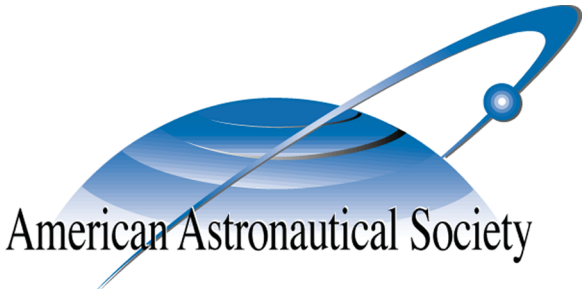
PROMOTE THE PROGRESS OF THE PACIFIC-BASIN REGION THROUGH SPACE INNOVATION

Front Cover Illustration:

Launch of the Epsilon-3 rocket from Uchinoura Space Center on January 18, 2018 carrying the radar satellite ASNARO-2 to a sun-synchronous orbit (Credit: JAXA).



PROMOTE THE PROGRESS OF THE PACIFIC-BASIN REGION THROUGH SPACE INNOVATION

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Edited by
Arun K. Misra
LI Ming
Yasuhiro Morita

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FOREWORD

This proceedings volume, which consists of one hard cover bound volume and a CD ROM supplement (also available in digital format), includes the available papers presented at the Fifteenth International Space Conference of Pacific-basin Societies (ISCOPS), July 10-13, 2018, Montréal, Québec, Canada. This sequence of ISCOPS volumes is usually published as a part of the AAS *Advances in the Astronautical Sciences* series. Earlier ISCOPS proceedings volumes are available through the American Astronautical Society as follows:

(1) The first symposium was held December 15-19, 1985 in Honolulu, Hawaii and was published as Volume 60, *Advances in the Astronautical Sciences* titled **Space Exploitation and Utilization**.

(2) The second symposium was held June 7-10, 1987 in Beijing, China. This publication was published in China and titled **Proceedings of the Pacific Basin International Symposium of Advances in Space Science Technology and its Applications (PISSTA)**.

(3) The third symposium was held November 6-8, 1989 in Los Angeles, California and was published as Volume 73, *Advances in the Astronautical Sciences* titled **Space Utilization and Applications in the Pacific**.

(4) The fourth symposium was held November 17-20, 1991, Kyoto, Japan and was published as Volume 77, *Advances in the Astronautical Sciences* titled **International Space Year (ISY) in the Pacific Basin**.

(5) The fifth symposium was held June 6-9, 1993, Shanghai, China. This volume was published in China (not available through the AAS).

(6) The sixth symposium was held December 6-8, 1995, Marina Del Rey, California, U.S.A. and was published as Volume 91, *Advances in the Astronautical Sciences* titled **Strengthening Cooperation in the 21st Century**.

(7) The Seventh symposium was held July 15-18, 1997, Nagasaki, Japan, and was published as Volume 96, *Advances in the Astronautical Sciences* titled **Space Cooperation into the 21st Century**.

(8) The eighth symposium was held June 23-26, 1999, Xian, China. This volume was published in China (not available through AAS).

(9) The ninth symposium was held November 14-16, 2001, Pasadena, California, U.S.A. and was published as Volume 110, *Advances in the Astronautical Sciences* titled **Space Development and Cooperation Among All Pacific Basin Countries**.

(10) The tenth symposium was held December 10-12, 2003, Tokyo, Japan, and was published as Volume 117, *Advances in the Astronautical Sciences* titled **Space Activities and Cooperation Contributing to All Pacific Basin Countries**.

(11) The eleventh symposium was held May 16-18, 2007, Beijing, China (not available through AAS).

(12) The twelfth symposium was held July 27-30, 2010, Montréal, Québec, Canada, and was published as Volume 138, *Advances in the Astronautical Sciences* titled **Applications of Space Technology for Humanity**.
(13) The thirteenth symposium was held May 15-18, 2012, Kyoto, Japan, and was published as Volume 146, *Advances in the Astronautical Sciences* titled **Space for Our Future**.
(14) The fourteenth symposium was held May 28-30, 2014, Xi'an, China (not available through AAS).

Several other sequences or subseries have been established in the *Advances in the Astronautical Sciences* series. Among them are: Astrodynamics, Spaceflight Mechanics, Guidance, Navigation and Control, and various other AAS-sponsored or co-sponsored conferences. Proceedings volumes for earlier conferences are still available either in hard copy or in microfiche form, and more recent volumes are available in digital format. The appendix at the end of this volume lists proceedings available through the American Astronautical Society.

In proceedings volumes of the American Astronautical Society the technical accuracy and editorial quality are essentially the responsibility of the authors because the papers are essentially composed of camera-ready copy provided by the authors. The reader should bear in mind that for an international conference, such as the Fifteenth ISCOPS, many papers were prepared by authors whose native language is not English. The session chairs and our editors do not review all papers in detail; however, format and layout are improved when necessary by our editors. In some cases the English is improved so it reads better. For this conference, the many authors whose native language is not English are to be congratulated on the quality of material submitted and are to be thanked for their significant contributions to this English-language volume. The editors wish to express their thanks to all those who have contributed to the success of this conference and to authors for their efforts in finalizing material for publication.

Robert H. Jacobs
Series Editor
Advances in the Astronautical Sciences

PREFACE

The Fifteenth International Space Conference of Pacific-basin Societies (15th ISCOPS), under the theme "Promote the Progress of the Pacific-basin Region through Space Innovation" was held at McGill University, Montreal, Canada from July 10 to July 13, 2018. This conference was the fifteenth in a continuing series of biennial conferences co-sponsored by the American Astronautical Society (AAS), the Chinese Society of Astronautics (CSA), and the Japanese Rocket Society (JRS).

The final program of the conference consisted of 62 presentations in total, including the Plenary Lectures as well as papers presented in nine Technical Sessions and in two International Student Competition Sessions. This volume of Proceedings includes most of the papers presented in the technical and student competition sessions. The topics covered in the nine technical sessions were Astrodynamics, Guidance and Control (2 sessions), Launch Vehicles, Space Exploration and Space Robotics, Space Power and Propulsion, Small Satellites, Formation Flying and Constellations, Space Materials and Structures, Space Systems and Infrastructure, as well as Space Debris.

The organizing committee of the 15th ISCOPS gratefully acknowledges the financial and logistical support provided by the McGill Institute for Aerospace Engineering (MIAE). The organizers are also grateful to the Canadian Space Agency and Dr. Alfred Ng for arranging an excellent technical tour.

We greatly appreciate the patience and painstaking effort of Mr. Robert H. Jacobs, the AAS Series Editor, in producing these Proceedings. We would also like to thank all the authors, session chairs and conference attendees who made the 15th ISCOPS a success.

The 16th ISCOPS will be hosted by the Japanese Rocket Society (JRS) in Japan and is planned for 2020. We look forward to working together again to ensure the continued success of the ISCOPS series.

