1996 Published Papers

The following pages contain the bibliographical information and a brief abstract of all papers formally published by Draper engineers during the 1996 calendar year.

Adams, M. (Draper); Kolitz, S. (Draper); Odoni, A. (MIT), **Evolutionary concepts for decentralized air traffic flow management**, presented at AIAA, Guidance, Navigation, and Control Conference, San Diego, CA, July 29-31, 1996

A variety of alternative approaches to modify the policies and procedures under which the air traffic flow management system operates are described, and an approach to evaluate those alternative approaches is discussed.

Ayer, F.; Coco, R.; Kelleher, W., **New opportunities for satellite integrated power and attitude control systems**, published in *Navigation Technology for the 3rd Millennium; Proceedings of the 52nd Annual Meeting of the Institute of Navigation*, Cambridge, MA, June 19-21, 1996 (A96-44576 12-04), Alexandria, VA, Institute of Navigation, 1996, p. 831-841

This paper presents the results of a feasibility study of a high-specific-energy flywheel to meet the energy and momentum exchange needs of a LandSat-class Low-Earth Orbit (LEO) satellite. This paper focuses on the optimization of two critical components: the high-speed composite rotor and the suspension system. A thin composite disk of constant thickness incorporating a mixture of circumferential and radial plies is selected as the best contender to achieve the maximum possible energy storage of a composite wheel. Two options are considered for suspending the flywheel: ball bearings and magnetic bearings.

Babcock, P. S., IV, **Channelization: the two-fault tolerant attitude control function for the Space Station Freedom**, published in *IEEE Aerospace and Electronics Systems Magazine*, Vol. 11, No. 5, p. 9-22

The Space Station Freedom was, from the mid-1980s through 1993, the design for an international orbiting laboratory facility. The Space Station Freedom comprised "utility" systems, such as power generation and distribution, thermal management, and data processing; and "user" systems, such as communication and tracking, propulsion, payload support, and guidance, navigation, and control. The challenge was to develop an architecture, or integration, of these systems that would achieve the specified level of fault-tolerant attitude control and operate autonomously for the three-month unmanned periods during the assembly process. The final design was accepted by the Space Station Control Board as the design baseline in July 1992.

Barbour, N. (Draper); Chichinadze, M.; Ilyin, V.; Novgorodski, A. (CRI Delphin, Moscow, Russia), **Accelerometer designs and fields of application**, presented at Saint Petersburg International Conference on Integrated Navigation Systems, 3rd, St. Petersburg, Russia, May 28, 29, 1996, *Proceedings*, Pt. 2 (A96-32176 08-35), St. Petersburg, Russia, State Research Center of Russia Elektropribor, 1996, p. 115-125

Accelerometer designs and fields of application are examined with particular reference to accelerometers for navigation systems, attitude reference systems, and gravimetric systems developed and produced in Russia, U.S.A., and France. The criteria for choosing the accelerometer type based on system requirements are identified, and some future trends in accelerometer design are discussed.

Barbour, N. (Draper); Chichinadze, M.; Vechtomov, V.; Novgorodski, A. (CRI Delphin, Moscow, Russia), **Investigation of high-speed sliding bearing support for DTGs**, presented at Saint Petersburg International Conference on Integrated Navigation Systems, 3rd, St. Petersburg, Russia, May 28, 29, 1996, *Proceedings*, Pt. 1 (A96-32176 08-35), St. Petersburg, Russia, State Research Center of Russia Elektropribor, 1996, p. 158-165

Ways of improving the performance of Dynamically-Tuned Gyros (DTGs) by reducing the vibrations generated by high-speed bearings are examined. A miniature high-speed sliding bearing support operating in the elastohydrodynamic lubrication mode is considered as an alternative to ball bearings. Preliminary test results for a prototype DTG with sliding bearings demonstrate the feasibility of the sliding support, but further evaluation is required.

Barbour, N., **Status of inertial systems**, published in *Proceedings of the National Technical Meeting*, Institute of Navigation, 1996, p. 7-15

This paper discusses major development efforts of inertial instrument technology in the following areas: (1) interferometric fiber-optic gyro; (2) silicon gyros and accelerometers; and (3) strategic mechanical systems. The focus of development efforts is on improving performance, lowering cost, leveraging off the communications industry, batch production, and supportability and reliability.

Barbour, N.; Connelly, J.; Gilmore, J.; Greiff, P.; Kourepenis, A.; Weinberg, M., **Micromechanical silicon instrument and systems development at Draper Laboratory**, presented at AIAA, Guidance, Navigation, and Control Conference, San Diego, CA, July 29-31, 1996

Draper Laboratory has been developing miniature micromechanical instruments for over 10 years, using silicon microfabrication techniques to achieve high yields in a batch processing environment. Current design efforts center on the tuning fork gyro and the pendulous accelerometer configurations. These units have successfully performed across a temperature range of -40 to 85 ˚C, and have survived 80,000 to 120,000-g shock tests along all axes. Integrated micromechanical inertial sensor assembly and GPS receiver configurations are being developed for applications ranging from projectile guidance to small satellites.

Barbour, N.; Connelly, J.; Gilmore, J.; Greiff, P.; Kourepenis, A.; Weinberg, M., **Microelectromechanical instrument and systems development at Draper Laboratory**, presented at Saint Petersburg International Conference on Integrated Navigation Systems, 3rd, St. Petersburg, Russia, May 28, 29, 1996, *Proceedings*, Pt. 1 (A96-32176 08-35), St. Petersburg, Russia, State Research Center of Russia Elektropribor, 1996, p. 3-10

Draper Laboratory has been developing miniature micromechanical instruments for over 10 years using silicon microfabrication techniques to achieve high yields in a batch processing environment. Continuing development activities are expected to yield over an order of magnitude in performance enhancement. Current design efforts center on the tuning-fork gyro and the pendulous accelerometer configurations.

