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ABSTRACTS

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MR-121-ACQ An Evolutionary Approach to Space Launch Commercialization. B. G. Chow. 1993.

This study classifies launch contracts into three types: government (GLs), commercial (CLs) and commercial-like launches (CLLs). Contrary to a view that GLs are more reliable, it found that the launch reliabilities under all three types cannot be considered statistically different with 95 percent confidence. An analytic approach was developed to determine whether a particular government launch program should be procured commercially. The study recommends an evolutionary approach to space launch commercialization, starting with small launchers and then medium-lift launchers such as the Deltas and Atlases. Whether the Titan IVs should be commercialized in the future depends on how well the commercialization of medium-lift launchers fares. The study also recommends that the Department of Defense concentrate its new launcher development on the most commercially relevant range, which is the capability to lift 10,000 to 50,000 pounds of payload into low earth orbits. Other recommendations are related to the deletion of undesirable contract features and steps to strengthen launch competitiveness.

MR-393-AF/A Modeling Global Positioning System Effects in the TLC/NLC Model. P. D. Allen. 1994.

Use of the Global Positioning System (GPS) can enhance the navigation of combat platforms and the guidance of munitions. This report presents a design for incorporating GPS into RAND's theater-level combat or nonlinear combat (TLC/NLC) model, which is used for policy analysis of military operations. The author's design looks first at GPS coverage, i.e., how position is located using one or more GPS satellites. Next, the author considers factors limiting the access of GPS-equipped assets to the system. Third, the author examines the benefits to assets so equipped: improved self-location accuracy, which enhances navigation and reduces fratricide; improved target location accuracy; and improved targeting of stand-off munitions. The final consideration is countermeasures against threats to GPS transmitters, receivers, and signals.

MR-482/1-ARPA An Optical Signal Processing Model for the Interferometric Fiber Optic Gyro. Vol. 1, Deterministic Model. J. M. Aein. 1995.

This report presents the results of a communication theoretic model used to analyze the operation of Interferometric Fiber Optic Gyroscopes (IFOG). The IFOG is an all-solid-state rotation-rate sensor employed in miniature inertial measurement units (MIMU). The IFOG can achieve a navigation grade of performance (0.01 degree/hour drift rate) and offers the considerable advantage of reducing instrument costs by a factor of two or more over the current ring laser gyroscope (RLG) technology base. A simplified classical propagation model is used to describe the optical beams employed. Optical signal modulation is impressed with the following goals: (1) increase the linearity of the rotation-rate measurement and (2) mitigate the deleterious effects of the optical scatter noise unavoidably generated by the desired light beams as they traverse the optical pathways of the IFOG. This report deals with goal (1) above. The following are analyzed: (1) AC bias modulation used to linearize the IFOG instrument; (2) closed-loop, feedback operation to extend the dynamic range; and (3) serrodyne operation. The analysis establishes the performance relationships among the appropriate optical signal parameters and allows for their optimization.

MR-517 Space: Emerging Options for National Power. D. J. Johnson, S. Pace, C. B. Gabbard. 1998.

This report presents the results of a study that examined the extent to which both military and economic spacepower will influence national security strategy and the conduct of future military operations. It attempts to articulate the key military space policy issues facing the United States and place them in the larger context of a changing strategic environment to define new options for the exercise of spacepower in the pursuit of national interests. The proliferation of military space forces from the Cold War to the present can be seen in the increasing capabilities of these forces and the expanding roles they are expected to play in future missions. Space forces will be expected to perform an array of space-related functions, including early warning and integrated tactical warning and attack assessment, weather/environmental monitoring, satellite communications, surveillance and reconnaissance, navigation and positioning, space control, and, possibly, ballistic missile defense and force application.

MR-614-OSTP The Global Positioning System: Assessing National Policies. S. Pace, G. Frost, I. Lachow, D. Frelinger, D. Fossum, D. K. Wassem, M. Pinto. 1995.

