1997 Published Papers

The following pages contain the bibliographical information and a brief abstract of all papers formally published by Draper engineers during the 1997 calendar year.

Adams, M.; Kolitz, S.; Milner, J.; Odoni, A.
Evolutionary concepts for decentralized air traffic flow management

Air Traffic Control Quarterly, Summer 1997

Alternative concepts for modifying the policies and procedures under which the air traffic flow management system operates are described, and an approach to the evaluation of those alternative concepts is discussed. Here, air traffic flow management includes all activities related to managing the flow of aircraft and related system resources from "block to block." The alternative concepts represent stages in the evolution from the current system, in which air traffic management decision-making is largely centralized within the Federal Aviation Agency (FAA), to a more decentralized approach wherein the airlines and other airspace users collaborate in air traffic management decision making with the FAA. Emphasis in the discussion is on a viable medium-term partially decentralized scenario that represents a phase of this evolution that is consistent with the decision-making approaches embodied in proposed "Free-Flight" concepts for air traffic management. System-level metrics for analyzing and evaluating the various alternatives are defined, and a simulation testbed developed to generate values for those metrics is described. The fundamental issue of modeling airline behavior in decentralized environments is also raised, and an example of such a model that deals with preserving flight bank integrity in hub airports is presented.

Adams, M.; Kolitz, S.; Odoni, A.
Modeling alternative air traffic flow management concepts

Proceedings of the IFAC Meeting, Greece, June 1997

This paper describes a range of alternative concepts for the policies and procedures under which the Air Traffic Flow Management (ATFM) system operates and a set of integrated models needed to examine their costs and benefits. The concepts represent a multistage evolution from the current system to increasingly decentralized approaches to decision making.

Agopovich, J. W.
PFC alternatives analysis

Precision Cleaning 5, (3), 19-22, 24-26, 28, 30-31 March 1997,
ISSN: 1068-6037

New classes of solvents that are alternatives to PFCs suitable for cleaning critical inertial guidance devices, such as gyroscopes and accelerometers that have complex geometries, are reviewed. Characteristics of solvents for precision cleaning, physical properties, cost, and criteria for evaluating cleanliness are discussed.

Agustin, R. M.; Mangoubi, R. S.; Hain, R. M.; Adams, N. J.
Robust thrust estimation for aerospace vehicle reaction control systems

Proceedings of the 1997 American Control Conference, 15th, Albuquerque, NM, June 1997

This paper considers the problem of estimating the thrust from multiple jets firing from the Reaction Control Systems (RCS) used by reusable launch vehicles. The thrust estimates can be used to monitor the health of the RCS, i.e., detecting jet failures. For accurately known state-space dynamics, the Kalman filter provides the optimal estimate in the least-squares sense for the jet thrust. During reentry, however, plant model uncertainties are a major problem for the filter as the vehicle's aerodynamics vary widely. Consequently, the Kalman filter estimate degrades severely. Transient, robust H-infinity or game-theoretic estimators are shown to give promising estimation and detection performance results for a wide range of Mach numbers and angles of attack when tried on a simulation of the Space Shuttle Orbiter's RCS.

Allinger, D. F.; Rosch, G.; Kuchar, J. K.
Integrated safety-analysis methodology for emerging air-transport technologies

Proceedings of the Annual Reliability and Maintainability Symposium, Anaheim, CA, January 1998

We demonstrate an approach to integrating reliability, performance, and operational procedures modeling into a system safety analysis. Our methodology is distinguished by its ability to merge system design information with the dynamic parameterization of a system's situation in order to measure accident statistics and reliable system operation. As an application of this methodology, we have considered the problem of simultaneous but independent approaches of two aircraft on closely-spaced parallel runways, Independent Approaches on Parallel Runways (IAPR). The IAPR concept presumes a flight-deck-based navigation, communication, surveillance, and alerting system. The potential exists for an aircraft on either runway to deviate off course toward another aircraft on the parallel runway. A variety of simulation projects have been undertaken within the last several years to explore alerting systems for the parallel approach situation, but the major limitation of statistical information generated from these studies is that it represents conditional safety statistics given the flight track simulated. To remove this conditioning, we have shown how to apply the probability of flying the approach with a given flight track using Markov analysis to compute this probability. The results show how each of the probabilities of reliable operation, accidents, and false alarms vary as a function of runway spacing.

Anderson, J. M.; Triantafyllou, M. S.; Kerrebrock, P. A.
Concept design of a flexible-hull unmanned undersea vehicle

Proceedings of the 1997 7th International Offshore
and Polar Engineering Conference

In recent years, research in the propulsion and maneuvering mechanisms used by fish has demonstrated the utility of biopropulsion for use on undersea vehicles. Despite recent advances in Unmanned Undersea Vehicle (UUV) technology, little progress has been made in improving propulsive efficiency and maneuverability. Most underwater vehicle designs employ a conventional propeller as the main propulsor and shrouded thrusters and/or control fins for maneuvering. Two types of vehicle designs are prevalent: torpedo-shaped bodies streamlined for speed and range, or box-shaped bodies designed for maneuvering and station keeping. Unfortunately, most future UUV missions require all these capabilities: high transit speed, long range/duration, maneuverability, and station keeping ability. Thus, we look to fish as a potentially optimal UUV design in that they are able to cruise great distances at significant speed, maneuver in tight spaces, and accelerate and decelerate quickly. This paper summarizes the relevant design issues and current work in the development of a flexible-hull UUV that propels and maneuvers like a fish. Following the morphology and kinematics of a yellowfin tuna, the Charles Stark Draper Laboratory Vorticity Control UUV (VCUUV) will be the first demonstration of a freely swimming Thunniform (tuna-like motion) robotic vehicle. Simulation of the required kinematics and loads indicate that Thunniform motion can be actuated with a rigid forebody comprising 60 percent of the total vehicle length and four rigid links actuating the tail section and caudal fin. Three

different actuation concepts were compared by analyzing possible components and arrangements to attain the required loads and mission duration. A recirculating hydraulics concept was chosen for prototyping due to the versatility of the design for study of a variety of swimming speeds and maneuvers.

Antkowiak, B. M.; Nelson, F. C.
Rotordynamic modeling of an actively controlled magnetic bearing gas turbine engine

Proceedings of the 1997 International Gas Turbine and Aeroengine Congress and Exposition, American Society of Mechanical Engineers, Orlando, FL, June 1997

This paper summarizes the development of a finite-element rotordynamic solution used in a closed-loop simulation for a magnetic bearing rotor system in a gas turbine engine. A magnetic bearing controlled rotor is analyzed, and the state dynamics matrix [A], the shaft control influence matrix [B], and the sensor matrix [C] are constructed. Bode plots of the state-space transfer function are also constructed and compared to the results of the rotor dynamic model.

Bello, M. G.
Acoustic/magnetic fusion system architecture variants and their classification performance

Proceedings of the Detection and Remediation Technologies for Mines and Minelike Targets II Conference, 1997

Research in FY 95 first addressed the problem of combining high-frequency (HF) side-scan sonar imagery, low-frequency (LF) side-scan sonar imagery, and magnetic gradiometer data in order to detect/classify undersea mines. The first approach developed, termed the 'Blob-Pair'-based Acoustic/Magnetic (AM) fusion system architecture, implicitly assumed that a target manifests itself in both HF and LF imagery, and was based on the fusion of single-sensor-derived neural network classifier discriminants at a collection of three 'decision' nodes identified with magnetic (M), HF/LF, and HF/LF/M-data fusion cases, respectively. In order to remove the restrictive assumption of a target manifesting in both HF and LF data, the 'generalized' AM-fusion architecture was developed, with a total of seven 'decision' nodes, identified with M, HF, HF/LF, LF, HF/M, HF/LF/M, and LF/M data fusion cases, respectively. However, the 'generalized' AM-fusion architecture was found empirically to have a significantly increased number of false alarms, relative to the 'Blob-Pair'-based system. Hence, through two additional AM-fusion architecture variants involving first the use of classification token 'post-processing' and decision node statistic modification, the performance 'gap' between 'Blob-Pair' and 'generalized' AM-fusion architecture performance was closed.

Bernstein, J. J.; Houston, K.; Niles, L. C.; Finberg, S. L.; Chen, H. D.; Cross, L.E.; Li, K. K.; Udayakumar, K.
Micromachined ferroelectric transducers for acoustic imaging

Proceedings of the 1997 International Conference on Solid-State Sensors and Actuators, Vol. 2

Sub-millimeter-sized ferroelectric monomorph sonar transducers have been built using sol-gel Lead Zirconate Titanate (PZT) on micromachined silicon wafers. 8 x 8 transducer arrays have been tested in water in the 0.3- to 2-MHz frequency range. An improved sol-gel process has yielded crack-free PZT films up to 12 µm in thickness, 12 times thicker than previously reported. Sensitivity, frequency response, acoustic images, and beam patterns are presented. High-resolution acoustic images at a 2-m range were made using the arrays and an acoustic lens. Applications include high-frequency imaging sonars, medical ultrasound, ultrasonic communication links, and flaw detection.