Bello, M. G., **Hierarchical multilayer perceptron network-based fusion algorithms for detection/classification of mines using multiple acoustic images and magnetic data**, published in *Proceedings of SPIE*, The International Society for Optical Engineering, Vol. 2765, 1996, p. 84-109

Hierarchical neural network approaches have been developed first for combining high- and low-frequency side-scan sonar imagery, and then for combining both acoustic images and magnetic data. The adopted acoustic data fusion approach consists in an image-screening/high/low-frequency blob matching stage, followed by an information fusion/classification stage. The resulting Detection/Classification Algorithm is evaluated based on a combined ground truth obtained from both acoustic and magnetic sources.

Bergmann, E. V.; McNamara, T.; Epstein, L.; Holmes, S.; Hanson, D.; Prince, W.; Goldman, W.; Natoli, L.; Larkin, N., **A/OA-10A GPS/INS integration, flight test experience, and lessons learned**, published in *Navigation Technology for the 3rd Millennium; Proceedings of the 52nd Annual Meeting of the Institute of Navigation*, Cambridge, MA, June 19-21, 1996 (A96-44576 12-04), Alexandria, VA, Institute of Navigation, 1996, p. 111-116

A navigation upgrade to the A-10 aircraft is described. A Collins RCVR-3A was installed into the aircraft and integrated with the existing LN-39 INS via Kalman filters implemented in a new control display unit. The upgrade architecture is described, and results of testing are summarized. Interaction of the upgraded navigation system with the weapons system computer is also discussed.

Bergmann, E. V.; McNamara, T.; Prince, W.; Duggin, S.; Hamilton, T.; McGee, J.; Goldman, W.; Larkin, N., **Integration of an embedded GPS/INS into an attack aircraft**, published in *Navigation Technology for the 3rd Millennium; Proceedings of the 52nd Annual Meeting of the Institute of Navigation*, Cambridge, MA, June 19-21, 1996 (A96-44576 12-04), Alexandria, VA, Institute of Navigation, 1996, p. 201-205

A navigation upgrade to the A-10 aircraft is described. A Honeywell Embedded Global Positioning System/Inertial Navigation System (GPS/INS) unit is being integrated with the new control display unit, flight instruments, and weapons system. The upgrade architecture is described, and results of preliminary testing are summarized. Interaction of the upgraded navigation system with the weapons system computer is also discussed.

Bergmann, E., **A new concept for aircraft formation-keeping guidance**, presented at AIAA, Guidance, Navigation, and Control Conference, San Diego, CA, July 29-31, 1996

A new type of formation-keeping guidance is proposed based on a new Improved Data Modem, which is to be integrated into the A-10 aircraft. This system provides greater accuracy than air-to-air TACAN, as well as vertical guidance, which TACAN does not. Advantages of the proposed system include relative position and velocity accuracy consistent with GPS accuracy (several meters, and better than 1 ft/s), accurate target altitude (better than 50 ft), and discrete tagging of information from different aircraft, avoiding clutter and confusion between aircraft.

Bernstein, J. J.; Niles, L. C. (Draper); Chen, H. D.; Udayakumar, K. R.; Gaskey, C. J.; Cross, L. E. (Pennsylvania State University, University Park), **Fabrication and electrical properties of lead zirconate titanate thick films**, published in *American Ceramic Society Journal* (ISSN 0002-7820), Vol. 79, No. 8, August 1996, p. 2189-2192

Thick films of lead zirconate titanate (PZT) of the morphotropic phase boundary composition, $Pb(Zr(0.52)Ti(0.48))O_3$, have been fabricated on

platinum-buffered silicon using a modified sol-gel spin-coating technique. Crack-free films of 12-μm thickness can be uniformly deposited on 3-in diameter wafers with high yield and properties comparable to those of bulk ceramics. The thickness dependence of film structure and the dielectric, ferroelectric, and piezoelectric properties have been characterized over the thickness range of 1 to 12 μm. A strong (1 0 0) texture develops as film thickness increases above microns. PZT films in this thickness range are extremely well-suited to applications such as electro-mechanical transduction media in silicon-based microelectromechanical systems.

Borenstein, J. T.; Greiff, P.; Sohn, J. B.; Weinberg, M. S., **Characterization of membrane curvature in micromachined silicon accelerometers and gyroscopes using optical interferometry**, published in *Proceedings of SPIE - The International Society for Optical Engineering*, Vol. 2879, 1996, p. 116-125

Micromachined silicon sensors often exhibit curvature of released membrane structures due to internal stresses, doping gradients, and crystalline defects. This curvature can be a significant source of error in inertial sensors such as accelerometers and gyroscopes. Development of process conditions that reduce curl requires a rapid, accurate method for obtaining high-resolution flatness data over a complex two-dimensional surface. This work reports on the use of a commercially available, nondestructive optical char-acterization tool that provides high-resolution profiles of micromachined structures.

Brancart, C. P.; Madden, J. P., **Autonomous minehunting and mapping at-sea testing**, published in *Oceans Conference Record (IEEE)*, Vol. 2, 1996, p. 800-806

A complex test program, such as the Defense Advanced Research Projects Agency Autonomous Minehunting and Mapping Technology (AMMT), demands detailed test planning. The AMMT Master Test Plan met this requirement. The plan prepared the test team for five months of field work and still preserved flexibility for unanticipated contingencies.

