Book Review

Spaceflight mechanics 2000

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Advances in the Astronautical Sciences, the general series to which the volume belongs, is a very valuable record of developments in the broad field of astronautics and related sciences. The series is not a homogeneous one, however. It is a sort of superseries which includes separate streams. One such subseries is Spaceflight Mechanics, and the volume under review is the tenth of the sequence. Consisting of about 1700 pages organised in two parts, the volume records the proceedings of the 2000 Space Flight Mechanics Meeting held during January 23-26, 2000, in Clearwater, Florida, cosponsored by the American Astronautical Society and the American Institute of Aeronautics and Astronautics. The international astrodynamics community was represented by 150 participants from 11 countries, including 24 students, who presented 98 papers organised into 15 sessions. The highlights of the various theme sessions are as summarized below.

'Topics in control theory' represent advances in control theory and applications that are necessitated by the ever-tightening demands on spacecraft performance in terms of manoeuvre and orbital and attitudinal accuracy. The first paper on this topic revisits the classical problem of attitude tracking for a rigid body where only attitude measurements are available. The author constructs globally stabilising control laws in terms of a minimal set of three-dimensional kinematic parameters that enable the rigid body to track any specified trajectory without requiring angular velocity measurements. A second paper in the section also deals with minimisation (convergence to zero) of tracking error in the presence of periodic disturbances through repetitive control methods, using matched basis functions for robustness.

Nonlinear control systems often provide functional or performance advantages over linear methods. However, while control theory for linear systems is very well developed, the understanding of nonlinear systems is at best patchy and *ad hoc*. Analytical closed-form solutions for optimal configurations in nonlinear control systems are more an exception than the rule. One paper in this area aims at numerical determination of optimal feedback control in nonlinear problems with state/control constraints. The algorithm adapts the optimal control for a specified nominal solution to disturbances of the state variables and the system parameters. The key feature of the algorithm is the numerical computation of a Taylor expansion of the adjoint variables based on an implicit function theorem for the necessary optimality conditions.

Another important issue in control applications is the effect of periodic disturbances and their rejection. A time-domain Clear-Box disturbance rejection algorithm is presented which creates a disturbance-free difference equation model of the system from disturbance-corrupted data. Then it identifies the periodic disturbance in the time domain, and computes the steady-state periodic input that will cancel it. The frequency-domain analog of this algorithm is also generated and its advantages and disadvantages assessed. The last paper in the session relates to iterative learning control, which refers to a class of control techniques that improves the performance of a process by repeated trials. Many iterative control laws have been devised independently, originating from linear control concepts. The paper presents a unified formulation from which global perspectives and general insights on these diverse laws can be gained and their interrelationship understood.

'Formation flying' of spacecraft is a subject of great current interest, with many applications such as interferometric synthetic aperture radar mapping demanding such flights. The minimum requirement for such flight is the synchronisation of the orbits of multiple (at least two) spacecraft and maintaining a constant or known separation between them. To ensure accurate separation, it is necessary to be able to measure the absolute and/ or relative position(s) of the spacecraft. In this context, the Global Positioning System (GPS) that provides position information over the entire earth and the near-space comes out as a natural aid. The first paper on the theme discusses the complex problem of design and implementation of synchronised autonomous orbit and attitude control for multiple spacecraft formation using GPS measurement feedback. Here not only the relative position but also even the attitudes of the spacecraft are synchronised with each other, using the GPS phase pseudorange measurement.

Ionospheric propagation uncertainties are the cause of the single largest component of errors in GPS positioning. Detailed study and characterisation of ionospheric propagation provide the only way of mitigating this effect. This has been a continuing process. A recent experiment in this direction is based on the Ionospheric Observation Nano-satellite Formation (ION-F) mission conducted under the University Nanosatellite Programme. It involves 10 universities building nanosatellites for one or two launches in 2002 on the Space Shuttle. The ION-F mission itself will comprise three small spacecraft cooperatively making measurements of the ionospheric electron density and its effect on GPS signal propagation. This calls for novel formation flying concepts and stationkeeping methods which form the subject of an interesting paper. Indeed, the three satellites employ dissimilar sensors and actuators for stationkeeping and microthrusting.

Yet another interesting project presented as a paper relates to MIT s Synchronized Position Hold Engage Re-orient Experimental Satellites (SPHERES) test bed for operation on a 2-D laboratory platform, first the KC-135 aircraft and then the International Space Station. The hardware consists of three 23-cm diameter, 3-kg satellites or spheres which can control their relative orientations. Each sphere carries all the subsystems typical of a conventional satellite. The SPHERES programme is intended to provide a long-term, replenishable, and upgradable test bed for validating high-risk metrology, control, and autonomy technologies needed for operating distributed satellites with direct astronaut interaction which exploits the microgravity conditions of space.