The Global Positioning System (GPS) is a military space system operated by the U.S. Air Force that continuously broadcasts precise time signals. These signals can be used worldwide to aid position location, navigation, and timing. GPS is an information resource that supports a wide range of civil, scientific, and commercial functions as well as

U.S. forces. National policy toward GPS has not, however, kept pace with the system's rapidly expanding international uses. This study identifies major opportunities and vulnerabilities created by GPS for U.S. defense, commercial, and foreign policy interests, and makes recommendations for U.S. policy toward GPS, including future governance and funding. If the United States promotes GPS as a global standard, it should address the dual-use nature of the technology through international agreements. If the United States becomes an unreliable steward for GPS, it risks losing the economic and diplomatic benefits from past investments in this technology.

MR-864-OSTP The Cosmos on a Shoestring: Small Spacecraft for Space and Earth Science. L. Sarsfield. 1998.

Small spacecraft have become popular for a number of reasons, most prominently the needs to reduce overall cost, be built more quickly, and spread mission risks. NASA has been challenged with crafting a program that continues to produce meaningful science within the constraints of the available budget. Still, pound for pound, small spacecraft are not precisely inexpensive, given the effects of complexity, launch costs, and a greater degree of risk. Historically, science spacecraft have demonstrated increasing reliability, but this trend might not continue, given the shift to managed risk. There is generally less money available to smaller programs to test spacecraft functions and operational procedures prior to launch. Small spacecraft are also generally less robust. Efforts to reduce failure potentials through the application of more reliable components, better testing, and advanced design techniques should receive greater attention. Despite the risks, however, small spacecraft fulfill important roles in earth science, astrophysics, space physics, and planetary science. NASA's current generation of small spacecraft is capable of impressive levels of performance.

MR-890-AF Proceedings of the RAND Project AIR FORCE Workshop on Transatmospheric Vehicles. D. R. Gonzales, M. Eisman, C. Shipbaugh, T. Bonds, A. T. Lê. 1997.

It may be possible for transatmospheric vehicles (TAVs) to insert payloads into low earth orbit or deliver payloads to distant targets within minutes, to carry out various types of military, civil, and commercial missions. The promise of TAVs lies in their reusability and their potential capability to launch payloads at much lower cost than existing rockets. In addition, if they were operated more like aircraft and less like rockets, they could permit responsive and flexible space operations, features that would be useful for a number of military missions. However, in spite of substantial past research, technology challenges remain, especially in propulsion, thermal protection systems, and overall vehicle integration. A workshop was held at RAND in April 1995 to examine TAV mission, technical feasibility, and design issues. This report summarizes the proceedings of that workshop and subsequent research into relevant questions flowing from the discussions.

MR-893-AF Life Cycle Cost Assessments for Military Transatmospheric Vehicles. M. Eisman, D. R. Gonzales. 1997.

Advanced technology and demonstration programs currently under way may ultimately lead to a transatmospheric reusable launch vehicle suitable for insertion into low earth orbit or for delivery of payloads to distant targets within minutes. While such a reusable vehicle may carry out military, civil, or commercial missions, this report focuses on military missions that a transatmospheric vehicle (TAV) might perform. It describes the differences between commercial uses and military missions in terms of objectives, maintainability, and response times—differences that would affect vehicle design. The report summarizes several military TAV design concepts, with emphasis on technical features. After describing cost ground rules and assumptions, and the unique methodology and rationale for estimating the costs of military TAVs, preliminary RDT&E and life cycle cost assessments on two of the military TAV design concepts are provided. The authors find that in the long term, an air-launched military TAV would be more cost-effective than a small expendable launch vehicle such as Pegasus.

MR-895-AF The Changing Role of the U.S. Military in Space. D. R. Gonzales. 1999.