Bernstein, J. J.; Houston, K.; Niles, L. C.; Li, K. K.; Chen, H. D.; Cross, L. E.; Udayakumar, K.
Integrated ferroelectric monomorph transducers for acoustic imaging

Proceedings of the 1997 8th International Symposium on Integrated Ferroelectrics, Part 2 (of 3)

Millimeter-sized ferroelectric monomorph sonar transducers have been using sol-gel Lead Zirconate Titanate (PZT) on micromachined silicon wafers. The fabrication of monolithic transducer arrays on silicon wafers is described. Transducers have been tested in water in the 0.5- to 4-MHz frequency range. Individual transducer diaphragms varied from 0.2 to 2 mm in size. Improvements to the sol-gel process have yielded high-quality, crack-free PZT films up to 12 µm in thickness, which leads directly to higher sensitivity and figure of merit for acoustic transducers. The longitudinal piezoelectric coefficient d//3//3 is 140-180 pC/N, measured through a double-beam laser interferometer. Remanent polarization of 34 µ C/cm**2, a coercive field of 42 kV/cm, and dielectric constant of 1400 were measured on 4-µm thick films. Results of air and in-water testing are presented, including frequency response, beam patterns, and output capacitance. High-resolution acoustic images have been generated using these transducers and a four-element underwater acoustic lens. Potential applications for these transducers include high-frequency imaging sonars, medical ultrasound, ultrasonic communication links, and flaw detection (NDT).

Bernstein, J. J.; Finberg, S. L.; Houston, K.; Niles, L. C.; Chen, H. D.; Cross, L. E.; Li, K. K.; Udayakumar, K.
Micromachined high-frequency ferroelectric sonar transducers

IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control, Vol. 44, No. 5, pp. 960-969, September 1997

Millimeter-sized ferroelectric monomorph sonar transducers have been built using sol-gel Lead Zirconate Titanate (PZT) on micromachined silicon wafers. First-generation transducer arrays with diaphragms varying in size from 0.2 to 2 mm were tested. Second-generation 8 x 8 arrays have also been built and tested in water in the 0.3- to 2-MHz frequency range. Improvements to the sol-gel process have yielded high-quality, crack-free PZT films up to 12 µm in thickness, which leads directly to higher sensitivity and figure of merit for acoustic transducers. The longitudinal piezoelectric coefficient d//3//3 is 140 to 240 pC/N, measured through a double-beam laser interferometer. Remanent polarization of 28 µ C/cm**2, a coercive field of 30 kV/cm, and dielectric constant of 1400 were measured on 4-µm thick films. Test results are presented, including frequency response, beam patterns, and sensitivity. High-resolution acoustic images have been generated using these transducers and a four-element underwater acoustic lens. Potential applications for these transducers include high-frequency imaging sonars, medical ultrasound, ultrasonic communication links, and flaw detection (NDT).

Bernstein, J. J.; Trainor, C.
Versatile micromechanical vibration sensor and applications

Proceedings of the AIAA Guidance, Navigation, and Control Conference, New Orleans, LA, August 1997

Micromechanical vibration sensors have been designed and are being fabricated that cover a sensing range from 3 Hz to 10 kHz. The primary application is for an air-dropped unattended ground sensor. The sensor is housed in a hermetically-sealed robust package to ensure function in harsh environments. Special attention is paid to the lowest possible noise floor resulting in a sensor that approaches geophone performance at a much smaller size and weight. Applications include: canard turbulence indicator, tank locator, ground-based battlefield acoustics, miniature geophones for nuclear test ban monitoring, underground facility locator (during both construction and operation), smart skins, health

monitoring of space structures and µg environment control, directional hydrophones for sonobuoys, and intelligent sensor modules. We discuss the current development of the Draper Laboratory vibration sensor and its applications.

Borenstein, J. T.; Wu, K. S.; Shay, P. A.; Fitzgerald, E. A.
Structural characterization of p++ Si:B layers for bulk micromachining

Materials for Mechanical and Optical Microsystems: Proceedings of the Materials Research Society Symposium

A range of techniques are used to characterize p++ silicon layers created by boron diffusion into (001) silicon wafers. These films are characterized by TEM, EBIC/SEM, triple-axis XRD, SIMS, and modified Schimmel etching. Boron profiles predicted by SUPREM-3 process simulation software are compared to SIMS data. The results reveal gradients in boron and lattice constant, as well as a graded 3-dimensional dislocation array from lattice-mismatch stress. Boron precipitation, induced by lattice-mismatch stress and concentrations above the solubility limit, is found to occur preferentially on dislocations. Also, the presence of dislocations is shown to affect the boron diffusion profile as well as etch morphology.

Borenstein, J. T.; Preble, D. M.
Yield enhancement in micromechanical sensor fabrication using statistical process control

Proceedings of the SPIE, the International Society for Optical Engineering, Issue 3223, pp. 276-283, 1997

Statistical Process Control (SPC) has gained wide acceptance in recent years as an essential tool for yield improvement in the microelectronics industry. In both manufacturing and research and development settings, statistical methods are extremely useful in process control and optimization. This paper describes the recent implementation of SPC in the micromachining fabrication process at Draper. A wide array of micromachined silicon sensors, including gyroscopes, accelerometers, and microphones, are routinely fabricated at Draper, often with rapidly changing designs and processes. In spite of Draper's requirements for rapid turnaround and relatively small, short production runs, SPC has turned out to be a critical component of the product development process. This paper describes the multipronged SPC approach we have developed and tailored to the particular requirements of an R&D micromachining process line. Standard tools such as Pareto charts, histograms, and cause-and-effect diagrams have been deployed to troubleshoot yield and performance problems in the micromachining process, and several examples of their use are described. More rigorous approaches, such as the use of control charts for variables and attributes, have been instituted with considerable success. The software package Cornerstone® was selected to handle the SPC program at Draper. We describe the highly automated process now in place for monitoring key processes, including diffusion, oxidation, photolithography, and etching. In addition to the process monitoring, gauge capability is applied to critical metrology tools on a regular basis. Applying these tools in the process line has resulted in sharply improved yields and shortened process cycles.

Bruce, D. M., et al.
Effects of high-temperature treatment on curl and microstructure of heavily boron-doped silicon

An experimental study was performed to investigate the effects of high-temperature treatment on the microstructure and curling behavior of heavily boron-doped silicon structures. Cantilever structures were created from p++ boron-diffused silicon wafers. The post-diffusion high-temperature 'anneal' treatment temperature was varied while the anneal time remained constant. The micromechanical cantilevers were analyzed for curl as a function of the anneal temperature using an optical profiler. Bulk sections from the wafers were analyzed to obtain boron concentration using Secondary Ion Mass Spectroscopy (SIMS) and to obtain the distribution of lattice constant using X-ray diffraction. The microstructure of plan-view and cross section samples was investigated with the Transmission Electron Microscope (TEM). Results of the curl measurements revealed that all nonannealed cantilever structures were curled in one direction, and those annealed for 90 min above 1100°C were all curled in the other direction, with an apparent transition temperature of about 1050°C. SIMS analysis confirmed that boron concentration becomes more uniform through the wafer thickness with increasing anneal temperature. X-ray diffraction revealed that the magnitude of the smallest lattice constant present in a wafer increases with increasing anneal temperature. TEM observations showed that dislocation and precipitate density do not change with anneal temperature.

Chhabra, N. K.; Scholten, J. R.
All angle-of-attack hydrodynamic model for underwater vehicles validated by tank test data

American Society of Mechanical Engineers Ocean Engineering Division, Publications-OED, 1997 ASME International Mechanical Engineering Congress, Vol. 14, pp. 173-182

An underwater vehicle's design and operation requires prediction of its performance at various velocities and angles of attack or sideslip. Traditional models based on headway motion at substantial speeds use coefficient-based equations of motion. Simulations based on these coefficients are not valid for hover, low speeds, or high angles of attack or sideslip. To remedy this severe limitation, nonlinear hydrodynamic models valid for all attitudes of underwater vehicles have been developed and are presented here. These models are derived from the physics of hydrodynamic phenomena. Forces and moments for the total vehicle are obtained by relying on body-buildup techniques. For the vehicle's hull, the models are profile drag, lift, crossflow force, and added mass. For appendages such as fins, the models are lift and drag when unstalled, normal force when stalled, transition between unstalled and stalled conditions, and hull interference effects. Whenever the equations contain parametric coefficients such as added-mass, drag, and lift, values are specified for all angles of attack and sideslip with a minimal use of empirical lookup tables. These models represent the state of the art in low-speed hydrodynamics at all angles of attack. The hydrodynamic models presented here have been improved and validated by analysis and comparison with test data. Subscale versions of two different vehicles have been tested in tow tanks at all angles of attack. The models have been implemented in a C language computer code that runs at high speed with no iteration required. This code is used regularly in faster-than-real-time vehicle performance simulations.

