, or to insert a new technology, more quickly and at a lower cost. Such a system may also be less vulnerable to adversarial threats. We model the value of a satellite program as that of the data that it provides, and use this approach to find optimal sequential decisions to choose and operate the satellite system. The model includes a failure risk analysis to assess and compare the benefits of different system configurations. In sum, we provide a model that enables value-based comparison of entire satellite architectures, where each technical and operational characteristic is optimally exploited. The results of this research indicate that risk-averse decision makers are likely to prefer a distributed satellite system. This work has implications for research on resilience, value, and mission analysis for future space systems.

13.0406 Optimizing Design for Reuse Decisions in Aerospace Systems

Richard Milford (Boeing Company),

Presentation: Richard Milford, Monday, March 9th, 10:35 AM, Lamar/Gibbon

In this paper, we extend prior work on Product Line reuse and platform design optimization to develop a framework for making reuse decisions while factoring in robustness to market uncertainty. We explore Product Line strategies for a portfolio of two communication satellite platforms that focused on optimizing investment decisions involving varying degrees of payload capability as a function of platform technology. Parametric models for satellite platform cost and mass, and the corresponding impact on available payload capacity were developed for three platform reuse strategies. First, the power subsystem capability was scaled as a function of payload power. Second, each platform in the portfolio utilized an enveloping power subsystem configuration to meet their full range of power levels. Third, the power subsystem was scaled using improved technology (i.e. more efficient solar cells), requiring additional upfront investment. Net present value (NPV) analysis was used to compare the economic performance, from the satellite manufacturer’s perspective, of each strategy in the presence of market uncertainty. The results show that NPV improves when optimizing hardware for narrower power ranges, compared with deploying enveloping designs. Despite the higher development costs, the use of improved technology was shown to further improve economic value across the product portfolio.

13.0407 The PRACA System as an “Incubator” for Lessons Learned

David Oberhettinger (NASA Jet Propulsion Lab),

Presentation: David Oberhettinger, Monday, March 9th, 11:00 AM, Lamar/Gibbon

NASA Centers are required to document lessons learned, and their Problem Reporting and Corrective Action (PRACA) systems may serve as an excellent source of pre-screened material. PRACA reports sometimes reveal enterprise-wide process deficiencies or other issues worthy of documentation as lessons learned, and they are subjected to a rigorous vetting process that includes formal analysis of proximate cause and root cause. Consequently, periodic review of the NASA/Caltech Jet Propulsion

Laboratory's (JPL's) PRACA repository by the JPL Lessons Learned Committee has enhanced the quantity and accuracy of source material for documentation of lessons that were learned from JPL spaceflight projects. A "well-incubated" PRACA report— i.e., one that has benefitted from thousands of labor dollars worth of engineering analysis and reflection— may provide ample objective evidence of a lesson that needs to be learned by other projects.

13.05 Mission Modeling, Concept Optimization and Concurrent Design

Session Organizer: Eric Mahr (Aerospace Corporation), Robert Oberto (The Aerospace Corporation),

13.0501 Operation of a Concurrent Design Facility for University Projects

Anton Ivanov (EPFL Space Center), Louis Masson (EPFL), Federico Belloni (EPFL), Larisa Pavlova (EPFL),

Presentation: Anton Ivanov, Tuesday, March 10th, 08:30 AM, Amphitheatre

Concurrent Design is a part of the systems engineering process, which has been widely adopted in space mission design. The Concurrent Design Facility at the EPFL Space Center EPFL has been operational for the last five years. We will descrobe how the concept of Concurrent Design can be used for education in space systems engineering as well as in other major fields (mechanical engineering, microelectronics). We will discuss lessons learned on how to engage students and how to include CDF studies into curriculum. We have established a process to develop both models (with engineers and senior students) and databases to create necessary ingredients for model based systems engineering. This process can be maintained, updated and synchronized with academic schedules. We have also used concurrent design for research projects beyond master level projects. Our in-house student satellite projects, allow establishing a process to validate our models and verify project requirements. CDF concept relies on social interaction between subsystem experts. The student environment is nurturing these kinds of interactions. This is one the key parts of engineering education at the Space Center.