Carter, S. S.; Cefola, P. J.; Proulx, R. J., **The determination of precision mean element sets from GPS receiver onboard navigation solutions**, published in *Astrodynamics 1995: Proceedings of the AAS/AIAA Astrodynamics Conference*, Halifax, Canada, February 14-17, 1995 (A96-23484 05-12), San Diego, CA, Univelt, Inc. (*Advances in the Astronautical Sciences*, Vol. 90, Pt. 2), 1996, p. 1203-1223

This paper examines the use of onboard GPS navigation solutions as observation data for precision ground-based orbit determination. Semianalytic and special perturbation satellite theories are employed to develop precision element sets for the Ocean Topography Experiment, Extreme Ultraviolet Explorer, and Technology for Autonomous Operational Survivability satellites using such navigation solutions.

Cefola, P. J. (Draper); Fonte, D. J. (USAF, Washington, DC), **Extension of the Naval Space Command satellite theory PPT2 to include a general tesseral M-daily model**, presented at AIAA/AAS Astrodynamics Conference, San Diego, CA, July 29-31, 1996, *Collection of Technical Papers* (A96-34712 09-12), Reston, VA, American Institute of Aeronautics and Astronautics, 1996, p. 306-327

The Naval Space Command PPT2 model of satellite motion has been used for 30 years to maintain a catalog of Earth satellites. A modified version of PPT2 is described, which includes a recursive analytical model for the portion of the tesseral harmonic perturbation that depends on just the Greenwich hour angle.

Cefola, P. J. (Draper); Draim, J. E. (Mobile Communications Holdings, Inc., Washington, DC); Sabol, C. (USAF, Phillips Lab, Kirtland AFB, NM), **Optimal orbit transfer to a sun-synchronous, critically-inclined orbit for the ELLIPSO personal communication system**, presented at AIAA/AAS Astro-dynamics Conference, San Diego, CA, July 29-31, 1996, *Collection of Technical Papers* (A96-34712 09-12), Reston, VA, American Institute of Aeronautics and Astronautics, 1996, p. 411-421

This paper explores orbit injection from a circular Low-Earth Orbit (LEO) into a sun-synchronous, critically-inclined orbit with application to the ELLIPSO global personal communications system. The focus is on the single optimal orbit transfer, which minimizes the total velocity impulse required with unconstrained transfer time and unspecified location on the initial and final orbits.

Cefola, P. J. (Draper); Fonte, D. J. (USAF, Washington, DC); Shah, N., **The inclusion of the Naval Space Command Satellite Theory PPT2 in the R&D GTDS Orbit Determination System**, published in *Spaceflight Mechanics 1996; Proceedings of the 6th AAS/AIAA Spaceflight Mechanics Conference*, Austin, TX, February 12-15, 1996 (A96-40059 11-12), San Diego, CA, Univelt, Inc. (*Advances in the Astronautical Sciences*, Vol. 93, Pt. 1), 1996, p. 665-691

Previously, the workstation version of the GTDS Orbit Determination Program was modified to include the Air Force Space Command general perturbation solutions: SGP, GP4, HANDE, and SALT. The current work adds the Naval Space Command PPT2 model. Together with existing numerical, analytical, and semianalytical options, the addition of PPT2 gives GTDS a comprehensive set of orbit propagation capabilities.

Cefola, P. J. (Draper); Sabol, C. (USAF, Phillips Lab, Kirtland AFB, NM); Draim, J. (Mobile Communications Holdings, Inc., Washington, DC), **Refinement of sun-synchronous, critically inclined orbit for the ELLIPSO personal communication system**, published in *Astrodynamics 1995: Proceedings of the AAS/AIAA Astrodynamics Conference,* Halifax, Canada, February 14-17, 1995 (A96-23484 05-12), San Diego, CA, Univelt, Inc. (*Advances in the Astronautical Sciences,* Vol. 90, Pt. 1), 1996, p. 675-694

This paper refines a sun-synchronous, critically inclined orbit with application to the ELLIPSO global personal communications system. Previous work has shown this class of orbit to be maintainable in the presence of long-term perturbations. The original versions of the orbit did, however, experience significant atmospheric drag and tesseral resonance effects. A convenient strategy for reducing these adverse effects has been found.

Cefola, P. J.; Proulx, R. J. (Draper); Carter, S. S. (USAF, Washington, DC), **Precision orbit determination from GPS receiver navigation solutions**, presented at AIAA/AAS Astrodynamics Conference, San Diego, CA, July 29-31, 1996, *Collection of Technical Papers* (A96-34712 09-12), Reston, VA, American Institute of Aeronautics and Astronautics, 1996, p. 297-305

The use of Earth-centered, Earth-fixed position and velocity information from an onboard GPS receiver in a ground-based orbit determination scheme is investigated. Semianalytic (SST) and special perturbation (SP) satellite theories are employed to develop precision element sets for the Ocean Topography Experiment (TOPEX), Extreme Ultraviolet Explorer (EUVE), and Technology for Autonomous Operational Survivability (TAOS) satellites. Evaluation of the derived orbits is accomplished through comparison to Precise Orbit Ephemerides (POEs).

Faiz, R. L., **Net RTM preforming process for cost-effective manufacturing of military ground vehicle composite structures**, published in *Technology Transfer in a Global Community; Proceedings of the 28th International SAMPE Technical Conference,* November 4-7, 1996, p. 381-392

This paper documents the successful definition and demonstration of the enabling technologies used for the development of cost-effective continuous reinforcement, oriented fiber, Resin Transfer Molding (RTM) preforms satisfying all performance requirements. Technologies address improvements in the application of innovative preform manufacturing techniques and equipment.