Chhabra, N. K.; Scholten, J. R.; Lozow, J. B.
Wave-generated forces and moments on submersibles: models for dynamic simulation at periscope depth

American Society of Mechanical Engineers Ocean Engineering Division, Publications-OED, 1997 ASME International Mechanical Engineering Congress, Vol. 14, pp. 183-192

Analysis of the wave-induced motion of underwater vehicles near the ocean surface is a difficult task. First, the action of the fluid must be decomposed into ideal (inviscid) and real (viscous) effects. Next, each effect must be modeled as to its interaction with the submerged body. The effect of the body on the waves must be considered. In shallow water, the ocean bottom has many effects: energy dissipation tends to reduce wave height; land proximity restricts the wave direction; and the bottom boundary changes the shape of the waves, attenuating the vertical (but not the horizontal) component of motion. This paper presents mathematical models for predicting realistic wave-generated forces and moments on submersible vehicles. Included are models that

generate typical wave spectra for deep and shallow waters, models for wave kinematics as affected by flat or sloping bottoms, and models for forces and moments on submersibles due to these surface waves. Forces and moments are computed using two alternative methods. One is a fast method based on analytical integration of dynamic pressure forces over the surface of an elongated ellipsoidal body. It gives first-order forces and moments limited to horizontal and restrained bodies. The second method, based on the Froude-Krylov approach, uses numerical integration of dynamic pressures to give forces and moments on any shape hull in any attitude. Unlike the first method, it can be extended to include broaching of the sea surface by the body. Hydrodynamic forces due to an unrestrained body's motion are accounted for with "added mass" terms. These mathematical models have been implemented in the C language in a real-time computer simulation. They are actively used to study the dynamic performance and control of submersibles at periscope depths.

Conley, J. F., Jr.; Lenahan, P. M.; Cole, P.
Predictive model of SOI buried oxide charging based on statistical mechanics and spin resonance data

1997 IEEE International SOI Conference Proceedings (Cat. No.97CH36069), pp. 176-177

In partially depleted NMOS transistors on SOI, back-channel leakage problems are caused by radiation-induced hole trapping at point defect precursors in the Buried Oxide (BOX). Thus, a predictive model of these hole traps would be quite useful. We show that a model developed recently for hole trapping in poly-capped thermally-grown oxides also effectively predicts trapped hole densities in Unibond and SIMOX buried oxides. The model is based on statistical thermodynamics and Electron Spin Resonance (ESR) measurements of defects known as E' centers.

Connelly, J. H.; Brand, G. N.
Advances in micromechanical systems for guidance, navigation, and control

Proceedings of the AIAA Guidance, Navigation, and Control Conference, New Orleans, LA, August 1997

Draper Laboratory and Boeing North American (formerly the Rockwell Corporation) have formed an alliance to develop and manufacture micromachined inertial sensors and systems. Initial products serve high-volume commercial markets with target prices below $25 per instrument. Recent performance improvements, however, will enable new systems for many military and space applications. One such application is the addition of guidance to low-end, previously unguided artillery munitions. This paper reviews existing and potential new application areas and describes micromachined inertial sensor design, operation, and fabrication methods. Development activities for a flexible production base to serve DoD/NASA needs are presented. Also included are the latest test data, projected performance improvements, and new concepts for low-cost, miniature, multi-axis systems.

Connelly, J. H.; Barbour, N.; Brand, G. N.
Manufacturing micromachined inertial sensor systems

Proceedings of the Saint Petersburg International Conference on Integrated Navigation Systems, 4th, St. Petersburg, Russia (A97-30869 07-35), pp. 362-370, May 1997

A flexible production base is being created to serve DoD system needs at the low cost enabled by high-volume commercial markets. This paper reviews current micromachined inertial instruments and fabrication methods, and presents ongoing development activities in low-cost manufacturing for higher-performance applications. The major challenges for military systems and improvement plans for cost, size, and performance are discussed, and concepts for multi-axis system configurations are proposed.

Cunningham, B. T.; Bernstein, J. J.
Wide-bandwidth silicon nitride membrane microphones

Proceedings of the 1997 SPIE Symposium on Micromachining and Microfabrication, The International Society for Optical Engineering, Issue 3223, pp. 56-63, 1997

Small, low-cost microphones with high sensitivity at frequencies greater than 20 kHz are desired for applications such as ultrasonic communication links. To minimize stray capacitance between the microphone and its amplifier circuit, process compatibility between the microphone and on-chip circuitry is also desired to facilitate integration. In this work, we have demonstrated micromachined microphones packaged with hybrid Junction Field Effect Transistor (JFET) amplifier circuitry with frequency response extending to 100 kHz, and voltage sensitivity of 1.0 mV/Pa at 40 kHz at a bias voltage of 13.5 V. The microphones are fabricated with membranes and fixed backplates made of low-temperature Plasma-Enhanced Chemical Vapor Deposited (PECVD) silicon nitride. Because the maximum temperature of the fabrication process is 300°C, microphones may be built on silicon wafers from any commercial Complementary Metal-Oxide Semiconductor (CMOS) foundry without affecting transistor characteristics, allowing integration with sophisticated amplifier circuitry. Low-stress silicon nitride deposition was used to produce membranes up to 2.0-mm diameter and 0.5-mm thickness with ±0.10-mm flatness as measured with a WYCO^{TM} optical interferometer. The excellent planarity of both the diaphragm and the backplate, combined with a narrow sense gap (~2 mm) results in high-output capacitance (up to 7.0 pF). The high-output capacitance results in noise spectral density that is approximately 3x lower than silicon diaphragm microphones previously fabricated by the authors. Diaphragms with corrugations were fabricated to relieve tensile stress, to increase deflection per unit pressure, and to increase deflection linearity with pressure. Corrugated and uncorrugated microphone measurements are compared.

De Fazio, T. L.; Delchambre, A.; De Lit, P.
Disassembly for recycling of office electronic equipment

European Journal of Mechanical Engineering, Vol. 42, No. 1, pp. 25-31, Spring 1997

Office electronic equipment continues to proliferate and to be discarded for a variety of reasons. This paper outlines the magnitude of the problem and why we chose Personal Computers (PCs) as our major consideration. The problems associated with discarding PCs are implied by or embodied in various details of PCs and in the customs of their use. These details and the manner in which they affect the disposal issue are reviewed, and the key issues affecting discarding computers and what is done in Europe and USA are presented. An attempt is made to capture and predict what the future may bring regarding the goal of reducing electronic office machinery mass going to the landfill, and policy issues are reviewed.

De Fazio, T. L.; Rhee, S. J.; Whitney, D. E.
Design-specific approach to Design-For-Assembly (DFA) for complex mechanical assemblies

Proceedings of the 1997 IEEE International Symposium on Assembly and Task Planning, ISATP'97

DFA issues of complex assemblies are addressed. Complex assemblies have very high parts counts, offer limited redesign options, and their assembly is an assembly of subassemblies. Conventional DFA is inadequate for complex assemblies as it omits the combinatorial aspects of assembly such as assembly sequence choice and partitioning subassemblies. Here, Assembly Sequence Analysis (ASA) is used as a basis for complex-assembly DFA. Searches for favorable subassembly partitioning and assembly sequences minimize assembly difficulty as

measured by kinematic degrees of freedom secured in assembly moves, while logical constraints that part geometry imposes on sequence choice are satisfied. Findings are: ASA can expose assembly issues and pinpoint DFA redesign candidates; limitations on redesign favor designing function-defining parts first; logically characterized issues dominate the quantitatively characterized issues when choosing sequences or partitioning; once the former issues are addressed, a quantitative sequence choice criterion often duplicates historic assembly sequence choices; and a quantitative sequence choice criterion favors sequential over branched assembly lines.