Arun K. Misra (AAS)
LI Ming (CSA)
Yasuhiro Morita (JRS)

Fifteenth ISCOPS Technical Tour to John H. Chapman Space Centre, Saint-Hubert, Quebec, Canada; 13 July 2018 (Source: Canadian Space Agency).

CONTENTS

INTERNATIONAL STUDENT COMPETITION Ph.D. LEVEL

Session C.1

Session Chairs:

A. Ng and LI Ming

The following papers were not available for publication:

AAS 18-708 “Effects of Swirling Oxidizer Flow on Fuel Regression Rate of the Low Melting Point Thermoplastic Fuel for Hybrid Rockets,” by Yo Kawabata, Chiba Institute of Technology (Not Available; Oral Presentation Only)

AAS 18-710 “Onboard Trajectory Optimization for Small Body Landing in Hazardous Terrains,” by Xu Yuan, BIT (Not Available; Oral Presentation Only)

AAS 18-704

FLIGHT TEST RESULTS OF PARAFOIL-TYPE VEHICLE WITH INFLATABLE STRUCTURE FOR THE MARTIAN EXPLORATION

Takahiro Moriyoshi,[*] Kazuhiko Yamada,[†]
Shinichiro Higashino[‡] and Hiroyuki Nishida[§]

One of the technologies to make the future planetary exploration more flexible and valuable is a vehicle which can fly freely in the Martian atmosphere. Our group proposes a paraglider which has a flexible and inflatable wing. The paraglider has a large and light wing which can be packed compactly in the launch and cruising phase. To realize this idea, free flight test from high altitude by the Atmospheric balloon must be carried out. However, it is difficult to succeed flight test from beginning. Therefore, we're going to carry out a relatively simple flight test from low altitude. In this study, result of flight test was reported. [View Full Paper]

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AAS 18-705

SPACE TRANSPORTATION SYSTEMS ENABLED BY A DRAMATIC REDUCTION OF STRUCTURAL MASS

Tomotaro Muto[*] and Yoshifumi Inatani[†]

Application of carbon nanotubes (CNTs) expects the realization of launch vehicles whose body is extremely lightweight. In this study, sizing of rocket-powered single-stage-to-orbit (SSTO) vehicles was conducted considering dramatic reduction of structural mass. Focusing on takeoff and landing methods, sizing and weight estimation were conducted on three vehicle configurations: horizontal takeoff & horizontal landing (HTHL), vertical takeoff & horizontal landing (VTHL) and vertical takeoff & vertical landing (VTVL). The design variables that minimize the gross take-off mass were determined by a genetic algorithm (GA) and the integrated optimization of vehicle shape and flight trajectory was performed. Sizing results clarified the required level of development of lightweight materials to establish SSTO vehicles whose body size is realistic. In addition, it turned out that the optimum vehicle configuration changes significantly based on the improvement of lightweight materials. It was suggested that landing is possible even with small wings or minimal propellant since the vehicle is very light-weight when landing. This research presented a new viewpoint that the design of a space transportation system greatly changes if the structural mass is dramatically reduced. [View Full Paper]

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AAS 18-706

CHARACTERISTICS OF COUPLED ORBITAL-ATTITUDE DYNAMICS OF FLEXIBLE ELECTRIC SOLAR WIND SAIL

Gangqiang LI[*] and Zhenghong ZHU[†]

This paper studies the dynamics of a tethered system with a moving climber in circular orbits in the framework of arbitrary Lagrangian-Euler (ALE) finite element method. The tethered space system is modeled by the nodal position finite element method, and the climber is implemented by positioning it at a moving node on the one-dimension medium, which is realized by variable-length element at either side of the moving node. The moving of climber is described by the increasing of the length on one side of the one-dimensional medium and a corresponding decreasing of the other side. The governing equations for the coupled system are derived in terms of D'Alembert's principle and the constraint equations are formulated in the standard form of differential algebraic equations of multibody systems. The technology of eliminating and adding of node is implemented to describe the climber moving along the flexible tether system. The dynamic response of the system when the moving climber moves along the tether connecting the two satellites is computed and analyzed. [View Full Paper]

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AAS 18-707

IMPACT OF THE SHAPE OF THE PRIMARY BODIES OF A BINARY ASTEROID SYSTEM ON THE DYNAMICS OF A SPACECRAFT IN ITS VICINITY

Isabelle Jean*

The interest for the development of the models of the dynamics of a spacecraft in the vicinity of binary asteroids is rapidly growing with the possibility of missions such as the Asteroid Impact and Deflection Assessment (AIDA) to binary asteroid 65803 Didymos. In the vicinity of a binary asteroid system, the gravitational potential is more complex than in the case of a system where both bodies can be modeled as spheres, like it is the case for the Earth-Moon system. The present study develops the gravitational potential of binary asteroids, having a combination of triaxial ellipsoids, peanut and double truncated cone shapes, based on the calculation of their second and fourth order moments of inertia. The model developed is easily implementable and can give a good estimation of possible trajectories to early mission development teams. [View Full Paper]

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AAS 18-709

THERMAL FLUID CHARACTERISTICS OF BOILING HYDROGEN IN A HORIZONTAL CIRCULAR PIPE FLOW

Yuki Sakamoto,[*] Hiroaki Kobayashi,[†] Yoshihiro Naruo,[†] Yuichiro Takesaki,[‡] Shohei Tane,[*] Kazuma Minote,[*] Yo Nakajima,[*] Atsuhiro Furuichi,[*] Hiroki Tsujimura,[*] Koki Kabayama[*] and Tetsuya Sato[§]

The aim of this study is a characterization of boiling hydrogen flow in horizontal circular pipe flow. The most important parameters for boiling flow are a void fraction and flow quality. Although the void fraction is measurable in some way, there is no established method for cryogenic fluid. The authors developed a capacitive void fraction sensor and applied it for boiling hydrogen flow experimental facility. The correlations between the void fraction and flow qualities are investigated by comparing the previously proposed models. The conversion model of the combination of Sekoguchi simple model and the Steiner model agrees very well with the experimental result. [View Full Paper]

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INTERNATIONAL STUDENT COMPETITION MASTER LEVEL

Session C.2

Session Chairs:

A. Ng and LI Ming

AAS 18-711

SPACE DEBRIS COLLISION AVOIDANCE FOR RECONFIGURABLE SPACECRAFT ELECTROMAGNETIC FORMATION FLYING

Yuchen Xie[*] and Jingrui Zhang[†]

This paper investigates the reconfiguration problem of Spacecraft Electromagnetic Formation Flying (EMFF) in a space debris environment. The proposed electromagnetic formation system consists of two cubic spacecraft using electromagnetic coils as actuators. In the real situation of formation flight, distances between the two cubic electromagnetic spacecraft are confined to a proper range. Firstly, the dynamic equations are derived by utilizing the Lagrange Method. Secondly, the optimal control problem is studied to obtain optimal trajectory of cubic spacecrafts under the constraints of inter-satellite collision avoidance, and collision avoidance between formation members and orbiting space debris as well, which is solved by using Gauss Pseudospectral Method (GPM). Finally, numerical simulation verifies the effectiveness of the proposed method.