Flory, S.; Hayes, S.; Luniewicz, M.; Musoff, H., **Instrumenting a long-arm centrifuge for dynamic calibration of an inertial guidance system using precision position updates**, published in *Navigation Technology for the 3rd Millennium; Proceedings of the 52nd Annual Meeting of the Institute of Navigation,* Cambridge, MA, June 19-21, 1996 (A96-44576 12-04), Alexandria, VA, Institute of Navigation, 1996, p. 93-101

Typical centrifuge testing of inertial guidance systems and components employs input acceleration as the controlled variable, and in this type of testing, accurate knowledge of centrifuge-produced acceleration is needed to analyze the data from the Unit-Under-Test (UUT). As UUT performance approaches the part-per-million (ppm) level, sufficiently precise measurement of applied acceleration becomes impractical. An alternative testing approach is described that is based on comparing guidance estimates of position with true position as measured by a Time-Space-Position Instrumentation (TSPI) system.

Gai, E., **Guidance, navigation, and control from instrumentation to information management**, published in the *Journal of Guidance, Control, and Dynamics,* Vol. 19, No. 1, pp.10-14

The classical Guidance, Navigation, and Control (GN&C) system is a feedback system that includes three subsystems: Navigation is the determination of the position and velocity vectors of a moving platform in a specified coordinate frame. Guidance is the determination of a trajectory from a current position and velocity to a desired position and velocity satisfying specified costs and constraints. Control is the determination of the commands to the vehicle actuators to implement the trajectory, preserving a stable feedback loop.

Greenspan, R. L., **GPS and inertial integration**, published in *Global Positioning System: Theory and Applications,* Vol. 2 (A96-20837 04-17), Washington, DC, American Institute of Aeronautics and Astronautics, Inc. (*Progress in Astronautics and Aeronautics,* Vol. 164), 1996, p. 187-220

Inertial Navigation Systems (INS) and GPS possess complementarities that allow a navigation system integrating them to achieve greater accuracy than one employing either type of system alone. A study is presented of the GPS/INS integration benefits that can be anticipated for a given application, the configuration of data paths between the two system components most appropriate for that application, and the degree of complexity required in the integration algorithms for a given level of performance.

Greenspan, R.L., **Global navigation satellite systems**, presented at the System Implications and Innovative Applications of Satellite Navigation Conference (AGARD-LS-207)

The Global Navigation Satellite System (GNSS) is the visionary goal for a world-wide utility that will ultimately provide reliable and dependable navigation and timing services to civil and national users. The enabling

technology is firmly rooted in operational satellite navigation systems that have been developed for military use, including the Global Positioning Satellite System (GPS) and the Global Navigation Satellite System (GLONASS) developed in the USA and in Russia, respectively. This paper provides an overview of the means by which individual design features of satellite navigation systems are seen to satisfy the mission requirements for specific user groups. The paper is organized from the viewpoint of the users of the satellite navigation services; it also includes a review of some applications of these services that were not even remotely anticipated by their original designers.

Greiff, P.; Antkowiak, B.; Campbell, J.; Petrovich, A., **Vibrating wheel micromechanical gyro**, published in the *Proceedings of Position, Location, and Navigation Symposium - PLANS '96*

Silicon micromechanical gyro performance has progressed to the threshold of useful initial applications, at least 1 deg/s. The Vibrating Wheel On a Gimbal (VWOG) is a new gyro design with the promise of improved manufacturability. With a variety of accelerometers from which to choose, the advent of the silicon gyro begins the era of silicon micromechanical inertial guidance.

Greiff, P.; Hopkins, R.; Lawson, R., **Silicon accelerometers**, published in *Navigation Technology for the 3rd Millennium; Proceedings of the 52nd Annual Meeting of the Institute of Navigation,* Cambridge, MA, June 19-21, 1996 (A96-44576 12-04), Alexandria, VA, Institute of Navigation, 1996, p. 713-718

A number of emerging markets have been identified for low-cost, small-size, moderate-accuracy accelerometers in the fields of tactical weapons systems, stabilization controls, robotics, and commercial applications. Micromechanical technology is well-suited to these needs, and a family of silicon-on-Pyrex accelerometers is being developed at Draper Laboratory to meet them. The size of our accelerometer chips is typically about 0.3 to 1 mm. Details of the design and process are described, and test results are presented for several different device geometries.

Griffin, A.; Griffin, C. W.; Turner, C. S. (Lone Peak Engineering, Draper, UT); Mumm, D. R.; Marshall, D. B. (Rockwell Science Center, Thousand Oaks, CA), **Hardness variations in multilayered ZrO_2-Al_2O_3 composites**, published in *American Ceramic Society Journal* (ISSN 0002-7820), Vol. 79, No. 5, May 1996, p. 1416-1418

The hardness of zirconia-alumina laminar composites has been measured over contact size scales ranging from much smaller to much larger than the layer thicknesses. The results correlate with a weighted average of the hardness of the two-layer constituents based on the volume of the plastic zone; they deviate significantly from a similar average based on the contact area.

Griffin, E. A.; Mumm, D. R.; Marshall, D. B., **Rapid prototyping of functional ceramic composites**, published in *American Ceramic Society Bulletin,* Vol. 75, No. 7, July 1996, p. 65-68

This paper describes an application of the CerLOW approach to produce multilayered composites of ZrO_2 and Al_2O_3. The choice of the materials is based on previous studies that showed that a beneficial increase in toughness can be achieved with multilayered microstructures in this system. Because the CerLOW process produces the component directly from a Computer-Aided Design (CAD) file without tooling, dies, or molds, the production is rapid and cost effective. Components of complex shape can be fabricated readily, and design changes can be made easily.