Other papers on the subject deal with orbit establishment for formation flying of satellites in a cooperative manner, software architectures for automation of flight dynamics of integrated satellite formations, and impulsive spacecraft formation flying control to establish specific mean orbit elements.

'Orbit determination and navigation' constitutes two ever-important aspects of space flight mechanics. While a variety of sensors and corresponding algorithms have been employed for these two purposes, the maturity of satellite navigation (satnav) systems in recent years has provided a simple, accurate, and integrated approach to these functions. The papers in this section reflect such a trend. The opening paper presents a comparison of GPS-based precision orbit determination approaches for a specific satellite (ICESAT), while the next one makes an assessment of the benefits of including GLONASS (the Russian satnav system) data in GPS-based precise orbit determination. This second paper, however, has already lost its topicality because the accuracy-degrading selective availability (SA) feature of GPS, whose effect the paper aims to mitigate by including GLONASS data, has already been switched off.

Much of the orbit determination work has conventionally been done through ground-based sensing. A novel approach to using space-based sensing for orbit determination is presented using observations from the space-based visible sensor package carried on the Midcourse Space Experiment satellite launched in April 1996. The sensor is a charge-coupled device (CCD) sensor primarily intended to observe resident space objects in the geosynchronous orbital belt.

The accuracy of user position determination from GPS signals is predicated upon the accuracy with which the temporal positions of the GPS satellites can be estimated. While post-processing can yield orbital positions with decimetre-level accuracy, short-term (few days) predictions can be made with a few metres accuracy. However, the satellites operate in the vicinity of deep resonance and the long-term behaviour cannot be accurately predicted. A paper in the section investigates the ephemeris behaviour in the vicinity of unstable node points that are particularly susceptible to chaotic behaviour. Another paper, also analytical in nature, considers the application of a stochastic filtering method for removing long-period orbit error using GPS software.

Spacecraft orbit determination problem is highly dependent upon the type of tracking data available at the ground station. One such problem, orbit determination at a single ground station using range rate data, is presented as a low-cost option.

One of the two papers on navigation deals with the implementation and operations experience of a ground system support of an onboard navigation system, and the other reports developments on an autonomous navigation system for the German small satellite mission BIRD.

'Attitude determination and estimation' is another classical area of research in space flight mechanics. One application considered here is the use of stellar reference system for the determination of laser pointing to an accuracy of 1.5 arcseconds in the Geoscience Laser Altimeter System (GLAS). Another one presents a suboptimal method for attitude determination from multiple star cameras using the QUEST algorithm. A following paper studies the performance improvement of attitude determination through enhancement of the QUEST

algorithm itself.

An interesting topic in this section relates to attitude determination in the context of formation flying, a theme discussed earlier in this review. The subsequent paper presents a Kalman filter approach to system calibration considers the problem of accurately estimating the pointing of a spacecraft from ground processing of attitude sensor, gyro, and payload telemetry. Another important paper presents an optimal linear attitude estimator for the case of a single-point realtime estimation using the Gibbs vector, a minimum-element attitude parametrisation. Such parametrisation is often associated with singularities, the avoidance of which is the subject of a companion paper. The proposed methods here are derived from the sequential rotation technique.

'Low-thrust orbit transfers' is an area of active research because of the prospect of using power-limited propulsion systems such as those derived from solar energy. Presented here are new analytic solutions to the fuel-optimal problem using low-thrust exhaust-modulated propulsion. Plasma propulsion with these characteristics is also considered for Earth-Mars expedition, and fuel-optimal three-dimensional trajectories are derived. Another problem addressed is that of the turning of an elliptic orbital plane via spherical intermediate thrust, for which an analytic solution is obtained. The classical problem of Hohmann transfer between coplanar circular orbits is revisited with the constraint of power-limited but continuous thrust.

Unmanned expeditions to comets and asteroids are rapidly developing as a challenging space frontier. A study on trajectories to comets using solar electric propulsion is very relevant in this context. Low-thrust propulsion is also applied to the familiar problem of LEO-GEO transfers (transfers between low-Earth and geostationary orbits) and the more generic problem of eccentricity and out-of-plane corrections.

Satellite constellations and formations is a section that deals with an aspect different from what was covered in the section on Formation flying. Topics covered here relate to radio interference between members of communication satellite constellations, orbital debris hazard assessment methodologies for constellations, average and maximum revisit time trade studies, implementation of techniques for maintaining constant distance between satellites in elliptic orbits, and using GPS reflections for satellite remote sensing.