[View Full Paper]

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AAS 18-712

NUMERICAL STUDY ON AERODYNAMIC IMPROVEMENT OF SLENDER-BODIED REUSABLE ROCKET BY FINS AND VORTEX FLAPS

Yuya Takagi,[*] Takuya Aogaki,[†] Keiichi Kitamura[‡] and Satoshi Nonaka[§]

Although many rockets have been launched so far, those conventional rockets have some problems such as high launching cost due to lack of reusability. Therefore, in Japan, the development of a reusable vertical-takeoff-and-vertical-landing (VTVL) rocket vehicle is being promoted, and the nose entry system is adopted as a returning flight system, in which the attitude changes (=turnover) by aerodynamic force, the engine re-ignites, and then the rocket lands on the ground. In order to accomplish this turnover safely, it is known to be necessary to reduce the difference between the maximum value and the minimum value of Cm (the pitching-moment coefficient). In this research, we attached the delta-wing with vortex flaps as fins to the reusable rockets in order to improve Cm characteristics during turnover. By attaching fins (the flap deflection angle is 0°: Flap_0), the nose-up Cm becomes smaller than the case without fins (Body-alone) at forward angles (angles of attack 0 – 90 degrees), but unfortunately, the nose-down Cm becomes larger at backward angles (AOA 90 – 180 degrees). On the other hand, by setting the flap deflection angle to -30° (Flap_-30), the nose-down Cm becomes smaller than that of Flap_0 at backward angles. Therefore, by setting Flap_0 at forward angles and Flap_-30 at backward angles, the difference between the maximum value and the minimum values of Cm can be reduced (12% smaller than Body-alone). [View Full Paper]

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AAS 18-713

FAULT DETECTION AND REMAINING USEFUL LIFE PREDICTION OF REACTION WHEELS ONBOARD KEPLER SPACECRAFT*

Vasanth Dhanagopal† and Krishna D. Kumar‡

In this paper faults of the reaction wheels onboard Kepler Spacecraft are analyzed using telemetry data received from the Kepler mission. The yearly sets of data which include the critical parameters of the mission namely speed, torque commands, rotor temperature, torque friction and attitude error are used for analysis. Feature of the data is extracted with correlation method. Ensuring the input is appropriate for normal distribution, it is further intrigued with Weibull analysis and classical friction theory model with linear function. Results of the analyses show that RW2 and RW4 have an early sign (~2 months) of their respective failures. While RW1 and RW3 data do not contain any anomaly and therefore, RW1 and RW3 are excepted to have more than 5 years of operational life. [View Full Paper]

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AAS 18-714

EXPERIMENTAL INVESTIGATION OF C* EFFICIENCY IN NITROUS OXIDE HYBRID ROCKETS

Erika Uchiyama,[*] Yurika Kiyotani,[†] Landon Kamps[‡] and Harunori Nagata[§]

Hybrid Rockets have advantages of low cost and high safety but there are few practical uses at the current state of the art. The combustion characteristics of N2O, which is very useful oxidizer, have not been researched in particular. This study is the investigation to clarify the dependency of the c* (characteristic exhaust velocity) efficiency ηc* in nitrous oxide (N2O) hybrid rockets on operating conditions through experimentation. Several firing tests were conducted using a 200N thrust class conventional hybrid rocket motor employing high density polyethylene (HDPE) as the fuel and liquid nitrous oxidizer as the oxidizer. The results reveal that there is no clear dependency of ηc* on mixture ratio, pressure or characteristic length, suggesting that efficiency must be improved through other design parameters. [View Full Paper]

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ASTRODYNAMICS, GUIDANCE AND CONTROL

Sessions B.1.1 and B.1.2

Session Chairs:

K. D. Kumar and K. Ui

The following papers were not available for publication:

AAS 18-715 “Multi-Objective Optimization for Spacecraft Station Keeping on Libration Halo Orbits of the Earth-Moon System,” by Y. Zhang, BIT (Paper Withdrawn)

AAS 18-721 “A New Strategy of Beam Pointing Steering for High Resolution Sliding Spotlight SAR by Satellite Attitude Maneuver,” by H. Yu, CASC (Paper Withdrawn)

AAS 18-723 “Research on Satellite System Failure Mode and Effects Analysis Method Applied Model-Based Systems Engineering,” by Y. Mao, CASC (Paper Withdrawn)

AAS 18-724 “A Method of Mission Optimization Based on Satellite Dynamic Imaging Modeling and Efficacy Evaluation,” by X. Zhang, CASC (Paper Withdrawn)

AAS 18-716

OVERVIEW OF SOLAR ELECTRIC SAIL THRUST MODELING FOR TERRESTRIAL PLANETS FLYBY MISSIONS

Harijono Djojodihardjo*

Since the introduction Solar Electric Sailing by Janhunen in 2004 for interplanetary travel, it has progressed significantly both in its theoretical, laboratory and experimental flight tests. The electric solar wind sail (E-sail) is a newly invented space propulsion concept which uses the natural solar wind dynamic pressure for producing thrust for a spacecraft by Coulomb interaction. The baseline con-figuration of an E-sail comprises a number of long, thin, conducting and centrifugally stretched tethers; by an onboard electron gun these are kept in a high positive potential. Associated with these issues and studies, the status of solar electric sailing is comprehensively reviewed in view of their relevance. Variability of Solar Wind Field in the Solar System and Influence of Solar wind field fluctuations on solar electric sail thrust for various solar electric propulsion architecture configuration and thrust vectoring of an electric solar wind sail with a realistic sail shape will be addressed. The paper review salient features and baseline thrust modeling of E-sail spacecraft for terrestrial planets flyby missions and assess some analytical trajectory predictions in view of their relevance. [View Full Paper]

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AAS 18-717

MULTIBODY MODELING OF SPACE ELEVATOR SYSTEM WITH THE ARBITRARY LAGRANGIAN-EULER NODAL POSITION FINITE ELEMENT METHOD

Gangqiang LI[*] and Zhenghong ZHU[†]

This paper studies the dynamics of a tethered system with a moving climber in circular orbits in the framework of arbitrary Lagrangian-Euler (ALE) finite element method. The tethered space system is modeled by the nodal position finite element method, and the climber is implemented by positioning it at a moving node on the one-dimension medium, which is realized by variable-length element at either side of the moving node. The moving of climber is described by the increasing of the length on one side of the one-dimensional medium and a corresponding decreasing of the other side. The governing equations for the coupled system are derived in terms of D'Alembert's principle and the constraint equations are formulated in the standard form of differential algebraic equations of multibody systems. The technology of eliminating and adding of node is implemented to describe the climber moving along the flexible tether system. The dynamic response of the system when the moving climber moves along the tether connecting the two satellites is computed and analyzed. [View Full Paper]