Gustafson, D. E., **GPS signal tracking using maximum likelihood parameter estimation**, published in *Navigation Technology for the 3rd Millennium; Proceedings of the 52nd Annual Meeting of the Institute of Navigation,* Cambridge, MA, June 19-21, 1996 (A96-44576 12-04), Alexandria, VA, Institute of Navigation, 1996, p. 477-486

This paper considers the use of maximum likelihood parameter estimation in GPS signal tracking. The specific problem considered is phase and frequency tracking in the presence of spurious modulation components. An example is GPS signal processing within a rotating reentry body with aft-mounted antennas. The rotation induces unwanted modulation components on both signal amplitude and phase. The desire is to track and remove these components. This is a nonlinear estimation problem, which is attacked here by posing it as a linear estimation problem with an unknown modulation parameter.

Hall, R. A. (Draper, Houston, TX); Kaznacheyev, Y. V. (Russian Space Corp. Energia, Kaliningrad, Russia), **Fuel-optimal rotations of the space station Mir**, presented at AIAA, Guidance, Navigation, and Control Conference, San Diego, CA, July 29-31, 1996

A fuel optimal trajectory for reorienting axisymmetric space vehicles in rotational space is presented. The paper includes a general discussion of rotational maneuvers

using spacecraft thruster systems, including the common Euler axis rotations employed by the Space Shuttle. The algorithm presented here is that currently implemented on the Russian space station Mir.

Hattis, P. D. (Draper); Messac, A. (Northeastern Univ., Boston, MA), **Physical programming design optimization for High-Speed Civil Transport**, published in *Journal of Aircraft* (ISSN 0021-8669), Vol. 33, No. 2, April 1996, p. 446-449

Physical programming, a new design optimization methodology, is applied to the preliminary design of the High-Speed Civil Transport (HSCT). The principles of physical programming are briefly presented, and the preliminary design of the HSCT is discussed. Some remarks are also provided on the applicability of physical programming to a large class of system design problems.

Henderson, T. C., **Design and testing of a broadband active vibration isolation system using stiff actuators**, published in *Guidance and Control 1996; Proceedings of the 19th Annual Rocky Mountain Guidance and Control Conference*, Breckenridge, CO, February 7-11, 1996 (A96-33663 08-12), San Diego, CA, American Astronautical Society Publication (*Advances in the Astronautical Sciences,* Vol. 92), 1996, p. 481-500

This paper describes the design, development, and testing of a six-axis broadband active vibration isolation system using stiff actuators. This work was conducted as a technology development program on a structure that consists of a 1000-lb, 102-in diameter telescope with simulated optics kinematically mounted via six support struts to a granite slab. The design goal for this system was to improve the performance of the system by greater than 20 dB over the 10 to 200-Hz frequency range while maintaining high static stiffness.

Houston, K. M., **3-D acoustical imaging using micromechanical hydrophones**, published in *Sea Technology,* Vol. 37, No. 9, September 1996, p. 29-34

Micromechanical 3-D acoustic sensors are described on the basis of audio-frequency Micromechanical Hydrophone (MMH), condenser microphone, and high-frequency MMH. The high-frequency MMHs are designed to be sensitive in the 1- to 3-MHz frequency range and to be useful for acoustical imaging applications. Potential advantages of these micromechanical acoustic sensors over conventional sensors are given, in particular: packaging and inter-connection techniques, compact size and fine feature resolution, repeatable characteristics, and low cost in production quantities.

Jackson, M.; Zimpfer, D.; Lepanto, J. (Draper, Nassau Bay, TX), **Identification of the Shuttle/Mir structural dynamics for notch filter tuning**, published in *Spaceflight Mechanics 1996; Proceedings of the 6th AAS/AIAA Spaceflight Mechanics Conference,* Austin, TX, February 12-15, 1996 (A96-40059 11-12), San Diego, CA, Univelt, Inc. (*Advances in the Astronautical Sciences,* Vol. 93, Pt. 1), 1996, p. 493-510

The Space Shuttle Flight Control System includes notch filters in the feedback path to attenuate flexible dynamics and to maintain control system stability. For the STS-71 Mir docking mission, linearized finite-element models of the mated Shuttle/Mir vehicle were used to design the notch filters. An in-flight test was conducted to validate these and gauge the accuracy of the notch filter design. Filter design techniques are discussed. The structural frequency identification process used on STS-71 is covered to show how notch filters can be redesigned in near real-time to reduce conservatism or to correct potential stability problems.

Johnson, E. (Draper); Pritchett, A. R.; Barhydt, R.; Hansman, R. J. (MIT), **Flight simulator testing of cockpit traffic displays using robust situation generation**, presented at AIAA Flight Simulation Technologies Conference, San Diego, CA, July 29-31, 1996, *Technical Papers* (A96-35001 09-01), Reston, VA, American Institute of Aeronautics and Astronautics, 1996, p. 705-715

Flight simulator experiments testing cockpit traffic displays are underway for applications such as free-flight and closely-spaced parallel approaches. To meet their repeatability requirements, the recently developed Robust Situation Generation (RSG) architecture is being used. However, the use of RSG mandates changes in the experiment design to include the development and testing of the RSG scripts of situations. To generate any one desired situation, the experiment designer can use one of several possible RSG command sequences, which have different characteristics. These variations are discussed.

Johnson, E. N. (Draper); Hansman, R. J. (MIT), **Multi-agent flight simulation with robust situation generation**, presented at AIAA Flight Simulation Technologies Conference, San Diego, CA, July 29-31, 1996, *Technical Papers* (A96-35001 09-01), Reston, VA, American Institute of Aeronautics and Astronautics, 1996, p. 694-704

Air traffic management systems, onboard aircraft systems, and proposed airspace management structures such as free-flight, are often operated with human operators in a simulated environment. Success often depends on human

subjects experiencing one or more specific situations. Generating specific situations in the presence of uncertainty is referred to as "robust situation generation." A robust situation generation architecture was developed to support flight simulation tests of air transport cockpit systems.