'Attitude dynamics and control' is yet another classical space research area. This is the last section in Part I, and includes topics such as attitude manoeuvres for MightySat II.1 hyperspectral data collects, attitude control system and star tracker performance, improvement of the satellite attitude stability by the sliding mode control during the working of a robot arm on a satellite, numerical calculation of flow field in equatorial mounted fluid-in-tube satellite dampers, and optimal design of a two-dimensional passive coning attenuator for spinning spacecraft under thrust.

'Orbit dynamics and stability' , the opening section of Part II and also an area of perennial interest, reports research on parallel numerical integration methods for orbital motion, MEO (medium-altitude Earth orbits) disposal orbit stability and

direct reentry strategy, spacecraft motion about slowly orbiting asteroids, stability analysis of Europa orbiter, temporary satellite capture of short-period Jupiter family comets from the perspective of dynamical systems, periodic orbits around geostationary positions, and focal-type elements based on quasi-Keplerian systems.

'*Mission analysis for earth observing satellites'* covers a very important segment of satellites from the utility point of view. Useful topics covered here include an improved strategy for maintaining repeat ground tracks at high latitudes, risk mitigation using Monte Carlo, ascent strategy for Earth Observing-1 satellite and Landsat-7, impact of uncertainties in disturbance environment and satellite force models on GRACE mission design, and mission planning for twin GRACE satellites covering gravity recovery and climate experiment.

'Interplanetary missions' is another theme of practical significance. The recent emphasis on space missions to asteroids and comets is reflected by the inclusion of three papers dealing respectively with altimeter range processing analysis for spacecraft navigation about small bodies, development of a target marker for landing on asteroids, and trajectory design for low-cost main-belt asteroid sample return mission. Another paper, interestingly titled Shoot the moon , applies a novel low-energy transfer technique, used in the Japanese Hiten mission, to produce the Petit Grand Tour of the Jovian moons. Other papers under the theme include Cassini manoeuver experience and orbit determination, aeroassist technology planning for exploration, and light-weight hypersonic inflatable drag device for a Neptune orbiter.

'Orbit transfers: Lunar and libration points' covers optimal trajectories for secondary payloads from geosynchronous transfer orbits to the Moon, efficient computation of transfer trajectories between the Earth orbit and L1 Halo orbit within the framework of the Sun-Earth restricted circular three-body problem, moon-assisted out-of-plane manoeuvers of Earth spacecraft, and zero-cost transfers between libration point orbits.

'Mission analysis tools' , a section which comprises diverse topics having a bearing on assessing mission performance, reports research on near-real-time atmospheric density correction using NAVSPASUR fence observations, precision of a multisatellite trajectory database estimated from satellite laser ranging, effect of atmospheric density uncertainty on collision probability, general method for calculating satellite collision probability, and accuracy assessment of the Naval Space Command special perturbations cataloguing system.

'Tethers and space structures' includes the important application area of tethered satellites. The topics covered in this context relate to nonplanar deployment dynamics of the ASTOR satellite system, a two-bar model for the dynamics and stability of electrodynamic tethers, effect of electromagnetic forces on the orbital dynamics, a new kind of dynamic instability in electrodynamic tethers, preliminary orbit determination, space anchor (a tethered drag device to enhance orbit capture), and use of tethered satellite estimation methods in identifying re-entering objects. The only article in the section that is not related to tethers discusses the motion of a flexible beam supporting a moving rigid body.

'Interplanetary missions: Mars' , as the name indicates, is a Mars-specific section. The first article in the section discusses a project to commemorate the 100th year of flying: the Wright Brothers Centennial Mars Airplane Mission in 2003. Under this plan gliders would be carried as a secondary payload on an Ariane-boosted geosynchronous communication satellite mission, and would subsequently be propelled to Mars, to enter its atmosphere and fly on 17 December 2003. Other topics covered are an evaluation of Mars entry reconstructed trajectories based on hypothetical quick-look entry navigation data, Mars Global Surveyor azimuth gimbal anomaly, aerobraking trajectory options for the First Mars Micro-Mission telecom orbiter, Earth-return aerocapture of the TransHab vehicle (an inflatable habitat) for a manned Mars mission, and Mars polar lander approach navigation.

'Control applications' is the last section of the volume and complements the articles on control theory compiled under an earlier session of the Meeting. The topics covered under this theme deal with structured adaptive model inversion applied to tracing spacecraft manoeuvres, optimal reorientation of a multibody spacecraft through joint motion using averaging theory, potential uses of solar radiation pressure in satellite formation flight, accuracy and optimality of direct transcription methods, control laws for minimum orbital changes applied to the satellite retrieval problem, and migrating multipath error by neural network.

'Spaceflight mechanics 2000' is a record of a very specialised meeting with a select audience. It represents a definite advance in the state of the art. It is a compelling reference for any scientist and engineer engaged in space research.