13.0502 Concurrent Engineering Methods and Models for Satellite Concept Design

Rob Stevens (Aerospace Corporation),

Presentation: Rob Stevens, Tuesday, March 10th, 08:55 AM, Amphitheatre

A common method of spacecraft concept design is to estimate size, mass, power and cost based on parametric or analogous relationships obtained from historical satellite data from similar systems that meet similar mission requirements. These are tried and true methods often used to perform early trade space analysis that depend heavily on the relevance and accuracy of the historical data. These methods fall short, however, when the goal is to generate a concept design for a system where the historical data is insufficient or irrelevant, mission requirements are not well defined, or the intent is to break from tradition and start a blank sheet design. Often this is the case for small satellites. The discussion will focus on how Concurrent Engineering Methods may be used to perform concept designs by applying a "bottoms up" approach in a manner that can be accomplished by a single engineer or a small team of engineers, depending on the desired level of fidelity. Simple mathematical models to estimate mass, power and performance for gimbaled solar array and attitude control subsystems are presented that may be implemented using a spreadsheet. The rapid iterative nature of the concurrent engineering methodology is shown to converge to a design solution in a fraction of the time required by using non-concurrent bottoms up methods.

13.0503 Team Xc: JPL's Concurrent Design Team for CubeSat, NonSats, and SmallSats

Pezhman Zarifian (Jet Propulsion Laboratory), Travis Imken (Jet Propulsion Laboratory), Steven Matousek (Jet Propulsion Laboratory), Robert Moeller (Jet Propulsion Laboratory, California Institute of Technology), Matthew Bennett , Charles Norton (Jet Propulsion Laboratory), Farah Alibay (Massachusetts Institute of Technology), Sara Spangelo (University of Michigan), Payam Banazadeh (Jet Propulsion Laboratory),

Presentation: Pezhman Zarifian, Tuesday, March 10th, 09:20 AM, Amphitheatre

Recently there has been an increasing demand for a rapid mission concept generation capability for CubeSats, NanoSats, and SmallSats at JPL and in the broader community in the Concept Maturity Level (CML) 2-5 range. To help address these needs, JPL's Innovation Foundry has extended its long-standing advanced concepts concurrent engineering team, Team X, with a new, agile, and collaborative design capability called Team Xc. This concurrent team-based approach provides rapid turnaround for small spacecraft mission and system early concept studies. The process is adaptable to a wide variety of CubeSat, NanoSat, and SmallSat customers and mission applications. Team Xc design and analysis services include feasibility assessments, trade space exploration studies, and point design studies, commensurate with the level of maturity of the mission concept. The team is assembled with experts experienced in designing, building, launching, and operating CubeSats; leaders in mission architecture, spacecraft design, and concurrent engineering methods; and subject matter experts tailored to the specific needs of each study and customer. The Team Xc capability has been applied to several studies and extended to cover a large breadth of missions spanning applications including Earth science, planetary science, astrophysics, and technology demonstration. Team Xc draws from Team X, JPL, and external subject matter experts to produce quick-turnaround reports targeted to each customer's needs.

13.0504 A Cubesat Catalog Design Tool for a Multi-Agent Architecture Development Framework

Monica Jacobs , Daniel Selva (Massachusetts Institute of Technology),

Presentation: Monica Jacobs, Tuesday, March 10th, 09:45 AM, Amphitheatre

Large space organizations around the world are now considering CubeSats in the architecture studies for the next generations of Earth observation and communications systems. The traditional topdown approach for designing large satellites is not appropriate for CubeSats, which have many fewer components and make heavy use of COTS. This paper presents a bottom-up, catalog design tool tailored for CubeSats. A CubeSat design is represented by a valid combination of components. Components are selected from a database of existing components containing information about mass, power, volume, cost, and performance of the components. The tool has two functioning modes: forward and backward. In the forward mode, the user creates a design by selecting a combination of components from the database, and the tool computes the properties of the resulting satellite: mass, power, and volume budgets, pointing accuracy, as well as cost and other system-level properties such as reliability. In the backward mode, the user enters a set of requirements (e.g. payload mass, power, volume, pointing accuracy, orbit) and the tool finds all valid combinations of components that satisfy all the requirements, and suggests one. If no valid design exists, the tool provides a set of explanations to the user pointing out the unmet requirements. The tool uses a rule-based approach to solve the configuration design problem, and implements the MadKit interface to be able to communicate with other agents in a multi-agent design environment. This paper describes the tool in technical detail and illustrates with examples using Earth observation payloads.