Kondoleon, A.; Seltzer, D.; Thornton, R.; Thompson, M., **Development of a large-scale, high-speed wheel test facility**, Journal Announcement: GRAI9710; STAR3414

For the past two years, Draper Laboratory has been funding a joint effort with MIT to develop a large-scale, high-speed wheel test facility. This facility was developed to perform experiments and carry out evaluations on levitation and propulsion designs for MagLev systems currently under consideration. This paper describes the development of this test facility. A detailed description of the major components is presented. Adaptation of this facility for linear motor and other propulsion and levitation testing is described.

Mackenzie, B. A., **Bootstrapping space resource utilization with tethers, regolith rockets and micro rovers**, published in *Engineering, Construction, and Operations in Space V; Proceedings of the 5th International Conference on Space '96,* Albuquerque, NM, June 1-6, 1996, Vol. 1 (A96-35955 09-12), New York, American Society of Civil Engineers, 1996, p. 321-327

"Bootstrapping" means to start with the least expensive manufacturing and transportation system, which then increases its own capacity using materials already in space. This proposal optimizes the locations of manufacturing, initially in low-earth orbit for lower launch and servicing costs, and later in high orbit to use continuous solar power. This system becomes self-financing and grows by producing oxygen, fiberglass tethers; metals for spacecraft, rovers, and habitats; solar panels; and slag for shielding. This breaks an economic barrier to enable settlements beyond Earth.

Musoff, H., **Analysis of disparate inertial systems data**, published in *Navigation Technology for the 3rd Millennium; Proceedings of the 52nd Annual Meeting of the Institute of Navigation*, Cambridge, MA, June 19-21, 1996 (A96-44576 12-04), Alexandria, VA, Institute of Navigation, 1996, p. 15-19

A common situation in inertial systems testing arises when there are data from a number of different systems taken at different times and it is required to compare the data from these systems. Also, data from different tests taken at different times on the same system must be compared as well. This paper presents and analyzes different methods for accomplishing this task.

Musoff, H.; Schmidt, G. T. (Draper); Gusinsky, V. Z.; Lesyuchevsky, V. M.; Litmanovich, Yu A. (State Research Center of Russia Elektropribor, St. Petersburg), **A new procedure for strapdown attitude algorithms' optimization as applied to stochastic motion input**, presented at Saint Petersburg International Conference on Integrated Navigation Systems, 3rd, St. Petersburg, Russia, May 28, 29, 1996, *Proceedings*, Pt. 2 (A96-32176 08-35), St. Petersburg, Russia, State Research Center of Russia Elektropribor, 1996, p. 3-12

A new procedure for deriving strapdown attitude algorithms, earlier suggested by the authors, is examined for the more general cases of motion inputs: regular precession and stochastic angular motion. It is shown analytically with a new procedure that the coefficients optimized for classical coning hold true for the motions under consideration as well.

Paglia, J. G., **DARPA's Autonomous Minehunting and Mapping Technologies (AMMT) Program, an overview**, published in *Oceans Conference Record (IEEE)*, Vol. 2, 1996, p. 794-799

Draper recently completed the at-sea test phase of the Autonomous Minehunting and Mapping Technologies (AMMT) Program for the Defense Advanced Research Projects Agency (DARPA). The primary objective of this program is to develop and demonstrate advanced minehunting technologies that will enable Unmanned Undersea Vehicles (UUVs) to clandestinely survey an undersea area for mines and collect data for post-mission mapping of the surveyed area. This paper provides an overview of the AMMT Program, and describes the development and integration of the technologies required to perform the clandestine AMMT mission.

Petrovich, A.; Kumar, K.; Lee, T.; Lawrence, P., **Recent developments in flexured mass accelerometer technology**, published in the *Proceedings of Position, Location, and Navigation Symposium - PLANS '96*

The Flexured Mass Accelerometer (FMA) is being developed for high-performance guidance applications. The focus of the current development is an accelerometer capable of meeting strategic missile thrust-axis requirements, but with a cost an order of magnitude lower than that for current thrust-axis accelerometers, and a Mean Time Between Failure (MTBF) in excess of 15 years. The FMA uses a microwave readout to measure the deflection of a proof mass. Critical to the performance of this device is the bias stability of the flexured mass under loading.

Phillips, R. E.; Schmidt, G. T., **GPS/INS integration**, presented at the System Implications and Innovative Applications of Satellite Navigation Conference (AGARD-LS-207)

An inertial navigation solution exhibits relatively low noise from second to second, but tends to drift over time. Typical aircraft inertial navigation errors grow at rates between 1 and 10 nmi/h (1.8 to 18 km/h) of operation. In contrast, Global Navigation Satellite System (GNSS) errors are relatively noisy from second to second, but exhibit no long-term drift. Using both these sensors is superior to using either alone. Integrating the information from each sensor results in a navigation system that operates like a drift-free Inertial Navigation System (INS). There are further benefits to be gained depending on the level at which the information is combined. This presentation focuses on integration architectures, including "loosely coupled" and "tightly coupled" configurations.

Phillips, R. E.; Schmidt, G. T., **Relative and differential GPS**, presented at the System Implications and Innovative Applications of Satellite Navigation Conference (AGARD-LS-207)

This paper explains how 10-ft accuracy in aerospace vehicles using Inertial Navigation System/Global Positioning System (INS/GPS) equipment operating in Differential GPS (DGPS) mode may be achieved. The paper explains how the use of relative GPS can solve the guidance problem and how the use of relative targeting in a GPS-based coordinate system can solve the target location problem. The use of DGPS is also discussed.