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AAS 18-718

SEQUENTIAL JOINT ESTIMATION OF A MULTI-AGENT SYSTEM IN CONSENSUS TRACKING WITH UNCERTAIN DYNAMICS

Michael Rososhansky,[*] Kaustav Jyoti Borah[†] and Krishna Dev Kumar[‡]

In this research, a new filter is proposed based on Rao-Blackwellize principle where the particle filtering technique is coupled with unscented transform algorithm for online joint estimation. The new filter is known as marginalized unscented particle filter (MUPF). The proposed filter is applied to an uncertain dynamic system which describe the evolution of a distributed multi-agent system in consensus tracking. A Chebyshev neural network (CNN) is incorporated to describe the uncertain dynamics of the multi agent system while nonlinear filtering policies are implemented to estimate the state of the multi-agent system and to train the internal parameters of the neural network as neatly as possible given a set of prior measurements. Much of the emphasis here is on variance reduction in the joint estimation process, as well as the capacity to train CNN to determine the uncertain dynamics of the system. Finally, obtained simulation results are compared to the adaptive law which has been proposed for estimating the internal parameters of CNN.

[View Full Paper]

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AAS 18-719

FAILURE PROGNOSIS AND REMAINING USEFUL LIFE OF CONTROL MOMENT GYROSCOPES ONBOARD SATELLITES

Venkatesh Muthusamy[*] and Krishna Dev Kumar[†]

Developing a Diagnosis, Prognosis and Health Monitoring (PHM) framework for a small satellite is a challenging task due to the limited availability of onboard health monitoring sensors and computational budget. This paper deals with the problem of developing PHM framework for a satellite attitude actuator system that uses single gimballed Control Moment Gyros (CMG) in a pyramid configuration using only the attitude measurement data to eliminate the need for subsystem level sensor data acquisition. A data-driven model is used to mimic the nominal plant dynamics and fault is induced in the spin motor of the CMG of the satellite dynamics to generate run to failure data of the attitude control system. A novel scheme is used for developing a data-driven model which fuses the symmetric property of the data and the system orientation property of actuators that reduces the need for historical data by 93.75% and Chebyshev Neural Network is used as a data-driven model. General path model is used for to capture the prognosis of the system and using the parameters from general path model as apriori information, Bayesian updating technique is used to predicting remaining useful life of a system in real time. The algorithm performs with 96.25% accuracy when 30% of data is available for online prediction. [View Full Paper]

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AAS 18-720

ATTITUDE CONTROL OF SOLAR POWER SAIL-CRAFT "OKEANOS"

Motoki Watanabe,[*] Toshihiro Chujo,[†] Osamu Mori[‡] and Yoshiki Sugawara[§]

It is generally known that attitude of spacecraft having angular momentum on the spin axis moves like a vortex due to the influence of solar radiation pressure. Taking advantage of this motion, this paper proposes attitude control methods using biased (pseudo) equilibrium point. Slight change of the equilibrium point leads to stabilization of the motion. As the merit, only constant input achieves this proposed method. The purpose of this study is to verify the usefulness of the control method by performing numerical analysis on the stability of attitude motion. [View Full Paper]

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AAS 18-722

LAGRANGIAN AND HAMILTONIAN FORMULATION AND ENERGY CONTROL FOR TETHERED SATELLITES DEPLOYMENT/RETRIEVAL

Junjie Kang[*] and Zheng H. Zhu[†]

In this paper, the dynamics equations of the tethered satellites system are derived by Lagrangian and Hamiltonian formulation, respectively. The relation between the Lagrangian and Hamiltonian is shown by Legendre transformation. The goodness of the Hamiltonian formulation is intuitive to reveal the Energy balance property as well as the passivity property from the Lagrangian formulation. In order to bring the system into operations, the energy based control is to achieve the tethered system for precise positioning. Hamiltonian energy function of tethered system is employed for facilitating the controller design. Simulations are used to verify the effectiveness of the proposed controllers.

[View Full Paper]

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LAUNCH VEHICLES

Session B.5.1

Session Chair:

J. Kashara

The following paper was not available for publication:

AAS 18-731 “System Study for Reusable Launch Vehicle as Future Operational Launcher,” by Y. Saito, JAXA (Paper Withdrawn)

AAS 18-725

CHALLENGE IN SOLID FUEL ROCKET TECHNOLOGIES

Yasuhiro Morita*

The JAXA had the third launching of the Epsilon launch vehicle in January 2018 to carry Earth observation Radar Satellite, ASNARO-2, into its SSO trajectory as the launch was epoch-making in the history of Japan's solid fuel rockets: firstly, it completed the Enhanced Epsilon program to make Epsilon more competitive in the world; secondly, it was the very first time Japan's solid rocket was utilized to a private company's satellite. In order to launch larger and heavier payload with minimized cost impact, the Enhanced Epsilon program was initiated just after the Epsilon made its maiden flight in September, 2013. The high performance and low-cost technologies of the Enhanced Epsilon is applied to the H3 program, now underway. In return, part of the low-cost components of H3 is to be utilized to upgrade the Epsilon afterward. It is called Epsilon's Synergy Development, which is to maximize the level of collaboration and utilize the H3 components as much as possible. Beyond this upcoming development, further evolution of the Epsilon is directed toward higher performance and lower cost launch systems under the novel design concept, "Universal Design" that is aimed at strong collaboration with even different industries. This paper reveals the design concept of the Epsilon and provides the future prospect of solid fuel rockets with examples including some of the associated academic researches that have been conducted by strong collaborations between JAXA and private companies including so called new space players. [View Full Paper]

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AAS 18-726

DEVELOPMENT RESULTS OF ENHANCED EPSILON LAUNCH VEHICLE AND FUTURE PLAN

Koji Nakaya[*] and Takayuki Imoto[†]

In 2014, Japan Aerospace Exploration Agency (JAXA) started development of the Enhanced Epsilon launch vehicle to meet predicted demands for launches in the small satellite market after successful maiden flight of Epsilon-1. The goals of the development are "to improve launch capacity (30% increase compared to Epsilon-1)" and "to expand fairing for large payloads". Epsilon-2, which was the first flight of the Enhanced Epsilon, demonstrated extended elliptical orbit mission successfully in 2016. Epsilon-3 then succeeded in demonstration of sun-synchronous orbit mission in 2018. JAXA completed the development of the Enhanced Epsilon launch vehicle through the two demonstration flights. This paper summarizes results of the development and demonstration flight. Two future plans are also referred. [View Full Paper]