13.0505 Concept Selection Method in Reverse to Describe Mission That Best Use a New Technology: Ornithopter

Daigo Terutsuki (Keio University), Xinyan Deng (Purdue University), William Crossley (Purdue University), Naohiko Kohtake (Keio University),

Presentation: Daigo Terutsuki, Tuesday, March 10th, 10:10 AM, Amphitheatre

A common approach in concept selection methods is to gather customer requirements and needs based upon missions or operational scenarios; these requirements and needs lead to objectives that are useful in concept selection methods. However, when introducing new, cutting-edge technology, it is extremely hard for researchers or developers to gather customer requirements because customers do not fully understand (or even know) the capabilities of the new technology. To tackle this problem and describe missions that would best use a bird-scale ornithopter, the authors have used a modification of the Weighted Objectives method.

13.0506 Multidisciplinary System Design Optimization of On-Orbit Satellite Assembly Architectures

David Sternberg (Massachusetts Institute of Technology), Mark Chodas (Massachusetts Institute of Technology), Christopher Jewison , Michael Jones (Massachusetts Institute of Technology), Olivier De Weck (Space Systems Laboratory),

Presentation: David Sternberg, Tuesday, March 10th, 10:35 AM, Amphitheatre

Multidisciplinary system design optimization is performed to determine an optimal on-orbit satellite assembly mission architecture. There are many benefits over the current method for relying on monolithic launches of complete satellites, such as reducing the net launch cost from launching multiple, smaller satellites and capitalizing upon rideshare programs. Additionally, launching satellites to be assembled on orbit increases the versatility of deployment by not restricting launches on account of payload weight capacity or geometric envelope, but by instead relying on reconfiguration on orbit to achieve a final operational configuration. To facilitate the realization of these and other benefits, this paper addresses the architecture of an on-orbit assembly mission that requires assembly satellite(s) to rendezvous with customer modules and assemble them into a complete satellite in the desired orbit. A model of this assembly mission is created. Five design variables are identified for this model, namely, the number of assembler satellites, the number of modules each assembler can manipulate at once, the starting location of each assembler, the autonomy level of the assemblers, and type of transfer orbits utilized by the assemblers. By varying these five aspects of the mission, an optimization is carried out which seeks to minimize total cost of the assembler mission and downtime of the customer satellites while holding to certain parameters and meeting constraints. This paper presents the problem, a simulation of the problem, the optimization methodology, and the results of that optimization.

13.0507 Multidisciplinary Design Optimization for a High-Resolution Earth-Imaging Constellation

Michael Curry (Massachusetts Institute of Technology),

Presentation: Michael Curry, Tuesday, March 10th, 11:00 AM, Amphitheatre

Imaging of the Earth's surface is a desired capability for many applications and problem domains. Space-based systems provide a unique platform that can provide persistent coverage over a wide region and have many advantages over atmospheric systems. The case study described here starts with the development of a concise mission statement for an affordable constellation of high-resolution Earth imaging satellites. The problem is modeled using integrated multidisciplinary analysis modules that were validated through simulation and comparison to three known real-world systems. Through

multiple techniques a Pareto Front of non-dominated designs is identified. Two candidate designs, which are on the Pareto front and balance the cost versus performance tradeoff, are identified through two different heuristic optimization methods, simulated annealing and genetic algorithms. Drivers of key trades are shown to be primarily driven by a subset of design variables. This is further shown to create three distinct design regions which trade-off system performance and cost.

13.0508 Subsystem Support Feasibility for Formation Flight Measuring Bi-Directional Reflectance

Sreeja Nag (Massachusetts Institute of Technology), Kerri Cahoy (Massachusetts Institute of Technology), Olivier De Weck (Space Systems Laboratory),

Presentation: Sreeja Nag, Tuesday, March 10th, 11:25 AM, Amphitheatre

Distributed Spacecraft Missions can be used to improve science performance in earth remote sensing by increasing the sampling in one or more of five dimensions: spatial, temporal, angular, spectral and radiometric. This paper identifies a gap in the angular sampling abilities of traditional monolithic spacecraft and proposes to address it using small satellite clusters in formation flight. The angular performance metric chosen to be Bi-directional Reflectance Distribution Function (BRDF), which describes the directional and spectral variation of reflectance of a surface element at any time instant. Current monolithic spacecraft sensors estimate it by virtue of their large swath (e.g. MODIS, POLDER), multiple forward and aft sensors (e.g. MISR, ATSR) and autonomous manoeuvrability (e.g. CHRIS, SPECTRA). However, their planes of measurement and angular coverage are limited. This study evaluates the technical feasibility of using clusters of nanosatellites in formation flight, each with a VNIR (visible and near infra-red) imaging spectrometer, to make multi-spectral reflectance measurements of a ground target, at different zenith and azimuthal angles simultaneously. Feasibility is verified for the following mission critical, inter-dependent modules that need to be customized to fit specific angular and spectral requirements: cluster geometry (and global orbits), guidance, navigation and control systems (GNC), payload, onboard processing and communication. Simulations using an integrated systems engineering and science evaluation tool indicate initial feasibility of all listed subsystems.