Regan, R. A., **Autonomous Minehunting and Mapping Technologies Program autonomous maneuvering capabilities**, published in *Oceans Conference Record (IEEE)*, Vol. 2, 1996, p. 807-812

The Defense Advanced Research Project Agency (DARPA) has sponsored the Autonomous Minehunting and Mapping Technologies (AMMT) Program to demonstrate undersea vehicle technologies critical to future Unmanned Undersea Vehicles (UUVs). To support program goals, the vehicle control system has been significantly upgraded to provide autonomous adaptive mission planning. The AMMT/V on-line mission planning system attempts to achieve mission goals via real-time assessment and trajectory planning and interfaces to the existing UUV guidance and control system.

Rosello, A.; Adams, N.; Appleby, B., **Vehicle health monitoring of the STS Reaction Control System via robust estimation**, presented at AIAA, Guidance, Navigation, and Control Conference, San Diego, CA, July 29-31, 1996

A general two-tier framework for Vehicle Health Monitoring of Guidance, Navigation, and Control (GN&C) system actuators, effectors, and propulsion devices is presented. In this context, a top-level monitor that estimates jet thrust is designed for the Space Shuttle Reaction Control System (RCS) during the reentry phase of flight. Issues of importance for the use of estimation technologies in vehicle health monitoring are investigated and quantified for the Shuttle RCS demonstration application.

Schmidt, G. T. (Draper); Gusinsky, B. Z.; Lesyuchevsky, V. M.; Litmanovich, Y. A.; Peshekhonov, V. G. (Central Scientific and Research Inst. 'Elektropribor,' St. Petersburg, Russia), **The use of informational redundancy in INS with ESG** (**Electrostatically Suspended Gyros**), published in *Navigation Technology for the 3rd Millennium; Proceedings of the 52nd Annual Meeting of the Institute of Navigation,* Cambridge, MA, June 19-21, 1996 (A96-44576 12-04), Alexandria, VA, Institute of Navigation, 1996, p. 417-425

A problem of using the redundant information in gimbaled Inertial Navigation Systems (INS) based on two Electrostatically Suspended Gyros (ESG) to calibrate the gyro drift models' parameters is investigated. Two basic versions of an Inertial Measurement Unit (IMU) construction are considered: with the ESG installed in individual gimbals or on a common gyrostabilized platform.

Sims, T., **Real-time recovery of fault-tolerant processing elements**, published in *AIAA/IEEE Digital Avionics Systems Conference - Proceedings 1996*, p. 485-490

A critical problem in the design of ultra-reliable, fault-tolerant systems is how to bring a redundant member back on line after a transient fault without degrading critical real-time. This paper describes a hardware-assisted recovery technique that uses memory "tags" to determine which memory segments need to be restored such that recovery can be performed incrementally without affecting real-time operational tasks.

Socha, M.; Cappiello, G.; Madden, P.; Metzinger, R.; Nokes, D.; Tung, C.; Stanley, M., **Development of a small satellite for precision pointing applications**, presented at AIAA, Space Programs and Technologies Conference, Huntsville, AL, September 24-26, 1996

The move toward miniaturizing satellites cannot be based solely on scaling down with a commensurate reduction in capability. The real goal should be to maintain high functionality and ultimately to increase capability in a small low-cost package. This paper describes MicroSat, a three-axis-stabilized satellite design for precision pointing applications. The heart of the design is the optics and pointing subsystems. The satellite concept design and the hardware ground test demonstration are described.

Storch, J. A., **Flutter of solar arrays in rarefied jet plumes**, published in *Spaceflight Mechanics 1996; Proceedings of the 6th AAS/AIAA Spaceflight Mechanics Conference,* Austin, TX, February 12-15, 1996 (A96-40059 11-12), San Diego, CA, Univelt, Inc. (*Advances in the Astronautical Sciences,* Vol. 93, Pt. 1), 1996, p. 511-528

The aeroelastic stability of a solar array in the flow field of a hypersonic jet is investigated. Aerodynamic loads are calculated employing an approximate analytical model of the jet in conjunction with free molecular flow theory. Using a discrete solar array structural dynamics model, it is shown that flutter instabilities can occur depending on angle of attack, distance from source, surface momentum accommodation, and structural parameters. The case of pulsed periodic flow is analyzed via Floquet Theory, and stability boundaries are obtained for various combinations of pulse width and spacing. The influence of damping on the stability boundaries is also addressed. Applications are presented for the solar arrays of the Mir Space Station in the presence of Shuttle primary jet plumes.

Tetewsky, A. K.; Mullen, F. E., **Carrier phase wrap-up induced by rotating GPS antennas**, published in *Navigation Technology for the 3rd Millennium; Proceedings of the 52nd Annual Meeting of the Institute of Navigation,* Cambridge, MA, June 19-21, 1996 (A96-44576 12-04), Alexandria, VA, Institute of Navigation, 1996, p. 21-28

With the advent of GPS receivers mounted on spinning vehicles such as artillery shells, an interesting additional error must now be accounted for: carrier phase wrap-up. This paper presents a formal procedure for calculating the effect of phase wrap-up on antenna output as a function of antenna type and satellite geometry. This procedure quantifies additional phase tracking errors for GPS receivers from which the effect on the navigation solution is determined. The procedure is applied to a common antenna type - the crossed dipole - and the results are compared to laboratory data.