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Book Review

The Richard H. Battin Astrodynamics Symposium

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Professor Richard H. Battin is the living legend of American astronautics. During a distinguished career spanning five decades at MIT, Prof. Battin has guided and inspired generations of scientists and engineers who have gone on to lead the American space programme and make that nation the first among the space powers of the world. He has not just developed original ideas and formulation in astronautical science, but has contributed directly to just about every major American space project, manned or unmanned. It is to honour this doyen of astronautics that the Texas A&M University, in association with the American Astronautical Society, organised The Richard H. Battin Astrodynamics Symposium during March 19-21, 2000, as a culmination of the year-long activities surrounding the award of Honorary Doctor of Science to him during May 1999. The Symposium had 23 invited papers besides less formal presentations by a number of distinguished colleagues of Dr Battin. The volume under review is a record of the proceedings of the Symposium.

It is only fit and proper that the keynote address to the Symposium was delivered by none other than Dr Battin himself. Dr Battin is not just a great researcher, but also a fantastic speaker both for the general and the specialised audiences, as this reviewer can testify from personal experience of listening to him live. In many of his general lectures and writings he brings forth a profound perspective of the historical aspects of the field, a good part of which is his own contribution. The keynote address to this Symposium, aptly titled A Scrapbook of Beautiful Equations and Great Ideas , is no exception. Astronautics, after all, is intensive in elegant mathematics and ideas, and the core of the science can be best captured through a holistic exposition of these.

Dr Battin starts with some of the simpler but profoundly important contributions of Euler such as the use of p to represent the ratio of the circumference of a circle to its diameter, e as the base for the natural logarithms, i for the imaginary quantity root of(-1), and the relation eif = cos f + i sin f. He recalls how, in the intellectual world of England in the early seventeenth century, mathematics was viewed as a mechanical rather than academic subject whose practitioners had no prospects of finding jobs even at Oxford or Cambridge. But one of these unwanted mathematicians , John Wallis, went on to express p as an elegant infinite product. And so on Prof. Battin discusses many more simple but seminal relations such as Euler s time equation for parabolic orbit, Kepler s equation, Lagrange s equations and new additions thereto, simple estimators (square-root, recursive, Potter s), Godal s hyperbolic locus, boundary value problem algorithms, and others which have a profound influence on astronautical calculations. He ends the article with the passionate reference to these formulae: I would not object if these were on my tombstone .

The remaining 22 articles in the volume are all invited papers organised under six themes starting with Orbital Manoeuvers . A practical and interesting type of trajectory manoeuvre consists of a small number of discrete impulses applied at proper instants with appropriate magnitude and directions for each impulse. The first paper in the section focuses on a two-impulse trajectory where the impulses are so far separated in time that multiple revolutions of the body can occur. The well-known Lambert problem then has multiple solutions. The paper provides an algorithm for determining all such trajectories. The second paper under the theme is an interesting one dealing with the effect of a constant radial thrust on an initially circular orbit. If the thrust is below a certain threshold then the orbit oscillates between an outer and an inner limit cycle. The outbound and inbound spirals are very different, but take the same time. The paper investigates the difference between the two spirals and shows that the process is almost periodic. The last of the three papers in the section studies transfer trajectories from low-earth orbit to a large L1-centred Class I Halo orbit in the Sun-Earth circular problem.

Interplanetary missions constitute a very visible and engaging facet of astronautics. An interesting paper under the theme Interplanetary Mission Design relates to sailing to the Sun. The author shows that after a spacecraft has escaped the earth s gravity, it is possible to deploy a solar sail in such a way as to (nearly) destroy the circumferential component of the velocity to zero, after which the craft will fall towards the sun under the sun s gravity. Yet another interesting and useful trajectory is a free-return trajectory which depart from a low-Earth orbit, go around a body such as the Moon or Mars, and return to the low-Earth orbit with propulsive manoeuvers only at the points of departure from and return to the low-Earth orbit. Other papers in the session relate to Earth-Mars transportation opportunities, and adaptive interplanetary navigation using genetic algorithms.

Formation flying of spacecraft is a recent development in astronautics and is aptly included as a theme in the volume. Papers on this subject pertain to optimal configurations for rotating spacecraft formations, Hill s equation in relation to formation flying of satellites, and dynamics and control of spacecraft formations.

Topics in spacecraft applications are somewhat diversified, covering control systems for flexible expendable launch vehicles, characterisation of space debris using spectroscopy, and space applications of the Global Positioning and Timing Service (GPtS). This last application is coming into its own after the GPtS has become operational and established in earthbound applications.

Adaptation and cooperation in control of multiple robot manipulators, control of spacecraft under actuator failure, and spectral patching method for direct trajectory optimisation are papers related to control application. Under the important theme of attitude determination, insightful papers on quaternion estimation from vector observations, focal-plane representation of rotations, attitude and position determination from line-of-sight measurements, analytical theory of orbit determination, and recursive attitude prediction discuss diverse aspects of the problem.