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AAS 18-727

DEVELOPMENT AND FLIGHT RESULT OF GUIDANCE AND CONTROL SYSTEM FOR ENHANCED EPSILON LAUNCH VEHICLE

Hiroyuki Yamaguchi,[*] Yasuhiro Morita,[*]
Takayuki Imoto,[*] Takayuki Yamamoto,[*] Takanao Saiki,[*]
Hirohito Ohtsuka[†] and Kensaku Tanaka[†]

The Epsilon launch vehicle, the newest version of Japan's solid propulsion rocket, made its maiden flight in September of 2013. The purpose of the Epsilon launch vehicle is to provide small satellites with responsive launching with low-cost, user-friendly and efficient launch system. The first flight was successfully finished, JAXA has been conducting intensive researches on a more powerful and lower cost version of Epsilon. In order to minimize technical risks and to keep up with demand of future payloads, JAXA plans to take a step-by-step approach toward Future Launch System. As the first upgrade toward Future Launch System, JAXA has started the development of the Enhanced Epsilon. This development is mainly the renewal of the second stage, and also includes each subsystem's improvement. This paper describes the development and flight result of the Enhanced Epsilon's Guidance and Control System. [View Full Paper]

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AAS 18-728

PAYLOAD MECHANICAL ENVIRONMENTAL CONDITIONS AND FLIGHT EVALUATION OF ENHANCED EPSILON LAUNCH VEHICLE

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Development of Epsilon launch vehicle has been completed through three successfully flights (E-1, E-2 and E-3) in 2013, 2016 and 2018. The purpose of the development was to achieve the most comfortable mechanical environmental conditions in the world. In particular, low level environments about sinusoidal vibration and shock are realized by the special payload attachment fitting (PAF) with a non-pyrotechnic device and vibration attenuation system. Furthermore, the acoustic environment is lowered by modifying the launch pad and flame duct. This paper de-scribes the payload mechanical environmental conditions and flight evaluation of three flights and introduces the primary payload inter-face in-formation of Enhanced Epsilon launch vehicle briefly. [View Full Paper]

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AAS 18-729

SYSTEM AND SUBSYSTEM LEVEL DEMONSTRATION FOR REUSABLE ROCKET

Satoshi Nonaka,[*] Takashi Ito[†] and Yoshifumi Inatani[‡]

In order to make the access to space for scientific researches much easier and make the opportunities of the rocket launches much frequent, a fully reusable sounding rocket is proposed in ISAS/JAXA. The mission definition of the proposed reusable sounding rocket are 1) To achieve 100km in altitude and returns to the launch site, 2) The 100kg payload to be carried, 3) Flight frequency is higher than 10 times per a year, 4) The minimum flight interval is one day, and 5) Operational flight cost should be an order of magnitude less than the existing ISAS sounding rocket. Reusable sounding rocket is different from the present expendable rockets in 1) repeated operations, 2) returning flight / reignition of engine / vertical landing, that is, 3) fault tolerant / health management. Some key technologies related to these characteristics of reusable system have been verified to design an operative reusable sounding rocket in phase-A. Technologies verifications respect to the reusable vehicle, 1) reusable engine development and repeated operations, 2) reusable insulation development for cryogenic tank, 3) aerodynamic design and model flight demonstration for returning flight, 4) cryogenic liquid propellant management demonstration, 5) landing gear development, and 6) health management system construction, have been successfully conducted from 2010 to 2016.After these technical demonstrations, we are proceeding with a study for system level verifications by a flight demonstrator from 2016 as the next step for the development of reusable sounding rocket. In this plan, a small test vehicle will be established for repeated flight demonstrations. Objectives of the demonstration are 1) system architecture study for repeated flight operation such as quick turnaround operation and fault tolerant design method, 2) life controlled and frequently repeated use of cryogenic propulsion system and its flight demonstrations, 3) study for the advanced returning flight method of vertical landers and its flight demonstrations, and 4) demonstration of advanced technology for future RLVs such as more composite on board, in flight fuel management, GH2/GOX auxiliary propulsion, health management, long-life & high performance engine. These system level studies by a reusable flight demonstrator will be conducted for next three years. [View Full Paper]

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AAS 18-730

FLIGHT RESULT OF WORLD'S SMALLEST CLASS SATELLITE LAUNCHER

Takayuki Yamamoto,[*] Takahiro Ito,[†] Takahiro Nakamura,[‡] Takashi Ito,[§] Satoshi Nonaka,[**] Hiroto Habu[††] and Yoshifumi Inatani[‡‡]

On February 3, 2018 at the JAXA Uchinoura Space Center, JAXA experimented SS-520 No. 5 launch with a 3U sized cube sat called TRICOM-1R aboard. After liftoff, flight of SS-520 No. 5 proceeded normally. Around 7 minutes 30 seconds into flight, TRICOM-1R separated and was inserted into its target orbit. And the launcher became the world's smallest class satellite launcher. SS-520 launch vehicle is one of sounding rockets operated in JAXA/ISAS, and originally two-stage rocket. In this experiment, to make this vehicle put a satellite into orbit, the third stage motor is added. And this sounding rocket has four tail fins for spin stabilization, but usually don't have an attitude control system during the flight. But in this mission, it is needed to control its attitude to ignite second and third motor toward horizontal after first stage burn-out. The gas jet system is installed into between the first stage and the second stage of the vehicle as a unique active attitude control system. The gas jet system can control the spin axis direction and the spin rate of the vehicle during the coasting fight. Because of this constraint, the apogee altitude after the burn out of the first stage motor almost correspond with the perigee altitude of the elliptical orbit. In this mission, the sounding rocket-based Nano launcher is planned to put TRICOM-1R into the elliptical orbit. Its targeted apogee altitude is about 1,800 km and its perigee altitude is about 180 km. Because the perigee altitude is relatively low, the orbit life is very short. One of the mission requirements is to make the vehicle an orbit insertion with more than 30 days orbital lifetime. The vehicle error or the environment error deeply affect the achieved trajectory. These errors must be small enough to put TRICOM-1R into orbit. This paper discusses about the trajectory design on how to manage the sounding rocket into a satellite launching vehicle, the effect of the orbital distribution depending on the various errors, the flight safety analysis, and finally flight performance evaluation. [View Full Paper]

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SPACE EXPLORATION AND SPACE ROBOTICS

Session B.2

Session Chair:

A. Misra

AAS 18-732

HIGH-SPEED FLYBY OBSERVATION OF SMALL ASTEROID BY DESTINY+

Shunsuke Sato,[*] Yuki Kayama,[†] Kento Ichinomiya,[‡] Kazutoshi Takemura,[§] Takuya Chikazawa,[**] Ko Ishibashi[††] and Yasuhiro Kawakatsu[‡‡]