DeBitetto, P. A.; Johnson, E. N.; Bosse, M. C.; Trott, C. A.
The Draper Laboratory small autonomous aerial vehicle

Proceedings of the SPIE, The International Society for Optical Engineering Conference, 1997

The Charles Stark Draper Laboratory, Inc. and students from the Massachusetts Institute of Technology and Boston University have cooperated to develop an autonomous aerial vehicle that won the 1996 International Aerial Robotics Competition. This paper describes the approach, system architecture, and subsystem designs for the entry. This entry represents a combination of many technology areas: navigation, guidance, control, vision processing, human factors, packaging, power, real-time software, and others. The aerial vehicle, an autonomous helicopter, performs navigation and control functions using multiple sensors: differential GPS, inertial measurement unit, sonar altimeter, and a flux compass. The aerial transmits video imagery to the ground. A ground-based vision processor converts the image data into target position and classification estimates. The system was designed, built, and flown in less than 1 year, and has provided many lessons about autonomous vehicle systems, several of which are discussed. Our current research in augmenting the navigation system with vision-based estimates is presented in an appendix.

DeBitetto, P. A.; Johnson, E. N.
Modeling and simulation for small autonomous helicopter development

Proceedings of the AIAA Guidance, Navigation, and Control Conference, New Orleans, LA, August 1997

The Charles Stark Draper Laboratory, Inc., the Massachusetts Institute of Technology, and Boston University have cooperated to develop an Autonomous Aerial Vehicle (AAV) that competed in and won the 1996 International Aerial Robotics Competition, sponsored by the Association for Unmanned Vehicle Systems, International (AUVSI). Development of the vehicle continues to support ongoing research in the area of autonomous systems. A simulation capability has been developed to support the design, development, and test of the navigation, control, guidance, and vision processing subsystems, as well as human-machine interfaces and procedures. The use of the simulation described in this paper is identified as a key factor in the success of the program at the competition and operations since then.

Dowdle, J. R.; Connelly, J.; Gustafson, D.; Marinis, T.; Prestero, M.
Technologies for precision-guided munitions

Proceedings of the Submarine Technology Symposium, Applied Physics Laboratory, Laurel, MD, May 1997

Precision-guided projectile efforts underway aim to develop new projectiles and to transform the current large inventory of low-accuracy projectiles into highly accurate precision strike resources. These objectives are to be accomplished by developing a low-cost Guidance, Navigation, and Control (GN&C) system consisting of an integrated Global Positioning System (GPS)/Microelectromechanical System (MEMS) Inertial Measurement Unit (IMU), and an associated flight control system. This GN&C system can be installed in place of the fuze in projectiles in the inventory. A succession of Navy-sponsored demonstrations are involved with this development. The combination of low-cost MEMS inertial sensors and the miniaturization of electronics packages in Multichip Modules (MCMs) suitable for inexpensive, high-volume production yet able to withstand the severe gun launch environment have enabled this development. Details of the adaptation of these technologies to this application and the trade-off analyses that demonstrated concept feasibility are presented.

Dowdle, J. R.; Thorvaldsen, T. P.; Kourepenis, A. S.
A GPS/INS guidance system for Navy 5-in projectiles

Proceedings of the AIAA Guidance, Navigation, and Control Conference, New Orleans, LA, August 1997

This paper describes the design, operation, test, and critical performance issues of the Extended-Range Guided Munition (ERGM) Demonstration GPS/MMIMU (Micromechanical Inertial Measurement Units), which is the guidance system for the Navy's 5-in ERGM Demonstration Round. This guidance system combines GPS position data with micromechanical inertial sensor measurements to produce the navigation solution, and uses the navigation data with a prespecified aimpoint location to generate guidance commands. In addition to the GPS receiver and the Micromechanical Inertial Sensor Assembly, the system includes a g-hardened reference oscillator, the guidance and navigation electronics, and the power conversion electronics, all packaged in an 8-lb(f) cylindrical volume 8.4 in long with a 4.35-in diameter.

D'Souza, C. N.
An optimal guidance law for planetary landing

Proceedings of the AIAA Guidance, Navigation, and Control Conference, New Orleans, LA, August 1997

A guidance law that minimizes the commanded acceleration along with the (weighted) final time is developed. This guidance law is a linear function of the states (relative to the landing point) and a nonlinear function of the time-to-go. The time-to-go is obtained as a solution to a quartic equation that is solved analytically. The advantage of this guidance law is that it does not involve any iterations whatsoever. It is the exact solution to the two-point boundary-value problem associated with the first variation necessary conditions. It also satisfies the second variation necessary conditions for a minimum. An example of a lunar landing is given to demonstrate the optimality of this guidance law.

Elwell, J.
GPS/INS guidance of terradynamic penetrators

Proceedings of the AIAA Guidance, Navigation, and Control Conference, New Orleans, LA, August 1997

Draper has been developing hardware and performing flight tests employing miniature low-cost precision guidance systems, incorporating inertial sensors that are capable of surviving significant Earth penetration. One objective of these developments has been to enable penetrators that are targetable against both shallow and deeply buried targets. GPS/INS is now being examined for such applications since integration provides important capabilities over that of unaided GPS. The inertial system provides an ongoing navigational capability should the GPS system lose lock, and also permits the carrier and code track loops to narrow their effective bandwidth, considerably enhancing the antijam capability of the system. Because of the high-shock survivability of silicon inertial instruments, concepts such as navigation within the Earth have become a consideration. Such capability will allow us to consider smart fuzing concepts, incorporating terradynamic navigation for Earth penetrators subsequent to ground entry.

Fischer, J. D.; Cefola, P. J.; Proulx, R. J.
The evolution of highly-eccentric orbits decay phase analysis

Proceedings of the AAS/AIAA Astrodynamics Conference, Sun Valley, Idaho, August 1997

Highly eccentric orbits pose a unique challenge to orbit determination processes based on semi-analytic satellite theories. These orbits may be perturbed by a broad spectrum of the natural forces that govern the motion of a space object and are difficult to model over long arcs. This work identifies the perturbation model improvements in the Draper R&D version of the Goddard Trajectory Determination System (GTDS) necessary to improve accuracy for a difficult orbit type known as the Molniya class orbit. Molniya orbits, with an eccentricity of approximately 0.7, exaggerate the effects of eccentricity truncation in the and tesseral resonance models. Additionally, these orbits may produce a steep reentry path and magnify the effects of atmospheric drag, particularly when the decay occurs near the minimum in the approximate 11-year solar cycle. This work analyzes the last portion of the evolution of these orbits, from the mission or operational phase to the final degradation of the orbit. The unique Draper Semianalytic Satellite Theory (DSST) and a Cowell numerical propagator are used for the long arc orbit determination processing and parameter estimation during this decay phase. The MSISE-90 atmospheric model is integrated into GTDS to more accurately model the decay phase, and a transition between the phases is investigated. By establishing the transition between the two orbital phases, improving the atmospheric model, analyzing the effects of drag short periodics, higher-order drag terms, and drag-oblateness coupling, and identifying the remaining improvements necessary to model this class of orbits accurately, this work serves as the first step in an effort to model the evolution of highly eccentric orbits accurately.

Gai, E.
Guiding munitions with a micromechanical INS/GPS system

Proceedings of the 38th Israel Annual Conference on Aerospace Sciences, February 1998

Micromechanical inertial sensors are the current leading edge technology in the development of guidance systems. Their small size, low cost, and ruggedness make them excellent guidance, navigation, and control sensors. Combined with miniature Global Positioning System (GPS) receivers, they can provide low-cost guidance for munitions with protection against jamming. In this paper, the author will review the micromechanical sensors and systems programs at the Charles Stark Draper Laboratory, Inc., the developer of the first Inertial Navigation System (INS)/GPS guidance system for the U.S. Navy 5-in gun.

Hain, R. M.; Carpenter, J. R.
Precise evaluation of orbital GPS attitude determination on the STS-77 GPS Attitude and Navigation Experiment (GANE)

Navigation and Positioning in the Information Age: Proceedings of the Institute of Navigation National Technical Meeting, Santa Monica, CA (A97-31149 08-32), January 1997

A recent Shuttle mission, STS-77, carried GANE, the highest priority of a series of risk mitigation experiments being performed by the Shuttle program for the International Space Station (ISS) program. GANE was a flight test of the ISS attitude determination and navigation systems, which consists of a multi-antenna interferometric GPS receiver for attitude determination and navigation, and a ring-laser rate gyro system for attitude rate determination. The purpose of GANE was to determine if the proposed ISS attitude determination and navigation system could meet ISS requirements in attitude, position, and semi-major axis. The Space Shuttle attitude reference system was used to determine the performance of attitude solutions from the GANE GPS receiver, a Trimble Advanced Navigation System Vector. These results are the first precise evaluation of a long-baseline (1.5-3 m) GPS attitude determination system in a space environment onboard an actively maneuvering and highly multipath-susceptible vehicle. The receiver generated attitude solutions that generally tracked the Orbiter attitude during all data takes in several ambiguity resolution and satellite selection modes.