The volume, rich and diverse, and presenting papers from many of the best names in astronautics, is a rich and apt tribute to Richard H. Battin, the father figure of modern American astronautics.

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Book Review

Spaceflight mechanics 2001

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The volume under review is the eleventh of a sequence of Spaceflight mechanics volumes which are published as a part of the general series *Advances in the Astronautical Sciences*, a very valuable record of developments in the broad field of astronautics and related sciences. The volume consists of two parts totalling about 2200 pages. It records the proceedings of the 11th Annual Space Flight Mechanics Meeting held during February 11-15, 2001, at Santa Barbara, California. Hosted by the American Astronautical Society (AAS), cosponsored by the American Institute of Aeronautics and Astronautics (AIAA), and organised by the AAS Space Flight Mechanics Technical Committee and the AIAA Astrodynamics Technical Committee, the Meeting brought together 191 participants to hear 129 presentations from nine countries in 24 scheduled technical sessions, conducted in three parallel streams.

Two whole sessions out of the 24 are devoted to *Mars missions* signifying the importance of the planet in the current thinking of the space establishment. The papers in these sessions provide an insight into the variety of the ongoing and forthcoming Mars missions. Preliminary orbit determination is a major topic of interest and is presented in the context of the Mars Global Surveyor Mapping Mission and Nozomi, the first Japanese spacecraft to explore Mars. Launched in 1998, the latter has an interesting fuel-minimizing trajectory, utilizing multiple lunar gravity assists and a powered earth swing-by. The analysis of the various legs of such a complex trajectory represents an interesting study. Another related study is the determination of optimal orbits for sparse constellations of Mars navigation satellites. Satellite constellations is a contemporary and interesting study by itself, and is the theme of a session as will be summarized below.

Positioning of explorer vehicles and stations on the Martian surface is also of high current interest. *Mars surface asset positioning using in-situ radio tracking* discusses a scheme for more accurate location of such surface assets through measurements collected by the Odyssey Orbiter, compared to previous positioning methods relying upon direct-to-earth radiometric observations. Hazard avoidance during landing at an unfamiliar site on Mars is also of prime concern, and Jet Propulsion Laboratory (JPL) scientists have outlined a lidar-based scheme for this purpose.

Braking a spacecraft s approach speed to make it orbit around a planet normally requires motor effort and hence premium propellant weight to be carried on the satellite. However, in the case of planets with atmosphere, it is possible to achieve braking by using the atmospheric drag. Navigation and guidance schemes for such an operation are critical, and an energy controller aerocapture guidance algorithm for the Mars Sample Return Orbiter is being developed by CNES of France.

Another paper pertaining to the same mission discusses orbit selection of a complementary demonstrator. Aerocapture combined with solar electric propulsion is proposed as a really attractive option for 2007-2009 sample return missions such as Phobos One from the point of view of mass saving and planetary protection. The latter purpose is also sought to be served by an aim-point biasing method proposed by CNES.

Attitude determination and control is an all-time important subject in space dynamics, and occupies prominence at this Meeting too. As many as three sessions have been devoted to these topics. A major emphasis in attitude control is on optimisation, with papers on local optimisation technique for attitude motion tracking using control moment gyroscopes, minimising the effects of transverse torques during thrusting for spin-stabilised spacecraft, optimal design of generalised three-dimensional active coning actuator for a spinning spacecraft under thrust, and constrained optimisation of passive coning actuators for the same craft. Other topics in attitude control comprise simultaneous precession manoeuvre, active nutation control and large-angle attitude state tracking control using GPS output feedback, fail-safe controller for an under-actuated rigid spacecraft, and feedback control of rigid body attitude with inclinometer and low-cost gyro measurements.

Papers related to attitude determination and control cover topics such as equilibria of a satellite subjected to a constant torque (analysis of stability), Kalman filtering using the quaternion extracted from vector measurements, and rejection of multiple periodic disturbances using MLEMS (Multiple Error Least Mean Square) with disturbance identification. Two papers deal with the classical problem of magnetic attitude determination and control of inertial pointing small momentum bias spacecraft, and modelling of the geomagnetic field in a segmented manner for use as high-accuracy reference vector.

The session also contains a set of papers focusing on the techniques for attitude determination and control. The use of solar electric propulsion for attitude control of a 3-axis stabilised spacecraft during orbital manoeuvres is an interesting concept since it minimises the need for onboard fuel storage, which often determines the useful life of a satellite. Other topics include a robust star identification technique for use in laser pointing determination of the ICESAT, attitude dynamics of CHAMP (Challenging Minisatellite Payload), a German small satellite mission for geoscientific and atmospheric research and application, and in-flight estimation of the Cassini spacecraft s inertia tensor. There is even a utilitarian paper describing web-based tools for spacecraft attitude dynamics and control simulation.