DESTINY+ flies by asteroid named Phaethon at a speed of 33 km/s. At flyby phase, it is planned to image Phaethon by 2 kinds of camera. To take good quality images in terms of science, it is necessary that the view of cameras continue to catch Phaethon. In this paper, to achieve this mission, how to track Phaethon and how to control the view of camera during flyby are showed. And it is indicated by numerical analysis that DESTINY+ can take the image which is satisfied scientific request. [View Full Paper]

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AAS 18-733

ROBUST TRAJECTORY TRACKING CONTROL FOR SOFT LANDING ON SMALL BODIES WITH INPUT SATURATION

Jiateng Long,[*] Yang Liu[†] and Pingyuan Cui[‡]

To deal with the uncertainties of asteroid gravitational field during landing on a small body, a fuzzy gain-scheduling output feedback control for robust trajectory tracking is proposed for soft landing on small body surface with actuator saturation via fuzzy Lyapunov function. For the saturation nonlinearity, the dead-zone function of control input is introduced as a supplementary controller input. Then, a gain-scheduling output feedback controller is introduced to stabilize the saturated Takagi-Sugeno (T-S) fuzzy system with optimal L2 gain performance. The application of the fuzzy Lyapunov function tackles with the conservation problem in controller design. As a result, the synthesized system enjoys an enlarged stability region and enhanced robust performance, which are essential for the success of small body soft landing. The landing control algorithm proposed in this paper is demonstrated by a flight dynamics simulating the powered descent on the asteroid of Eros 433. [View Full Paper]

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AAS 18-734

MARTIAN MOONS EXPLORATION (MMX) MISSION AND VEHICLE CONCEPT

Takane Imada[*] and Yasuhiro Kawakatsu[†]

Martian Moons eXploration (MMX) mission focus on the Martian moons. The spacecraft will make close-up remote sensing and in-situ observations of both moons, and collect a sample from one of the moons to bring back to Earth. [View Full Paper]

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AAS 18-735

CONTROL OF A RECONFIGURABLE FREE-FLOATING SPACE MANIPULATOR WITH SCALABLE BOOMS*

Mana Mirmirani,† Farhad Aghili‡ and Ramin Sedaghati§

In recent years, the number of human made objects performing a broad range of tasks in various space missions has increased. Because of limited area in space-crafts, it is essential to keep every tool compact. One of the advanced types of space-based robots is a reconfigurable manipulator. A reconfigurable manipulator is capable of changing its kinematics without the use of any modular joint. In this study, a reconfigurable manipulator with two telescopic and six revolute joints and floating base has been considered. The advantage of this manipulator is its minimal weight and high mobility capable of operating in various configurations. The position of each link can be defined by homogenous transformation matrices and D-H parameters. Using the information from forward kinematics, the inverse kinematics can also be conducted to identify joint angles for the specific manipulator's end effector position and orientation in 3D space considering the redundancy of the reconfigurable manipulator. The nonlinear optimization methodology based on Sequential Quadratic Programming (SQP) technique has been utilized to identify the joints' variables with the singularity and obstacle avoidance for the given end-effector position and orientation. Effective control laws have been proposed to perform a large number of tasks while the manipulator is floating in the space. Proportional, Integral, and Derivative (PID) controllers are utilized for position control of each joint of the manipulator independently. Each joints' controller is based on single input and single output (SISO) system. There in the first case, the performance of the controller on each joint has been evaluated for open-chain system with floating base and locked telescopic joints. For the second case, the performance of the controller in close chain, when the telescopic joints are released, has been investigated. After reconfiguration the value of joints will be considered for both cases and some numerical results will be reported.

[View Full Paper]

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* Only an abstract of this paper was available for publication.

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SPACE POWER AND PROPULSION

Session B.4.1

Session Chair:

S. Nonaka

The following papers were not available for publication:

AAS 18-737 “Thrust Measurement and Combustion Visualization of a Cylindrical Rotating Detonation Engine for Rocket Propulsion,” by Akira Kawasaki, Nagoya University (Not Available; Oral Presentation Only)

AAS 18-738 “Study on a Reflective Shuttling Detonation Combustor,” by Ken Matsuoka, Nagoya University (Not Available; Oral Presentation Only)

AAS 18-739 “Research and Development of Rotation Detonation Engines for Sounding Rocket Flight Experiments,” by Jiro Kasahara, Nagoya University (Not Available; Oral Presentation Only)

AAS 18-740 “Comparative Analysis of 5N and 60N (HAN)-Based Monopropellant Thruster Working Process in Hot-Firing Test and Numerical Simulation,” by X. Yu, CASC (Paper Withdrawn)

AAS 18-741 “The Design and Experiment of Micro-Cathode Thruster,” by L. Tian, CASC (Paper Withdrawn)

AAS 18-742 “The Rocketplane XS-1 Suborbital Satellite Launch Spaceplane as an Enabler for Reusable In-Space Transportation,” by Chuck Lauer, Rocketplane Global (Not Available; Oral Presentation Only)

AAS 18-736

MODAL SIMULATION ANALYSIS AND EXPERIMENTAL STUDY ON THE WORKING PROCESS OF A DUAL PULSE SOLID ROCKET MOTOR

LE Hao,[*] WANG Lei,[†] CHEN Jun,[‡] SHI Xiao Ming[§] and ZHAO Yu[**]

In order to comprehensively analyze the dynamic characteristics of the spacecraft during flight and improve its maneuverability, both numerical simulation and experimental studies on the modal feature of dual pulse solid rocket motor were carried out. According to the research, the natural frequencies and mode shapes of the motor under full-load and no-load conditions were obtained by test and simulation. And, there was a high correlation between them, which proved that the model established was correct. Based on the law of grain motion, the function of motor's mass and time was proposed, then the characteristic moments were chosen by the "state frozen" method, which was the key to estimate the dynamic behavior of mass-variable system in operative conditions. Finally, the function of frequency and time were obtained with the model established above, which has great significance on the cooperative design of motor and spacecraft.

[View Full Paper]

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SMALL SATELLITES, FORMATION FLYING AND CONSTELLATIONS

Session B.3

Session Chair:

K. Chan

The following papers were not available for publication:

AAS 18-743 “Hardware and Software Modularized Approach for On-Board Processing Capabilities of Small Satellites,” by Shinichi Kimura, Tokyo University of Science, Noda (Paper Withdrawn)

AAS 18-744 “Concept Design for In-Orbit Self-Reconfiguration Modular,” by Z. Yang, CASC (Paper Withdrawn)

AAS 18-745

TASK ANALYSIS AND CONSTELLATION DESIGN FOR EARTHQUAKE MONITORING INSAR SATELLITES SYSTEMS

LU Qing,[*] CHEN Yang,[†] LIU Yanyang[‡] and SUN Yongyan[§]

In the paper, the task requirements of the earthquake monitoring InSAR satellite system are firstly introduced. Secondly, according to the distribution of seismic zones and revisit requirements, the low-inclination orbit is selected to achieve the vertical distribution of the ground track and the coverage of the middle and low latitudes. Thirdly, the constellation parameters are optimized to meet the requirements of ground track repetition, and to achieve high time resolution revisit. Finally, the key technologies of satellite system are analyzed, including strict orbit regression control, InSAR data processing and so on.