Hammett, R.
Seawolf ship control - experience with performance monitoring and fault localization

Proceedings of the 1997 11th Ship Control Systems Symposium

Lessons learned from the development of the Performance Monitoring (PM) and Fault Localization (FL) functions of the Seawolf ship control system are related. This functionality, in conjunction with redundant components, provides automatic detection, recovery, and reporting failures of ship control electronics, sensors, actuation components, valves, and ship control machinery. It improves the ship's ability to perform its mission and reduces overall life-cycle operating costs. The design of the hardware architecture and the level of redundancy were guided by the needs of the PM/FL approach. Verification of the functionality was achieved by performing both software-only and simulated full-system fault-injection testing.

Hattis, P. D.; Appleby, B. D.; Fill, T. J.; Benney, R.
Precision-guided airdrop system flight test results

Collection of Technical Papers from the AIAA Aerodynamic Decelerator Systems Technology Conference, 14th, San Francisco, CA (A97-31273 08-03), June 1997

The Army has sponsored the development of gliding, steerable airdrop systems that can be deployed from high altitudes, with large offset, carrying small through large payloads. The goal was to enable payload delivery within 100 m of the target. Under this effort, Draper developed modular Guidance, Navigation, and Control (GN&C) software to precision guide ram-air parafoils using a combination of GPS and Inertial Navigation System (INS) data. A high-fidelity simulator was constructed to evaluate the expected performance of the Draper software. Also, in conjunction with NASA, flight tests with an 88-ft^2 parafoil and a 170-lb payload were performed to evaluate the GN&C system performance under real flight conditions. A number of GN&C system design refinements were formulated after review of initial flight test results that ultimately enabled a payload delivery accuracy of about 50 m. This paper summarizes the motivation for precision-guided airdrop systems, reviews the Draper GPS/INS-based GN&C for ram-air parafoils, and presents both simulation and flight test results.

Huang, J.; Castanon, D. A.
Nonlinear estimation of misalignment errors in adaptive optics

Proceedings of the 36th IEEE Conference on Decision and Control

The performance of adaptive optics systems degrades rapidly in the presence of optical misalignment errors between the deformable mirror and the wavefront sensor. In order to compensate for this effect, it is necessary to estimate the misalignment error. In this paper, we present a model for misregistration estimation and a nonlinear estimation algorithm for generating globally optimal estimates of misregistration errors. The performance of the algorithm is illustrated using an experimental adaptive optics system.

Kantsiper, B.; Weiss, S.
An analytic approach to calculating earth coverage

Proceedings of the AAS/AIAA Astrodynamics Conference, Sun Valley, Idaho, August 1997

The recent proliferation of satellite networks for global telecommunication systems has led to an increase of interest in understanding the dynamics of constellations of satellites. One of the primary metrics used to describe a constellation is its percent coverage,

i.e., what percent of the earth's surface can be seen by the satellites at any given time. This parameter is typically evaluated numerically, requiring the use of a very dense grid. When there are a large number of satellites or fine precision requirements, this method can be rather slow and becomes even slower if one is interested in multiple satellite coverage. This paper discusses an alternate approach to dramatically decrease the calculation time. The new approach is an analytical method using the inclusion-exclusion principle of set theory. It is found that the area of the region on a sphere defined by the overlap of circles on that sphere is integratable. A spherical earth and nadir-pointing satellites are assumed. The new method shows a significant improvement in accuracy over traditional numerical integrations for similar execution times.

Kelleher, W. P.; Kondoleon, A. S.
Magnetic bearing suspension system for high-temperature gas turbine applications

Proceedings of the Turbo97 International Gas Turbine Institute, American Society of Mechanical Engineers

Magnetic bearings, unlike traditional mechanical bearings, consist of a series of components that, when mated together, form a stabilized system. The correct design of the actuator and sensor will provide a cost-effective device with low power requirements. The proper choice of a control system uses the variables necessary to control the system in an efficient manner. The specific application will determine the optimum design of the magnetic bearing system, including the touchdown bearing. Draper has been a leader in all these fields for the past 30 years. This paper will present the results carried out at Draper in the development of a high-temperature magnetic bearing suspension system for a high-temperature gas turbine application. This paper will detail the design of the radial and axial magnetic actuators for use in the desired high-temperature and high-speed system. Experimental results carried out on material and processes developed for the fabrication of the actuators will be presented.

Kelleher, W. P.; Kondoleon, A. S.
Magnetic bearing suspension system for high-temperature gas turbine applications, Part III: Magnetic actuator development

Proceedings of the 1997 International Gas Turbine and Aeroengine Congress and Exposition, American Society of Mechanical Engineers

Magnetic bearings, unlike traditional mechanical bearings, consist of a series of components that, when mated together, form a stabilized system. A series of four papers will summarize the results carried out at Draper in the development of a high-temperature magnetic bearing suspension system for a gas turbine application. Part I documents our approach for rotordynamics modeling of the turbine shaft and developing models for use in our simulation programs. Part II documents the simulation efforts and the control system that resulted from this effort. Parts III and IV document the design and fabrication of the magnetic bearing actuators and the auxiliary touchdown bearings. This paper, Part III, deals with the design of the high-temperature magnetic bearing actuators. Two radial and one axial magnetic bearing actuator were designed to meet the requirements for the turbine application. No bias coils are included in these designs. The biasing flux is provided by current from the control power amplifiers. All the coils are made from ceramic-coated copper wire and are terminated to high-temperature connectors designed into the actuators. The new high-strength Hiperco 50 HS material was chosen for the rotor lamination material for the radial bearings. A customized heat treatment process for this material in a high-vacuum environment was developed to ensure that maximum strength was obtained with the maximum magnetic properties. High-temperature ceramic-coated copper wire and bonding and potting material used for the coil assembly were tested up to 650°C without failures.

Kondoleon, A. S.; Kelleher, W. P.; Ozanne, J.; Walker, R.
Bearings technology at Draper Laboratory

Proceedings of the International Rolling Element Bearing Symposium

Draper Laboratory has been active in the design and development of journal, ball, and magnetic bearing suspension technologies for over 30 years. As such, we are able to examine each candidate with a clear understanding of the advantages they offer in terms of performance, weight, cost, reliability, and ease of fabrication. For demanding applications where the state of the art is required, we have found that few are application specific. In this paper, we present basic scaling laws and design practices for magnetic, ball, and journal bearings (both gas and fluid). The viability of each suspension option is discussed and general comparisons are made with each of the other technologies.

Kondoleon, A. S.; Thompson, M.
Test results from a large-scale, high-speed EDS Maglev wheel test facility

Proceedings of the NASA Fourth International Symposium on Magnetic Suspension Technology

For the past two years, Draper Laboratory, with its internal research and development budget, has been funding a joint effort with the Massachusetts Institute of Technology (MIT) for the development of 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. The facility was developed to rotate a large (2 m) wheel that could operate with peripheral speeds of greater than 100 m/s. The rim of the wheel was constructed of a nonmagnetic, nonconductive composite material to avoid generating errors from spurious forces. A sensor package containing a multi-axis force and torque sensor mounted to the base of the station provides a signal of the lift and drag forces on the package being tested. Position tables mounted on the station allow the introduction of errors in real time. A computer-controlled data acquisition system was developed around a Mac II to record the test data and control the speed of the wheel. This paper describes the development of this test facility. A detailed description of the major components is presented. Recently completed tests carried out on a novel Electrodynamic Suspension (EDS) developed at MIT as part of this joint effort are described and presented. Adaptation of this facility for linear motor and other propulsion and levitation testing is also described.

Kourepenis, A.; Borenstein, J.; Connelly, J.; Ward, P.; Weinberg, M.
Performance of small, low-cost rate sensors for military and commercial applications

Proceedings of the AIAA Guidance, Navigation, and Control Conference, New Orleans, LA, August 1997

Draper Laboratory and Boeing North American (formerly the Rockwell Corporation) have formed an alliance to develop small, low-cost rate sensors for commercial and military applications. Advanced silicon micromachining techniques produce sensors of high performance, ruggedness, and inherent symmetry. When integrated with Application-Specific Integrated Circuits (ASICs), the rate sensor will fit in a 3-cm/side flat pack and operate from a single 5-Vdc supply. Gyros are fabricated using a dissolved wafer process that features single-crystal Si anodically bonded to a glass substrate, resulting in a sensor die size of about 1 mm. Uncompensated bias and scale-factor performance of 0.5/s and 1.0 percent are nominally demonstrated over the automotive temperature range of -40°C to +85°C. Bias stability over smaller temperature ranges of 0.5°C has surpassed 10 deg/h in 6-h tests. Nominal resolution is 150 deg/h in a 60-Hz bandwidth, yielding an angle random walk of 0.25 deg/$\sqrt{h}$. The robustness of the design with regard to environment has been demonstrated in the ability to survive air guns tests in excess of 60,000 g.