13.06 Systems Architecture, Engineering and System of Systems

Session Organizer: Henry Stone (Jet Propulsion Laboratory),

13.0601 SMART: A Quantitative Trade Analysis and Risk Assessment Tool for a Complex Mission

Masahiro Ono (JPL), Austin Nicholas (Massachusetts Institute of Technology), Farah Alibay (Massachusetts Institute of Technology), Joseph Parrish (Jet Propulsion Laboratory),

Presentation: Masahiro Ono, Wednesday, March 11th, 10:35 AM, Madison

This paper introduces a new trade analysis software called the Space Mission Architecture and Risk Analysis Tool (SMART). This tool supports a high-level system trade study on a complex mission, such as a potential Mars Sample Return (MSR) mission, in an intuitive and quantitative manner. In a complex mission, a common approach to increase the probability of success is to have redundancy and prepare backups. Quantitatively evaluating the utility of adding redundancy to a system is important but not straightforward, particularly when the failure of parallel subsystems are correlated. SMART offers the unique capability of handling correlated redundancies and accurately evaluating the probability of mission success as well as its sensitivity to the reliability of mission components. It can also perform Monte-Carlo analysis to find the confidence interval of the success probability, total mission cost, and total mass. Additionally, SMART provides a GUI interface based on Matlab/Simulink that allows users to graphi-

cally define mission architecture as well as the logical relationship between mission components and outcomes. These analysis capabilities enable to answer questions such as:□"for a given upper bound on total cost and mass, or which subsystem we should implement redundancy to maximize the chance of mission success?"□The analysis capabilities are enabled by our unique propositional logic-based approach. □SMART translates the graphical mission model to a propositional logic representation through symbolic computation.□We demonstrate SMART's analysis capabilities on a MSR model as well as a model of a fictional mission.

13.07 Technology Transfer and Infusion

Session Organizer: Howard Neely (Three Birds Systems), Andrea Belz (USC Marshall School of Business),

13.0701 Translating Technology Taxonomies to Facilitate Cross-Industry Innovation

Alexandra Landegger , Brady Decker (NASA), Jill Hardash (Booz Allen Hamilton),
Presentation: Jill Hardash, Wednesday, March 11th, 10:35 AM, Elbow 1

Innovate.Gov—is a cross-government extension of the Innovate.NASA (https://innovate.nasa.gov) platform, which was designed to crowdsource new opportunities for NASA technology. Innovate.Gov is a virtual collaboration platform to share technology across Federal agencies and serves as a unified hub for the public to access and innovate with government technology. Using this platform, government agencies share out technology information and engage the public to innovate with these inventions. The Innovate.Gov community collaborates to design improvements and integrations to revitalize these inventions, or propose new applications for these technologies (within and outside of their respective agencies). Innovate.Gov targets participants across a full range of organizations, professions, and areas of expertise, including: government, academia, research labs, private industry, and independent innovators. In order to fulfill the Innovate.Gov mission, technology information posted to the website must be made accessible to this diverse group of participants by applying a universal technology taxonomy. This presentation explores our approach, challenges and solutions to translate the language of each agency’s technology across multiple disciplines to enable Innovate.Gov to tap into the power of open innovation.

13.08 Promoting (and Provoking) Cultural Change

Session Organizer: David Scott (NASA - Marshall Space Flight Center),

13.0801 The Rebirth of the US Space Program: In through the Out Door

Michael Mc Grath (LASP University of Colorado),
Presentation: Michael Mc Grath, Friday, March 13th, 08:30 AM, Gallatin

In the beginning there were two, two decades later a few, and now more than sixty countries have national space programs. The “culture” of space is changing as the world community joins – advancing New Space ideals vs. Old Space lessons learned. In observing the global space market evolve in Europe, Asia, the Middle East, Africa, and North America, contrasts in behaviors between the established players and new entrants into the space enterprise are beginning to show. This paper will discuss behavioral trends within the US space enterprise that, while well intended, are isolating the US from the growing international space enterprise, and in doing so seem to be enabling a new space culture outside of the US. Removing the US from the world space market may ultimately hold opportunity to reinvigorate the US space community. This paper will discuss how the world market is evolving, identify the new behaviors that are coming into play, and offer suggestions for how the US space enterprise might benefit from these.