Wallace, S. T.; Proulx, R. J.; Cefola, P. J., **Parallel orbit propagation and the analysis of satellite constellations**, published in *Astrodynamics 1995: Proceedings of the AAS/AIAA Astrodynamics Conference,* Halifax, Canada, February 14-17, 1995 (A96-23484 05-12), San Diego, CA, Univelt, Inc. (*Advances in the Astronautical Sciences,* Vol. 90, Pt. 2), 1996, p. 1913-1932

This paper describes the development of a scalable, portable parallel orbit propagator and its application to the analysis of satellite constellations. The Draper Semianalytic Satellite Theory (DSST) is coupled with the Parallel Virtual Machine (PVM) software package to demonstrate the power of the networked computing paradigm. This concept is also extended to investigate the automation of optimal satellite constellation design.

Weinberg, M. S.; Bernstein, J.; Borenstein, J. T.; Campbell, J.; Cousens, J.; Cunningham, R. K.; Fields, R.; Greiff, P.; Hugh, B.; Niles, L.; Sohn, J. B., **Micromachining inertial instruments**, published in *Proceedings of SPIE - The International Society for Optical Engineering,* Vol. 2879, 1996, p. 26-36

Draper Laboratory, using silicon microfabrication techniques to achieve high yields by batch processing, has been developing miniature microelectromechanical instruments for over 10 years. During this time, considerable progress has been made in the development and fabrication of micromechanical gyroscopes, accelerometers, and acoustic sensors. Continuing development activities are expected to yield over an order of magnitude in performance enhancement. This paper focuses on sensor fabrication. Rules of thumb that have guided Draper's micromachining efforts are discussed.

Youngberg, J. W., **An infrastructure architecture for the testing of GPS sensors tightly coupled with other sensor systems**, published in *Navigation Technology for the 3rd Millennium; Proceedings of the 52nd Annual Meeting of the Institute of Navigation,* Cambridge, MA, June 19-21, 1996 (A96-44576 12-04), Alexandria, VA, Institute of Navigation, 1996, p. 11-14

A legacy of programs has endowed Draper Laboratory with a large inventory of test facilities in predominantly mechanical laboratory areas. As succeeding programs' requirements mounted, demands for test system inventory and access grew. Simultaneously, an interconnection infrastructure began to evolve. This paper discusses the architecture, technical challenges, features, and benefits of the evolving infrastructure.

Zarchan, P. (Draper); Gratt, H. (Missile Systems and Technologies, Inc., Huntsville, AL), **Adaptive radome compensation using dither**, presented at AIAA, Guidance, Navigation, and Control Conference, San Diego, CA, July 29-31, 1996

The paper presents a technique for estimating a radar homing missile's radome slope using a nondestructive dither signal on the acceleration command. An easy-to-follow planar example is presented in detail showing how bandpass filtering and common sense are used to extract the radome slope estimate and then compensate for unwanted radome aberration angle effects. Another example is presented showing how Kalman filtering techniques can also be used for the same planar example to estimate the radome slope.

Zarchan, P., **The challenge of intercepting spiraling tactical ballistic missiles**, published in *Navigation Technology for the 3rd Millennium; Proceedings of the 52nd Annual Meeting of the Institute of Navigation,* Cambridge, MA, June 19-21, 1996 (A96-44576 12-04), Alexandria, VA, Institute of Navigation, 1996, p. 223-231

Intentional or unintentional spiraling maneuvers on the part of a tactical ballistic missile target can make it particularly difficult for a pursuing missile to hit. This paper presents normalized miss distance curves showing how the target spiraling frequency and amplitude, along with the interceptor guidance system time constant and navigation ratio, determine the miss distance for a proportional navigation guidance system. It is also shown how more advanced guidance techniques can be used to improve system performance against spiraling targets.

Zimpfer, D. (Draper, Nassau Bay, TX); Spehar, P. (Lockheed Martin Engineering & Science Services, Houston, TX), **STS-71 Shuttle/Mir GNC mission overview**, published in *Spaceflight Mechanics 1996; Proceedings of the 6th AAS/AIAA Spaceflight Mechanics Conference,* Austin, TX, February 12-15, 1996 (A96-40059 11-12), San Diego, CA, Univelt, Inc. (*Advances in the Astronautical Sciences*, Vol. 93, Pt. 1), 1996, p. 441-460

The STS-71 Space Shuttle Atlantis/Russian Mir Space Station docking mission represented several firsts in both the American and Russian space programs. A significant aspect was the guidance, navigation, and control capabilities of the American and Russian spacecraft. This paper provides a summary of the GNC tasks completed during the STS-71 joint mission.

Zimpfer, D.; Kirchwey, C.; Hanson, D.; Jackson, M. (Draper, Nassau Bay, TX); Smith, N. (NASA, Johnson Space Center, Houston, TX), **Shuttle stability and control of the STS-71 Shuttle/Mir mated configuration**, published in *Spaceflight Mechanics 1996; Proceedings of the 6th AAS/AIAA Spaceflight Mechanics Conference,* Austin, TX, February 12-15, 1996 (A96-40059 11-12), San Diego, CA, Univelt, Inc. (*Advances in the Astronautical Sciences*, Vol. 93, Pt. 1), 1996, p. 473-492

The STS-71 Shuttle/Mir docking mission initiated Phase I of the International Space Station. It successfully demonstrated several key elements required for the assembly of the station, including demonstrating the capability of the Shuttle control system to provide stable attitude control with large flexible space stations docked to the Orbiter. This paper provides an overview of the Shuttle attitude control system, a summary of the analysis and design process employed to develop controllable, stable Shuttle flight control configurations, and a review of the actual flight results from the STS-71 mated Shuttle/Mir joint flight operations.