Lala, J. H.; Benjamin, A. L.
Advanced fault-tolerant computing for future manned space missions

Proceedings, Vol. 2 (A98-14005 02-01), 16th AIAA/IEEE Digital Avionics Systems Conference (DASC), Irvine, CA, October 1997

To enable human Mars exploration and meet system demands for increased safety, reliability, and autonomy, this paper presents a technology plan to foster the development of the next-generation fault-tolerant computing technology. This paper discusses Mars stringent baseline requirements and constraints, and presents fault-tolerant approaches, techniques, and design building block strategies that include standby redundancy, reconfigurable voting, backup sparing, and graceful degradation. The contemporary approach and recognized inadequacies of their application to long-duration space missions are discussed. Certain problems are identified and viable solutions are offered. Various aspects of fault-tolerant designs and implementations are discussed, including component selection, radiation tolerance, high-density packaging technology, computational integrity, and fault coverage. Architectural solutions that can make systems affordable, such as open systems, standardization, and ease of validation are highlighted. The paper concludes with a technology demonstration plan to achieve the desired baseline requirements and goals.

Lintereur, B. V.; McGovern, L. K.
Constrained H_2 design via convex optimization applied to precision pointing attitude control

Proceedings of the 36th IEEE Conference on Decision and Control (Cat. No.97CH36124), Vol. 2, pp. 1389-1394

A convex optimization controller design method is presented that minimizes the closed-loop H_2 norm, subject to constraints on the magnitude of closed-loop transfer functions and transient responses due to fixed inputs. This method is applied to the roll axis of the EOS-AM1 spacecraft attitude control system, with a set of performance and robustness specifications. This example serves as a good benchmark problem because it has been used for previous model-based control studies. A controller is designed using constrained H_2 that meets all the design specifications of a previous study successfully.

Lozow, J. B.
Analysis of direct P(Y)-code acquisition

Journal of the Institute of Navigation

GPS signal acquisition consists of a two-dimensional search in a time / frequency space to synchronize a receiver-generated reference signal with the received GPS signal in code phase and frequency. User uncertainties in code phase and frequency offsets determine the size of the region to be searched, and hence the code acquisition time. Encrypted P(Y)-code, transmitted on L1 and L2 frequencies, provides more precise (16-m Spherical Error Probable (SEP)) user positioning and inherently more jamming immunity than does C/A-code. The purpose of this study is to explore the use of existing signal detection concepts for quantifying the time to achieve direct acquisition of the P(Y)-code in a jamming environment. Of particular interest is the mitigating effect of parallel processing in reducing acquisition time in the presence of initial (receiver) position, time, velocity, and frequency errors and/or uncertainties.

Mangoubi, R. S.; Ho, N.; Lozano, P.; Martinez-Sanchez, M.
Failure detection and isolation for the Space Shuttle Main Engine (SSME)

Proceedings of the AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit, 33rd, Seattle, WA, July 1997

The Generalized Likelihood Ratio Test for Failure Detection and Isolation (FDI) is designed for the SSME. The algorithm uses the entire 37-state model of the SSME, as well as a set of 15 sensors. It can be used for online FDI, as well as for post-flight analysis. At the design stage, it can help determine the detectability and distinguishability of failures, given a sensor configuration. Emphasis in the paper is on input/output failures, i.e., failures in the valves and sensors, but the likelihood ratio approach can be extended to include structural failures.

Mangoubi, R. S.; Hain, R. M.; Adams, N. J.; Agustin, R. M.
Robust thrust estimation for aerospace vehicle reaction control systems

Proceedings of the 1997 American Control Conference, 15th, Vol. 1 (A98-15310 02-63), Albuquerque, NM, June 1997

This paper considers the problem of estimating the thrust from multiple jets firing from the Reaction Control Systems (RCS) used by reusable launch vehicles. The thrust estimates can be used for monitoring the health of the RCS, i.e., detecting jet failures. For accurately known state-space dynamics, the Kalman filter provides the optimal estimate in the least-squares sense for the jet thrust. During reentry, however, plant model uncertainties are a major problem for the filter, as the vehicle's aerodynamics vary widely. Consequently, the Kalman filter estimate degrades severely. Transient, robust H-infinity or game-theoretic estimators are shown to give promising estimation and detection performance results for a wide range of Mach numbers and angles of attack when tried on a simulation of the Space Shuttle Orbiter's RCS.

Marchand, F. P. Jr.
Touchdown bearing development for a magnetic bearing system used in a high-temperature gas turbine

Proceedings of the 1997 International Gas Turbine and Aeroengine Congress and Exposition, Orlando, FL

This paper describes the design and development of a touchdown bearing system. The touchdown bearing is one of the important elements in any high-speed magnetic bearing system. The touchdown bearing functions to fully off-load or load share with the magnetic bearing and prevent catastrophic system failures. The proper design of this component is a critical step in the design of the total system and was not treated as a stand-alone subcomponent. The impact loads that these bearings have to endure is a challenge to the designer. The high-temperature environment on this bearing adds additional constraints to the design options with which the designer has to work. A design was produced that will function under these conditions. The use of silicon nitride balls with silver-coated CPM Rex 20 races will be described. The bearing is mounted on a replaceable journal, which in turn is mounted on the magnetic bearing. Design and test data for use of these bearing materials in a high-temperature gas turbine application is included in this paper.

McConley, M. W.; Appleby, B. D.; Dahleh, M. A.; Feron, E.
Control Lyapunov function approach to robust stabilization of nonlinear systems

Proceedings of the 1997 American Control Conference

We propose an alternative to gain scheduling for stabilizing a class of nonlinear systems. The computation times required to find stability regions for a given control Lyapunov function vary polynomially with the state dimension for a fixed number of scheduling variables. Control Lyapunov functions to various trim points are used to expand the stability region, and a Lyapunov-based synthesis formula yields a control law guaranteeing stability over this region. Robustness to bounded disturbances is easily handled, and the optimal stability margin, defined as a Lyapunov derivative, is recovered asymptotically. We apply the procedure to an example.

McConley, M. W.; Dahleh, M. A.; Feron, E.
Polytopic control Lyapunov functions for robust stabilization of a class of nonlinear systems
Proceedings of the 1997 American Control Conference

Nonlinear control systems can be stabilized by constructing control Lyapunov functions and computing the regions of state space over which such functions decrease along trajectories of the closed-loop system under an appropriate control law. For systems with dynamics that are nonlinear in only a few state variables, we develop a method for computing such a region based on a given polytopic control Lyapunov function. The procedure is computationally tractable in the sense that computation times vary polynomially with the state dimension for a fixed number of 'nonlinear states.' Control constraints and robustness to bounded disturbances are easily incorporated into this framework.

McGovern, L. K.; Henderson, T. C.
Design of an active vibration isolation control system using constrained optimization

Proceedings of the 1997 American Control Conference

A controller design for an active vibration isolation system is described in this paper. The controllers were designed using a constrained optimization design method based on quadratic programming. The closed loop was directly constrained to satisfy a set of performance and robustness specifications. The controllers were successfully implemented and tested on the hardware system.

Miller, M.
Integrated design environment for mixed electronic-mechanical system

Electronic Engineering (London), Vol. 69, No. 846, pp. 24-26, 28, June 1997

Aircraft reliability is very important. Reliable aircraft can be created by means of correct designing. Modern designing is performed with the use of advanced technical facilities. The Charles Stark Draper Laboratory, Inc., is now working to build a comprehensive simulation environment that crosses electrical, mechanical, and software boundaries. It is in the process of integrating a Vantage VHSIC (Very-High-Speed Integrated Circuit) Hardware Description Language (VHDL) simulator with Boeing Corporation's Easy5 system simulator. It is possible to simulate mechanical elements as they interact with electrical elements of design. New system-level simulators must be capable of modeling both mechanical and electrical phenomena. A new level of integration to electromechanical system design will be provided.

Musoff, H.; Schmidt, G.; Gusinsky, V. Z.; Lesyuchevsky, V. M.; Litmanovich, Y. A.
Optimization of a strapdown attitude algorithm for a stochastic motion

Navigation (ISSN 0028-1522), Vol. 44, No. 2, pp. 163-170, 1997

A new procedure for deriving strapdown attitude algorithms is examined for the more general cases of motion inputs, namely, 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. The contribution of the third term in the rotation vector differential equation, which is conventionally discarded, is studied. The condition of the need for its inclusion to render the algorithm optimal is stated. Simulation results of the nontruncated algorithm with the optimized coefficients are presented and discussed.