[View Full Paper]

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SPACE MATERIALS AND STRUCTURES

Session B.4.2

Session Chair:

H. Djojodihardjo

The following papers were not available for publication:

AAS 18-748 “Thermal Analysis of Composite Insulation Structure for Liquid Hydrogen Tank On-Orbit,” by S. Zhang, CASC (Paper Withdrawn)

AAS 18-749 “The Optimization of Spacecraft Composite Structures Based on Thermo-Mechanical Coupling,” by F. Chen, CASC (Paper Withdrawn)

AAS 18-752 “Spacecraft Surface Potential Controlled Through Super Capacitor,” by Z. Peng, CASC (Paper Withdrawn)

AAS 18-746

DESIGN AND DEPLOYMENT SIMULATION OF A LARGE-SIZE DEPLOYABLE TRUSS REFLECTOR

Xiaokai Wang,[*] Qifeng Cui,[*] Jianghua Du,[*] Xiaofeng Chen,[*] Guanghui Wang[†] and Xin Zhou[*]

A novel mission concept namely NEXRAD-In-Space (NIS) has been developed for monitoring hurricanes, cyclones and other severe storms from a geostationary orbit. It requires a space deployable 35-meter diameter Ka-band reflector. To meet the requirements of the radar system, a Membrane Shell Reflector Segment (MSRS) reflector technology has been developed and several technologies have been evaluated. However, the design theory and deployment analysis of this large size and high-precision reflector have not been investigated. In this paper, a deployable mesh reflector configuration consists of tetrahedral truss modules has been proposed. A design principle considering advanced spherical characteristics has been developed to avoid over constraints of the spherical reflector during its deployment and packaging process. Deployment dynamics analysis of this spherical reflector has been performed using ADAMS to understand its deployment dynamic behaviors. Considering the flexible characteristics of the struts, a primitive joint and a flexible strut were introduced to the analytical model and they can effectively eliminate over constraints of the model. By using a high-speed camera and a force transducer, a deployment experiment of a single-bay tetrahedral module with a spring tape driving system has been conducted. With the tested results, an optimization process has been performed to obtain the parameters of the analytical model. These parameters were incorporated to the analytical model of the whole reflector. It is observed from the analysis results that the deployment process of the reflector with a fixed boundary experiences three stages. These stages are rapid deployment stage, slow deployment stage and impact stage. The impact force of every strut was studied and the distribution of axial force peak has been given. The insight of the force peak distributions of the reflector can help the optimization design of the structure. [View Full Paper]

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AAS 18-747

A STUDY ON SHAPE AND STIFFNESS CONTROL OF LARGE SCALE MEMBRANE STRUCTURE USING MEMBRANE DEVICE

Rikushi Kato,[*] Osamu Mori,[†] Toshihiro Chujo,[‡] Yasutaka Sato,[§] Nobukatsu Okuizumi[**] and Hiroaki Tsunoda[††]

Solar power sail technique was demonstrated in the IKAROS mission. However, unexpected phenomena were confirmed. The membrane surface of IKAROS has deformed to a shape that was not flat. In the shape change of the film surface, it is known that the whole membrane surface changes greatly like an umbrella shape or a saddle shape depending on the warping direction of the thin film solar cell. Objection of this study is to clarify mechanism of influence on solar radiation pressure torque due to warp of membrane device and its solution method. Therefore, the shape of the overall membrane surface is clarified by using a simple FEM model and the SRP torque with respect to the shape is calculated, and the mechanism of the overall shape change in warpage and its influence is clarified. As a result, the influence on SRP is related to membrane surface stiff-ness and warped direction and it was found that it is best that the membrane is warped in the radial direction and its outermost stiffness is high. [View Full Paper]

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AAS 18-750

ANALYTICAL STUDY ON ROLL-UP METHOD FOR DEPLOYABLE MEMBRANE

Masaya Kurakawa,[*] Osamu Mori, Nobukatsu Okuizumi, Yasutaka Sato,[†] Yasuyuki Miyazaki,[‡] Hiraku Sakamoto,[§] Yoshiki Sugawara[**] and Kazuya Saito[††]

In recent years, a large space film structure having a thickness of several micro and a shape of several to several tens of meters attracts attention, and various storing methods have been studied. Considering the thickness of the film surface at the time of winding before launching, there is a problem that circumferential difference occurs inside and outside of the folded film surface. In order to solve this problem, a method of solving the difference between the inner and outer circumference by predicting the inner / outer circumferential difference arising from the film surface and the thickness of the device and managing the phase has been proposed. On the other hand, the point that the target value for adjusting the phase is unknown and empirical was pointed out, and as a result of adjusting the phase, the wave-like slack that occurred caused the unevenness of the film thickness in the circumferential direction. In this research, we derive target value of phase management analytically, compare with experiment, and verify. [View Full Paper]

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AAS 18-751

LIGHTWEIGHT RESEARCH AND APPLICATION OF AEROSPACE CABLE

Jianwu Zhao,[*] Wenqing Yin,[†] Bin Li,[‡] Shuo Jiang,[§] Xingxing Li,[**] Beifei Sheng,[††] Feng Li,[‡‡] Chuntu Yao[§§] and Shaoqiang Cheng[***]

The main method of lightweight aerospace cable is to reduce the weight of non-metallic materials such as wire insulation layer and sheath, and to reduce the weight of metal conductors and shield layer. This paper discusses the weight reduction advantages of light weight copper-clad aluminum alloy conductor, analyzes the feasibility of reducing the thickness of cable insulation layer by using ultra-thin-walled extrusion technics, and discusses the advantages of flat wire weaving, spiral weaving instead of round copper wire weaving. It also introduces a new method to replace the original wire weaving with silver-plated aramid weaving. Finally, this paper verifies the reliability of several lightweight methods, and discussed the commercial value of lightweight cable and the specific application prospects in spacecraft. [View Full Paper]

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SPACE SYSTEMS
AND INFRASTRUCTURE

Session B.5.2

Session Chair:

Meng Guang

The following papers were not available for publication:

AAS 18-753 “Remote Sensing Satellites in China’s National Space Infrastructure – Status and Prospects,” by Ming Li, CASC (Not Available; Oral Presentation Only)

AAS 18-754 “Technology Study of Quantum Remote Sensing Based on Squeezed State Light,” by X. Lin, CASC (Paper Withdrawn)

AAS 18-755 “The Power Sequence and Flight Safety Control by Control Box Using Semiconductor Relay,” by Shuhei Okada, JAXA (Not Available; Oral Presentation Only)

AAS 18-756 “Spaceborne High Spectral Resolution Lidar for Cloud/Aerosol Detection,” by C. Song, CASC (Paper Withdrawn)

AAS 18-757

PROMOTING SPACE INTERNATIONALIZATION DEVELOPMENT BASED ON QIAN XUESEN THINK TANK

Xue Huifeng*

Today, the "division" thought of the "Reductionism" makes people feel helpless and gradually recognize the consequence of the social alienation. Based on 20 years in America, 28 years' practice in China's space industry, and nearly 30 years' research, Qian Xuesen integrated the Western Reductionism with the Eastern Holism to form the Qian Xuesen Think Tank thought and the Hall for Workshop of Metasynthetic Engineering from qualitative to quantitative, promoting the space internationalization to play an irreplaceable role in the development of technology, engineering and industrialization. [View Full Paper]

* President, China Aerospace Academy of Systems Science and Engineering, CASC, China.