The near-earth space is no more the pristine void it used to be from creation till just three decades ago. Defunct satellites and jettisoned and disintegrated parts of satellites and upper stages of launch vehicles have populated many useful satellite orbital belts to such an extent that the danger of damage to new and existing useful satellites due to collision with this debris is clear, present, and escalating. *Orbital debris* is thus a topic of great concern in recent years, and aptly forms a theme session at the Meeting. Because of the large speed of orbiting bodies, even a millimetre-sized particle such as a small nut or foil scrap can puncture a hole in a satellite structure. Obviously all debris of sizes down to this level or lower cannot be catalogued individually, and an accurate statistical description would be the best bet. This is the thrust of most papers in the session, with additional emphasis on collision probability/risk analysis, debris reentry trajectory prediction, and mitigation measures.

Beyond a few hundred kilometres above the earth s surface, the density of the atmosphere becomes negligible for most practical purposes. In fact, many low-earth satellites are located in orbits beyond such heights for extended periods. Yet the atmosphere is not quite nonexistent at these heights, and continues to affect their orbits. An interesting single paper in a session devoted to *Atmospheric flight and modeling* reports studies on atmospheric density variation in the 1500-4000 km height band by analysing long-term perturbations to satellite orbits.

With several missions to asteroids and comets either completed or under way, *Missions to small bodies* is a topic of great contemporary interest. Such missions, of necessity, have to be unmanned, autonomous, small, and cheap. Additional complexities arise from the extremely small gravity (and hence escape velocities), irregular and often unknown shapes, and lack of knowledge about their surface characteristics such as density, strength and dust layers. The first three papers of the session pertain to the Japanese MUSES-C mission for asteroid sample collection and return, dealing with autonomous touchdown via optical sensors, ground simulation of the touchdown process, and the robotic lander Minerva to be carried on the satellite for surface exploration.

Small-body missions often have to orbit very close to the bodies, and make grazing and soft landings on the body. These aspects are dealt with in two papers focusing on a test of autonomous navigation using the range finder data from the successful NEAR mission, and design and analysis of landing and low-altitude asteroid flyovers. Other allied aspects covered in companion papers include approaching small bodies, dynamical behaviour of a spacecraft orbiting elongated celestial bodies, manoeuvre strategy for station keeping and global mapping around an asteroid, and hovering and translational motion over small bodies. Possibilities of collecting samples from multiple asteroids through a single spacecraft mission are also discussed.

Interplanetary missions using spacecraft have been man s dream from early days, and is achievable with current technology. In a session on this theme, two papers discuss new trajectory options for ballistic Mercury Orbiter mission, and Sun-Mars libration points and Mars mission simulations. Two other papers dwell on more ambitious missions for fast travel to outer solar system and out-of-the-ecliptic space-borne observatories, and discuss trajectory options.

Earth and lunar missions may now seem routine, but there always are challenges and new applications even in these missions. Six papers in the relative theme present aspects of a high power rocket demonstrator of a reusable glide-back booster, a semianalytical evaluation of launcher performances, lessons learned from the recovery of NASDA s ETS-VII satellite from anomalies and necessity of risk management, geostationary positioning phase from super-synchronous transfer orbit in relation to Hispasat 1C mission, WIND lunar backflip and distant prograde orbit implementation, and SIRTF trajectory design and optimisation.

Many modern space applications such as 3-D mapping require precise location and coordinated operation of multiple satellites. *Satellite clusters and formation flying* is a requirement of many current and future space programmes. Under this thematic session are papers discussing the dynamics of relative satellite motion, analytical results on the effects of solar radiation pressure on satellite formation flight, ground tracking and control of geosynchronous cluster satellites using the Raven telescope, and the state transition matrix of relative motion for the perturbed noncircular reference orbit.

Under a related topic, *Satellite constellations*, there are six papers reporting on Molniya/ Tundra orbit constellation considerations for commercial applications, probability of overlap for footprints of formation-flying satellites, a new concept for controlling formation-flying satellite constellations, an improved strategy for maintaining constant distance between satellites in an elliptically orbiting constellation, and the accelerometer proof mass offset calibration of the GRACE satellite.

Navigation is a classical discipline feeding to space activities, but the ever-tightening demands on mission accuracy and versatility requires continuous research and innovation. Such emphasis is borne out by the papers dealing with simulation of high-accuracy intersatellite ranging measurements (of importance for formation flying), orbit and manoeuvre estimation of interplanetary mission based on Delta-VLBI and radiometric measurements, accurate navigation for lunar lander/orbiter based on crater identification, recursive mode star identification algorithms, a factorisation and least-squares method for multipass sensor alignment calibration, and spacecraft rendezvous using GPS relative navigation.