Musoff, H.; Schmidt, G. T.; Gusinsky, V. Z.; Lesyuchevsky, V. M.; Litmanovich, Y. A.
New procedure for deriving optimized strapdown attitude algorithms

Journal of Guidance, Control, and Dynamics (ISSN 0731-5090), Vol. 20, No. 4, pp. 673-680, August 1997, from the St. Petersburg International Conference on Gyroscopic Technology and Navigation, 2nd, St. Petersburg, Russia, May 1995

A new procedure for deriving strapdown attitude algorithms is described and justified. This procedure allows optimization of the solution when the vehicle angular rate components are known analytically. It is based on Miller's approach, but it uses the analytical relationship between angular rate derivatives and does not require the derivation of an analytical expression for the error quaternion. The procedure was tested for both classical and more general conic motion, when vehicle angular rate components are described as the Jacobian elliptic functions. It is shown that the coefficients optimized for classical coning hold true for general coning as well, but only if the rate component peak values are properly specified, and the third term of the rotation vector differential equation is taken into account. A new kinematically correct description for the generalized coning is presented, and two variants of the angular rate's representation that meet this criterion are derived. A statistical refinement of the deterministic Miller's procedure, which imparts smoothing properties to an algorithm, is formulated and an example of its application is presented.

Neelon, J. G., Jr.; Cefola, P. J.; Proulx, R. J.
Current development of the Draper semianalytical satellite theory stand-alone orbit propagator package

Proceedings of the AAS/AIAA Astrodynamics Conference, Sun Valley, Idaho, August 1997

Early development of the Draper Semianalytical Satellite Theory (DSST) was motivated by the goal of a nonsingular, semianalytical theory that combined the best characteristics of existing numerical and semianalytical satellite theories. By early 1983, the Draper Goddard Trajectory Determination System (GTDS) implementation of the DSST included the major physical models: higher-order geopotential (21 x 21), atmospheric drag, lunar-solar point masses, and solar radiation pressure. To provide greater access to the DSST, a stand-alone version that operated separately from GTDS was constructed. GTDS and the stand-alone each developed through incremental changes, but in different directions. Currently, an effort is underway to improve the accuracy and maintainability of the stand-alone. The improvements include new models for the coordinate system reference (J2000), geopotential (50 x 50), and solid Earth tides, and modifications to the short-periodic model. The most recent application of this stand-alone is the Automated Station-Keeping Simulator (ASKS) tool for satellite constellations.

Phillips, R.
Relative and differential GPS data transfer and error analysis

Proceedings of the 1997 53rd Annual ION Meeting

The distinction between the Relative Global Positioning System (RGPS) and Differential GPS (DGPS) is studied. Both terms imply a transfer of information from a reference receiver. Expressions for the errors associated with three different data transfer formats are derived. A numerical evaluation of the errors associated with one of these formats is made.

Pien, H. H.; Desai, M.; Shah, J.
Segmentation of MR images using curve evolution and prior information

International Journal of Pattern Recognition and Artificial Intelligence, Vol. 11, No. 8, pp. 1233-1245

Segmentation of anatomic structures of the human brain from MR images is important to assess treatment efficacy, screen for anomalies, and improve our understanding of human development. The labor-intensive nature of manual segmentation, however, makes such a technique viable only in selected cases. In this paper, we present a new approach to segmentation that involves only minimal human interactions. The technique uses a variational formulation to obtain an edge-strength function over the region of interest, and uses curve evolution and a presegmented atlas to guide the actual segmentation process. The approach is demonstrated via both phantoms and actual MR images, and when applied to the lateral ventricles and caudate nucleus, showed a size accuracy error of 5 to 20 percent with respect to manual segmentation, depending on the manual segmentation method used.

Pien, H.; Sibel Goktepe Tari, Z.; Shah, J.
Extraction of shape skeletons from grayscale images

Computer Vision and Image Understanding, Vol. 66, No. 2, Academic Press, Inc., San Diego, CA, ISSN: 1077-3142 CODEN: CVIUF4, pp. 133-146, May 1997

Shape skeletons have been used in computer vision to represent shapes and discover their salient features. Earlier attempts were based on a morphological approach in which a shape is eroded successively and uniformly until it is reduced to its skeleton. The main difficulty with this approach is its sensitivity to noise, and several approaches have been proposed to deal with this problem. In this paper, we propose a new method based on diffusion to smooth out the noise and extract shape skeletons in a robust way. In the process, we also obtain segmentation of the shape into parts. The main tool for shape analysis is a function called the 'edge-strength' function. Its level curves are smoothed analogs of the successive shape outlines obtained during the morphological erosion. The new method is closely related to the popular method of curve evolution, but has several advantages over it. Since the governing equation is linear, the implementation is simpler and faster. The same equation applies to problems in higher dimensions. Unlike most other methods, the new method is applicable to shapes that may have junctions such as triple points. Another advantage is that the method is robust with respect to gaps in the shape outline. Since it is seldom possible to extract complete shape outlines from a noisy grayscale image, this is obviously a very important feature. The key point is that the edge strength may be calculated from grayscale images without first extracting the shape outline. Thus, the method can be applied directly to grayscale images.

Ricard, M.; Sauer, B.
Autonomous mission planning for spin-stabilized science satellites

Proceedings (A98-14676 02-12), 11th Annual AIAA/Utah State University Conference on Small Satellites, Logan, UT, September 1997

This paper describes a scheduler for a class of spin-stabilized science satellites. Using a linear programming model of the mission, the value gained from the use of the instruments is optimized with respect to a given set of operational constraints. As a proof of concept, the scheduler is demonstrated in a case study. Finally, consideration of dynamic rescheduling in response to system failures is provided in an additional set of case studies.

Sackett, L. L.; Kirchwey, C. B.; Johnson, M. C.; Barrington, R. D.
Flight control, dynamics, and structural interaction on the second Hubble Space Telescope servicing mission

Proceedings of the AAS/AIAA Astrodynamics Conference, Sun Valley, Idaho, August 1997

The second Hubble Space Telescope servicing mission occurred in February 1997 on STS-82. Throughout the servicing, the fragile Hubble solar arrays were deployed and loads on the solar arrays caused by the Space Shuttle control jet firings were of great concern. Extensive preflight analyses of possible solar array loads and deflections were performed, and flight control system constraints and operational procedures were recommended to mitigate the effect of jet firings. Because of the concern about using the large primary Shuttle jets for a reboost maneuver, a scheme was developed to use the smaller vernier jets to perform orbit-raising maneuvers. Flight control system stability with a large flexible payload was also considered.

Schmidt, G. T.
GPS/INS technology trends for military systems

Proceedings of the AIAA Guidance, Navigation, and Control Conference, New Orleans, LA, August 1997

We discuss technology trends for inertial sensors, GPS accuracies, and integrated GPS/INS systems (including jamming considerations) for military platforms and weapons that will lead to 1-m accuracy global navigation systems of the future. For inertial sensors, trend-setting sensor technologies applicable to military systems are described. They are fiber-optic gyros, silicon micromechanical gyros, resonating beam accelerometers, and silicon micromechanical accelerometers. A vision of the inertial sensor instrument field and inertial systems for military applications for the next few decades is given. GPS-specified and observed current accuracies are described, as well as planned accuracy improvements due to various stages of the Wide-Area GPS Enhancements implementation, intersatellite ranging, and 'all-in-view' tracking. Uses of relative and differential GPS are discussed. The trend toward tightly-coupled GPS/INS, where both code and carrier tracking loops are aided with inertial sensor information, is described and the synergistic benefits are explored.

Schmidt, G. T., et al.
Precision terminal guidance for munitions

NATO/AGARD Advisory Report 342, February 1997

Working Group 02 (originally Guidance and Control Panel Working Group 13) was approved by the AGARD National Delegates Board in the Spring of 1991, shortly after the Gulf War with Iraq. The effectiveness of the guided munitions used in that conflict emphasized their importance in "conventional" warfare. Following this experience, the lessons learned from military interventions by NATO nations has often yielded less clear-cut results. In spite of these recent events, it seems clear that the future of precision guidance is assured, for reasons similar to those prevailing during the Gulf War; that is, their usefulness as a "force multiplier." This enables them to maximize the effective fire power of launch platforms, minimize the number of missions required to carry out a given task, and reduce collateral damage to non-combatants to a minimum. The Working Group oriented its aims toward NATO military needs and the review of terminal guidance technology in relation to those needs. The AGARD planning guidelines (which give a top-down view, derived from the NATO strategic concept) and an analysis by GCP of the implications of the Gulf War for guidance and control were used as a starting point. The review of terminal guidance technologies was also aimed at identifying new capabilities not currently part of NATO's armory. Projections into the future often produce speculative concepts that, in the light of deeper study, turn out to be unworkable,

unaffordable, or even misguided. But new ideas, however impractical at first sight, are the stimulus NATO needs to stay at the forefront of technology advances.