AAS 18-758

THE NEXT STEPS OF NEWSPACE FOR SPACE COMMERCIALIZATION – AFTER TWO NEW SPACE LAWS IN JAPAN

Misuzu Onuki*

Now space commercialization is a big wave all over the world. Smallsat constellations have brought a manufacturing revolution and scale merit into space as well as creating innovative technologies and applications. 3D printing in space and manufacturing in space has been started, which will enable the assembly of large space structures in orbit. Killer apps from microgravity expect to contribute to our quality of life as well. Reusable vehicles, on-orbit servicing, next-gen propulsion and so on also have contributed to a technology revolution. Furthermore, new technologies which connect space based data information with big data, cloud, IOT, and AI; what is called digitalization. 3D printing, nanotechnology, new materials, etc. are also focused as cross cutting areas for economic expansion. This phenomenon is also happening in Japan, which has adopted policies encouraging commercial space business development. There are now about twenty space venture companies in Japan and several of them have gotten VC funding, including the largest Series A funding anywhere in the world, which is about $100M for a space resources utilization company. In addition to space venture companies, non-space companies have gotten into space business such as Canon and Sony. Furthermore, experts, investors as well as traditional big, middle, small space companies are now becoming active. All have created and broadened a borderless industry blast off for space commerce. The new space business ecosystem in Japan is created under a public private partnership model. Up to now the space industry ecosystem has been a tier structure with traditional big companies and middle and small suppliers within a government dominated space budget. Two new laws on space activities and satellite remote sensing have been passed in November, 2016 that are now driving space commercialization in Japan. The third space policy proposal was released by the LDP in April, 2017. Following that the Space Industry Vision 2030 was issued by the Cabinet Office in May, 2017. To encourage commercial space business, a Space Ventures & SMEs space business committee, what is called New Space Committee was formed in August, 2017. There are over 60 member companies, in addition to that, experts and government people as advisors. New Space and Old Space synergies have been brought into this committee, and several business matchmaking efforts have started. This committee will function as a space policy think tank and commercial space trade association. The challenges and opportunities for New Space companies after two new space laws. [View Full Paper]

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SPACE DEBRIS

Session B.6

Session Chair:

A. Misra

The following papers were not available for publication:

AAS 18-760 “Dynamics of Tethered Tug-Debris System with Rigid-Flexible Coupling,” by Rui Qi, BIT (Not Available; Oral Presentation Only)

AAS 18-763 “Six-DOF Ground Simulation Experiment Verification of Combination Control,” by Y. Han, CASC (Paper Withdrawn)

AAS 18-759

COMPARISON OF METHODS FOR SPACECRAFT COLLISION PROBABILITY COMPUTATIONS

Ken Chan*

This paper compares the various methods of computing the probability of collision between two orbiting objects during a short-term encounter. The comparisons are first made for the case of spherical conjuncting objects so that the collision cross sections are circular. Moreover, the combined probability density function is assumed to be Gaussian. This encompasses all the existing six methods, three of which are analytical and all the other three are numerical. The comparisons are then extended to non-circular cross section collision areas for which there are three left. In this case, only one is analytical and the remaining two are numerical. The one remaining analytical method is based on a combination of the Method of Equivalent Areas (MECSA) and the Rician Integral (RI). The results show that it is superior to the rest in terms of accuracy and computation times. [View Full Paper]

* Chan Aerospace Consultants, 25803 Anderby Lane, South Riding, Virginia 20152, USA.

AAS 18-761

COMPARISON OF METHODS FOR SPACECRAFT MANEUVER COMPUTATIONS

Ken Chan*

This paper compares seven institutional publicly known computer software systems for performing maneuvers when a spacecraft is at risk in colliding with another orbiting object. In the course of planning these maneuvers, all of them have to perform numerous high precision time-consuming orbit propagations to determine accurately the distance of closest approach in the computation of collision probability. Then, they have to determine the applied impulse $\Delta\mathbf{v}$ to achieve specified goals such as maximum miss distance or minimum collision probability. Each of these systems has to design optimization algorithms to meet their stated objectives. These invariably invoke using one, some or all of the six methods of computing collision probability discussed in a previous paper. Because the collision probability cannot be expressed in simple closed-form expressions in terms of $\Delta\mathbf{v}$, the computing time can be very excessive and the maneuvers cannot be performed in time if the particular optimization formulation involves numerous high precision orbit propagations. [View Full Paper]

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AAS 18-762

STUDY ON PERFORMANCE OF GTO DEBRIS REMOVAL USING AN ELECTRODYNAMIC TETHER

Rui ZHONG[*] and Yue WANG[†]

This paper studies the debris removal in geostationary transfer orbits (GTOs) using electrodynamic tethers. For simplicity, the electrodynamic tethered system is assumed as a point mass in the orbital dynamics analysis, whereas it is assumed as a rigid dumbbell with tether mass included in the tether libration dynamics analysis. Afterwards, major environmental perturbation forces on the electrodynamic tethered system are analyzed, such as the solar radiation pressure, the Earth's non-spherical gravity, the atmospheric drag force, the electrodynamic force, and the lunisolar attraction. A bare tether is assumed and the current-voltage relationship along the tether is derived based on the orbital-motion-limited model. High order international geomagnetic reference field and international reference ionosphere are adopted for model accuracy. Numerical simulations are performed where hypothesis targets in Chinese Long March series' GTOs are deorbited by using the electrodynamic tether. The decay efficiencies of the targets with the electrodynamic tether, the non-electrodynamic tether and without the tether are compared. Simulation results reveal that the tether libration caused by the orbital eccentricity is too large to suppress for the electrodynamic force. The electrodynamic tether has the ability to greatly increase the decay rate, especially for the GTOs with smaller inclination angles.

[View Full Paper]

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(Fifteenth International Space Conference of Pacific-basin Societies (15th ISCOPS), 10–13 July 2018, Montreal, Canada)

* Unless otherwise indicated all papers appear in Volume 166, *Advances in the Astronautical Sciences*.

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