Orbit determination, the subject area in space dynamics, features papers on the accuracy requirements for orbit determination for collision avoidance, estimation of periodic accelerations to improve orbit ephemeris accuracy, satellite selection strategy for low-earth orbit determination from GPS and GLONASS constellations using double differences, and a new approach to orbit determination strategy to improve the Stardust dynamic models. An interesting and useful paper estimates the earth radiation pressure effects on the orbit determination of GPS (Global Positioning Satellites), the inaccuracy of which directly affects a multitude of current position location navigation functions on the earth.

The importance of *Tether systems* in current space programmes is indicated by the two sessions it occupies at the Meeting. Modelling and dynamics analysis of tethered formations for space interferometry are presented, as are periodic solutions and damping aspects of rigid electrodynamic tethers. Active control of tether satellites via boom rotation, nonplanar spin-up dynamics of the ASTOR tethered satellite system, equilibrium configurations of tethered threebody systems and their stability, quick-look identification and orbit determination of a tethered satellite, analysis of tether aerobraking manoeuvres using a lifting probe with parametric uncertainties, and analysis of the validity of recent predictions for tethers on elliptical orbits are other topics covered. Two aspects of the Power Sail are considered: a novel control design methodology for maintaining its position and attitude, and a study of its dynamics and control.

In the theme session on *Control systems* the first three papers pertain to repetitive control, outlining tradeoffs between feedback, feedforward, and repetitive control for systems subject to periodic disturbances, repetitive control methods when the disturbance period is not an integer multiple of the sample time, and waterbed effect in repetitive control using zero-phase filtering. Other topics in the section relate to simulation of a closed loop test for the SELENE modelfollowing system using the flying test bed, joint dynamics modelling and parameter identification for space robot applications, and dynamics of a gyroscopic hopping rover. This last topic is of great interest for application in low-cost autonomous surface explorers on Mars and asteroids.

Low thrust missions are an area of special current interest because they can use solar energy for ionic propulsion over long distances, minimising the need for carrying premium fuel on board. The technology has its own set of problems which are addressed through six papers covering the anatomy of the constant radial thrust problem, application of a novel optimal control algorithm to low-thrust trajectory optimisation, direct approach to low-thrust positioning computation under satellite constraints, optimal low-thrust trajectories combined with an aeroassist manoeuvre about Mars, solar electric propulsion leverage relating to Electric Delta-Vega scheme, and a comparison of solar sail and solar electric propulsion for deep space missions.

Under *Multi-body dynamics and libration points*, results are reported on resonance-induced coupled planar N-body collinear point solutions, effect of perturbations in Coriolis and centrifugal forces on the location and stability of the equilibrium point, nonlinear stability of L4 in the restricted three-body problem, long-duration Lissajous orbit control for the ACE Sun-Earth L1 libration point mission, and trajectory arcs with lunar encounters for transfers to small amplitude Lissajous orbits.

Guidance and control is, in a manner of speaking, the bread and butter of space operations, and the relative theme session sports topics such as fuel-optimal rendezvous in a central force field with linear drag, linear optimal periodic position control for elliptical orbits, applications of autonomous onboard orbit control, aerodynamic manoeuvring for stability and control of lowperigee satellites, and optimal re-entry trajectory design by interactive multiobjective optimisation with parallel programming. Two topics that are not exactly in the space domain are also included: adaptive sliding mode control of a hypersonic flight vehicle, and discrete control of kinetic energy projectile trajectories.

Yet another core area of space dynamics, *Orbit dynamics and design*, covers useful topics like orbital analysis of space passenger operations depicted in the legendary movie 2001: A space odyssey , GPS disposal orbit stability and sensitivity study, class of orbits with 24-hour sun exposure, sunset-synchronous orbits and other astrodynamics support for the optical calibration sphere, the effect of tidal forces on orbit transfers, and mission design of an in-orbit satellite servicing.

Some papers of an essentially mathematical nature are grouped under the theme *Special topics in astrodynamics.* These pertain to mitigation of effects of eclipse boundary crossings on the numerical integration of orbit trajectories, resonant stability around the sphere of influence, variational calculus and approximate solutions of algebraic and differential equations, among others.

The volume ends with a *Plenary lecture* titled In quest of better attitudes , delivered by Malcolm D. Shuster of the Orbital Sciences Corporation as the first of a series of annual lectures by the latest recipient of the Dirk Brouwer Award of the American Astronautical Society. The title is an interesting play of key words, focusing on QUEST (Quarternion Estimate) which is a popular and powerful algorithm for satellite attitude determination.The article, covering history and science aspects of the algorithm, is a very good introduction for someone wishing to get on stream with the important subject of attitude determination.