Schmidt, G. T.
High-integrity global precision navigation systems

Proceedings of the AGARD Symposium on Future Aerospace Technology in the Service of the Alliance, AGARD-CP-600, Vol. 2, April 1997

This paper focuses on the usefulness of highly precise and robust navigation systems based on INS/GPS to future NATO military missions.

Schmidt, G. T.
The inertial/GPS combination

Proceedings of the Association of Old Crows Conference on Navigation Warfare, September 1997

This paper was presented at a classified conference dealing with navigation warfare issues centered on GPS vulnerability. The core technology presented was inertial systems that are invulnerable to jamming signals.

Scholten, J. R.
Magnetic bearing suspension system for high-temperature gas turbine applications: control system design

Proceedings of the 1997 International Gas Turbine and Aeroengine Congress and Exposition

A proportional-integral-derivative magnetic-bearing control system is designed based on modeling and simulation of the dynamics of a jet engine turbine shaft and bearing system. Simulations demonstrated that the design keeps the shaft within 2 mils of its desired location at the magnetic bearings, under all normal loads. Under extreme external loads, the capacity of the magnetic bearings exceeds and touchdown occurs on backup mechanical bearings. The control design handles this critical event, which determines the force slew rate required from the actuators.

Shah, N. H.; Proulx, R. J.; Kantsiper, B.; Cefola, P. J.; Draim, J.
Automated station-keeping for satellite constellations

Proceedings of the AAS/AIAA Astrodynamics Conference, Sun Valley, Idaho, August 1997

The on-orbit control of future satellite constellations poses a great challenge. New approaches are required that result in viable control systems that are flexible, reliable, and efficient. This work develops new methods for the maintenance of satellite constellations. Strategies that employ these methods are applied to analyze the control and coverage characteristics of the Ellipso^{TM} constellation. The Automated Station-Keeping Simulator (ASKS), a software package developed for this project, is employed.

Sims, J. T.
Redundancy management software services for Seawolf ship control system

Digest of Papers, 27th Annual International Symposium on Fault-Tolerant Computing

The ship control system for the U.S. Navy's newest attack submarine, Seawolf, incorporates hardware modular redundancy both in its core processing and its input/output system. This paper provides a practical experience report on the redundancy management software services developed for this system. Introductory material is presented to provide contextual information regarding the overall ship control system. An overview of the system's processing platform is presented in sufficient detail to define the problems associated with redundancy management and to describe hardware functionality that supports the software services. Policies and procedures to detect and isolate faults are discussed as are reconfiguration responses to faults.

Sims, J. T.
Real-time recovery of fault-tolerant processing elements

IEEE Aerospace and Electronic Systems Magazine, Vol. 12, pp. 13-18, December 12, 1997

A critical problem in the design of ultra-reliable fault-tolerant systems is that of how to bring a redundant member back on-line after a transient fault without degrading critical real-time functions. Recovery from transients is imperative to maintain necessary system reliability in the face of transient errors that have been estimated to occur at a rate of 5 to 100 times that of permanent failures. Excessive delays associated with recovery become a problem when as much as 1 MB of RAM in the faulty processor must be made congruent with the processing majority while maintaining full functionality of critical, real-time control algorithms. 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. Also presented are performance data associated with this technique's application to a Draper Laboratory quad-redundant processor responsible for vehicle control of a manned undersea vehicle.

Socha, M. M.; Hain, R.; Dever, C.; Madden, P.; Mangoubi, R.; Metzinger, R.
Small satellite design and development for precision pointing applications

Proceedings (A98-14676 02-12), 11th Annual AIAA/Utah State University Conference on Small Satellites, Logan, UT, September 1997

This paper describes MicroSat, a three-axis stabilized satellite design for precision pointing applications. The heart of the design is the optics and the pointing subsystems. MicroSat uses an integrated Inertial Navigation System/Global Positioning System (INS/GPS)-based attitude reference system with custom designed and fabricated reaction wheels for pointing control. Multiple units can be launched from a Pegasus-class vehicle, providing a once-per-day revisit of a designated area with 1-m class resolution in the visible range. This paper describes the satellite concept design and the hardware ground test demonstration.

Tetewsky, A.; Soltz, A.; Fuhry, D.; Barton, G.; Eyring, D.; Goossens, B.; Dodds, M.; Fava, L.; Greenspan, R.; Youngberg, J.
Validating the validating tool: defining and measuring GPS simulator specifications

Proceedings of the 1997 10th International Technical Meeting of the Satellite Division of the Institute of Navigation, ION GPS-97

There are three critical reasons why GPS simulators are expensive, difficult for users to understand, and difficult to validate. By understanding these reasons, the simulator validation problem can be reduced into a series of well-defined, smaller, solvable problems. This article presents strawman solutions to these problems. An example of supporting measurements is also given.

Tuohy, S. T.; Maekawa, T.; Shen, G.; Patrikalakis, N. M.
Approximation of measured data with interval B-splines

Computer-Aided Design, Vol. 29, No. 11, pp. 791-799, November 1997

The objective of this paper is to provide an efficient and reliable method for interpolating or approximating a set of measured data with an interval B-spline curve or surface. In general, measured data possess uncertainty, arising from sensor precision and measurement registration, which can be represented as an interval. Both the interpolation and approximation techniques presented in this paper produce interval bounding geometries that strictly enclose the intervals of the original data; in the case of our interpolation method, the achieved fit is

extremely tight, and in the case of our approximation technique, the achieved fit depends on the number of control points one is willing to allow. Examples using measured data illustrate our method.

Tuohy, S. T.
Visual tool for demonstrating surface curvature

Computer Applications in Engineering Education,
Vol. 5, No. 1, pp. 21-27, 1997

In this article, we demonstrate a computer tool for teaching surface curvature. Through the display of parametric derivatives, surface normals, surface curvature, and other intrinsic surface properties (such as the osculating plane), the user can explore complex surface shapes using interactive graphics and advanced visualization. An illustration of the system is provided to demonstrate how the concept of surface shape can be displayed in a clear and intelligible manner.

Tureaud, T. F.
Numerical simulation of receptivity phenomena in transitional boundary-layer flows

AIAA Journal (ISSN 0001-1452), Vol. 35, No. 5, pp. 789-795, May 1997

A computational fluid-acoustic methodology is described and used to simulate induced and acoustic receptivity in unsteady boundary-layer flows. The methodology solves a finite compressibility form of the Navier-Stokes equations using a flux differenced, finite-volume technique. Special attention is paid to nonreflective boundary conditions appropriate for unsteady, multidimensional problems, including those involving viscous shear and propagating waves. The numerical experiments include the simulation of acoustic receptivity due to surface inhomogeneity in which the acoustic phenomena are modeled using physically appropriate wavelengths. Required steady solution accuracy, convergence acceleration techniques, boundary condition/flow-field interactions, and the challenges of scale resolution vs computational cost are addressed in a series of simulations. The computed results are shown to be in agreement with linear stability theory and experimental measurements.

Weinberg, M.; Connelly, J.; Kourepenis, A.; Sargent, D.
Microelectromechanical instrument and systems development at the Charles Stark Draper Laboratory, Inc.

Proceedings of the 1997 16th AIAA/IEEE Digital Avionics Systems, DASC

Draper Laboratory and Boeing North American (formerly, Rockwell Corporation) have formed an alliance to develop very small, low-cost rate sensors for commercial and military applications. Several generations of micromechanical gyroscopes have been developed at Draper using a dissolved wafer process that features single-crystal silicon anodically bonded to a glass substrate. Resulting sensor die size is approximately 1 mm. When integrated with Application-Specific Integrated Circuits (ASICs), the sensor fits in a 3-cm/side flat pack operating from a single 5-Vdc supply. Bias stability over temperature ranges of 0.5°C has surpassed 10 deg/h. Best resolution and angle random walk performance to date is 25 deg/h in 60 Hz and 0.04 deg/√h, respectively. The sensors are extremely robust, having survived air gun tests in excess of 60,000 g. With recent performance improvements, this technology becomes useful for spacecraft inertial guidance. Size, mass, and power of inertial systems can be reduced by orders of magnitude, providing benefits of paramount importance to the new class of miniature satellites, rovers, and spacecraft. However, significant challenges remain before this technology is routinely available for space applications related to performance and space environmental effects. This paper discusses the principle of operation, measured and projected performance, and approaches being taken at Draper Laboratory to develop micromechanical instruments suitable for use in military and space systems.