13.0802 On the Need for Significant Reform to Aerospace Engineering Education

Lyle Long (Penn State Univ.),

Presentation: Lyle Long, Friday, March 13th, 08:55 AM, Gallatin

This paper discusses the need for academia to be more responsive to the needs of students and society. The slow speed of change in academia is causing our educational programs to lose value. Technology has been advancing at an exponential rate for decades, yet academia changes at almost glacial speed. While the example used herein (engineering, and in particular aerospace engineering) is one familiar to the author, the ideas in this paper apply to all academic disciplines, including Science and Liberal Arts. The problems are due to rapid changes in technology, inflated bureaucracies at universities, the emphasis on revenue and research, and limits to human learning. There is no question that this is the Information Age, yet academia has not adjusted to this dramatic new world. Academia has changed little in 500 years, and aerospace engineering curricula has changed little in 30 years. Students need to understand this and be pro-active to prepare themselves for the future and choose the right courses, majors, and universities. The paper also discusses how Penn State University has been trying to address these issues.

13.0803 Germinating the 2050 Cis-Lunar Econosphere

David Scott (NASA - Marshall Space Flight Center), Peter Curreri (NASA - Marshall Space Flight Center), Cynthia Ferguson (NASA - Marshall Space Flight Center), Jessica Gaskin (NASA - Marshall Space Flight Center), Joshua Moore , Mark Nall (NASA - Marshall Space Flight Center), Michael Tinker (NASA Marshall Space Flight Center), Gregory Wright (NASA - Marshall Space Flight Center),

Presentation: Jessica Gaskin, Friday, March 13th, 09:20 AM, Gallatin

In early 2013, Marshall Space Flight Center’s upper management chartered a diverse team for a six-week “sprint” to envision how earth, space, and public/private entities might be operating and relating to each other… in the year 2100. In 2014, the "Space 2100” team, ran a slightly longer exercise to a) develop more detailed estimates of the operations and economics of space activities in the vicinity of the Earth and Moon in the 2050 time frame, b) identify evolutionary paths, barriers, and opportunities, and c) suggest actions and philosophies to enable and invigorate progress towards the vision. This paper explores Space 2100's first two sprints, how they’ve enhanced cross-discipline communication, and projections of NASA’s role in what will likely be a highly networked, international space industry and cis-lunar infrastructure.

13.0804 Creating Robust Human –Intensive Systems: A Systems Engineering Approach

Robert Wright (Raytheon Space and Airborne Systems),

Presentation: Robert Wright, Friday, March 13th, 09:45 AM, Gallatin

Engineers are really good at making cool things, and they're used to following a good systems engineering-based product development process along the way. However, what happens when human beings are an integral part of the operation of your system? Designing "bullet proof" systems which intimately involve humans as part of the system solution is difficult for many reasons. This paper addresses some of the special needs of human-intensive systems, and offer a framework to help systems engineers think through everything they'll need in place to create a human intensive system that works.

TRACK 14: GOVERNMENT PLANS, POLICIES AND EDUCATION

Track Organizers: Dave Lavery (NASA Headquarters),

14.01 Panel: Competition Robotics for Education and Workforce Development

Session Organizer: Dave Lavery (NASA Headquarters),

14.02 Panel: Technology Development for Science-Driven Missions

Session Organizer: Patricia Beauchamp (Jet Propulsion Laboratory),

14.03 Panel: Emerging Technologies for Mars Exploration

Session Organizer: Charles Edwards (Jet Propulsion Laboratory),

14.04 Panel: Mars Sample Return: Updates and Alternatives

Session Organizer: Lisa May (NASA Headquarters),

14.05 Panel: Mission Options and Technologies for Human Exploration

Session Organizer: Robert Ambrose (NASA - Johnson Space Center),

14.06 Panel: Access To Space and Emerging Mission Capabilities

Session Organizer: Eleni Sims (Aerospace Corporation),

14.07 Panel: Operational Uses of Consumer-Class Unmanned Aerial Vehicles

Session Organizer: Jeff Norris (NASA Jet Propulsion Laboratory), Dave Lavery (NASA Headquarters),

14.08 PANEL: Model-based Engineering – Paradigm Shift or Business as Usual?

Session Organizer: Sanda Mandutianu (Jet Propulsion Laboratory),

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