The mammoth two-part volume is a treasure house of information and knowledge on the esoteric science of astrodynamics, and conveys the most recent in the field from the most authentic mouths.

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Book Review

Current topics in computational molecular biology

edited by Tao Jiang, Ying Xu and Michael Q. Zhang, The MIT Press, 5, Cambridge Center, Cambridge, MA 02142, 2002, pp. 542, $55.

Computational molecular biology or bioinformatics is interdisciplinary and calls upon expertise in many different disciplines such as biology, mathematics, statistics, physics, chemistry, computer science and engineering. The Human Genome project has led to a generation of massive amount of data, which has acted as a catalyst for developments in the area of biotechnologies. This book is an excellent treatment of several topics in computational biology, ranging from traditional ones such as protein structure modeling and sequence alignment, to the recent topics such as expression, data analysis and comparative genomics. The book is a unique one in the sense that it combines algorithmic, statistical, database and AI-based methods for solving biological problems including topics such as gene expression analysis and pathway databases.

The 19 chapters are grouped into four sections. The introductory section is an excellent coverage of the historical perspectives of bioinformatics. The second has indepth coverage on computational methods for comparative sequence and genome analyses. The third contains excellent papers on computational methods for mining biological data and discovering hidden patterns in the data. The fourth has a very systematic presentation of computational approaches for structure prediction and modeling macromoloecules.

The second section presents the conceptual importance of statistical modeling and Bayesian methodology. Methods for comparing two sequences and their applications in the analysis of DNA and protein sequences are also covered in this section. Other topics covered are a survey on computation methods for multiple sequence alignment, basic concepts in phylogenetics, the design and development of computational tools using the quartet methods, basic concepts of genome rearrangement and applications, and compression algorithms for DNA sequences.

The third section covers an overview of the major statistical techniques for quantitative trait analysis, statistical methods for the recognition of eukaryotic genes, computational methods used for identifying eukaryotic PoIII promoter elements, algorithms for clustering gene expression data, latest developments of the KEGG database, and techniques for determining and knowledge discovery in the biomedical domain.

The last section covers topics such as overview of predictions of RNA secondary structures, computational methods for protein secondary structure prediction, and for protein folding, use of protein models to functional analysis, protein threading for protein structure calculation, and algorithms for docking and for generation of epitopes on molecular surfaces.

On the whole, this is an excellent coverage of material that is of great interest to researchers interested in the broad discipline of bioinformatics and related computational methods.

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Book Review

Analog VLSI : Circuits and principles

by Shih-Chii Liu, Jorg Kramer, Giacomo Indiveri, Tobias Delbruck and Rodney Douglas, The MIT Press, 5, Cambridge Center, Cambridge, MA 02142, 2002, pp. 434, $60.

Analog circuits are in the centre stage of electronic systems in recent years. Design of systems such as wideband wired and wireless data modems, cellular telephones, optical transmitters and receivers, demands deep knowledge in the design and analysis of analog circuits. This book is an excellent treatment of the various topics of current interest to researchers and industry professionals interested in analog VLSI circuits and systems.

The first four chapters contain an excellent coverage of semiconductor device physics and MOSFETs. The underlying physics of the devices particularly the operation of the MOSFET in the subthreshold region and a discussion of analog charge storage using floating-gate technology are presented in a lucid manner. The section on Statics spreads over Chapters 5-7 describing examples of linear and nonlinear static functions that can be implemented by simple circuits. An interesting analog design paradigm where currents represent the signal and state variables in a circuit has been presented. Methodology for implementing a large class of linear and nonlinear functions has been very elegantly developed.

The section on Dynamics deals with circuits which process time-varying signals. Concepts of linear system theory needed for the small-signal analysis of circuits are very meticulously presented. Chapter 10 on Photosensors is an extremely interesting chapter on semiconductor photosensors dealing with circuits that model prominent properties of biological photoreceptors. Basic concepts on image sensing principles are brought out very systematically.

The last section is an excellent collection of special topics devoted to areas such as noise in transistors, flow from design to layout to fabrication, and scaling of semiconductor technology in future. Sources of noise in a transistor and their measurement are presented very systematically. A novel way of demonstrating the equivalence of thermal noise and shot noise is highlighted. Few topics related to chip design and fabrication are covered from the current and futuristic points of view so that the details are of interest to researchers and practising design engineers. Some of these topics are on circuit layout masks needed to specify a layout to a fabrication house, layout tips for good circuit performance, processing steps in a 0.25 micron process and scaling of transistors in future.

On the whole, this is an excellent book which must find a place among the collection of books of any one interested in VLSI analog circuits. Since the emphasis in future is most likely to be on analog and mixed signals, the topics covered in this book will be actively pursued by VLSI chip designers.

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