Growth in the technical capabilities of commercial and foreign space systems, potential exploitation of space by adversaries, increasing use of commercial space capabilities by U.S. forces, and continuing budget constraints are all changing the role of the U.S. military in space. The growth of commercial space markets, and the rapid privatization and increasing foreign ownership of commercial space assets, suggest that the Department of Defense must develop a long-term strategy to ensure adequate and secure access to commercial communications satellites and other commercial space resources. Space control will assume increasing importance in military operations, and space itself may become a theater of military operations. The United States should develop a long-term strategy to enable the U.S. military to deny space capabilities to potential adversaries. Such a strategy should rely on system or operational concepts that minimize collateral damage to commercial, civil, and third-party space assets and that do not violate existing arms control agreements or treaties. Space surveillance—the ability to precisely identify, track, and

predict the position of objects in space —is an essential aspect of space control. Space control and changing space surveillance needs have implications for the Air Force as an institution.

MR-972-OSTP International Agreements on Cooperation in Remote Sensing and Earth Observation. C. S. Wagner. 1998.

As of the end of 1997, the United States had cooperative agreements with 76 countries and six multinational organizations covering the operations of 32 active satellites, most often covering the collection of weather data. These agreements are entered into by a number of agencies, with five agencies accounting for 90 percent of the agreements identified for this project: the National Oceanic and Atmospheric Administration, the U.S. Air Force, the Defense Mapping Agency, the U.S. Geological Survey, the National Aeronautics and Space Administration, and the U.S. Forest Service. This report catalogs the agreements and assesses the extent of interagency coordination that take place when agreements are negotiated and signed. Three possible policy actions emerged: rationalizing the terms of and descriptions for international agreements across agencies; creating a central clearinghouse for information on agreements, perhaps using the World Wide Web; and streamlining the available formal coordination process to increase the frequency of its use.

MR-1209-AF Space Weapons Earth Wars. B. Preston, D. J. Johnson, S. J. A. Edwards, M. D. Miller, C. Shipbaugh. 2002.

Space weapons have been debated intensely in the past. The latest instance of prominent debate is over their use for ballistic missile defense. But this is not the only possible role for space weapons, and that fact raises a further concern: What if an adversary were to develop such weapons? Could one? Why would it? It is time for broader public discussion of the issues. Before deciding to acquire or forgo space weapons for terrestrial conflict, the United States should fully discuss what such weapons can do, what they will cost, and the likely consequences of acquiring them. The authors of this report seek to aid this discussion not by arguing for or against space weapons but by describing their attributes, classifying and comparing them, and explaining how each might be used. The authors also explore how a nation might decide to acquire such weapons and how other nations might react.

MR-1229 Commercial Observation Satellites: At the Leading Edge of Global Transparency. J. C. Baker, K. M. O'Connell, R. A. Williamson. 2001.

Wide access to satellite imagery and related products has expanded rapidly since the end of the Cold War. Leading the way into this new era of global transparency is a new generation of high-resolution commercial and civilian imaging satellites that will offer almost anyone timely overhead images of locations that are geographically remote, politically inaccessible, or simply difficult to comprehend without an overhead perspective. But whether these systems are commercially viable remains to be seen in the long run. The probable effects on world affairs are highly uncertain and depend deeply on other economic, technological, and political trends. Still, on balance, greater transparency is likely to provide significant benefits. And the policy community will need to improve its ability to deal with new technologies. But regardless of how one views the political and economic effects, the phenomenon of global transparency is still developing, both from the standpoint of data from high-resolution earth-observation satellites and from the other information technologies that support these data and make them particularly useful in monitoring and better understanding global developments.

MR-1372-NRO Policy Issues and Challenges for Interagency Space System Acquisition. D. J. Johnson, G. H. Hilgenberg, L. Sarsfield. 2001.

Agencies within the national security space community recently have come under increasing pressure to conduct joint or interagency programs to take advantage of potentially shared objectives and mission synergies. Such joint endeavors, it is hoped, will make the agencies more efficient and effective and eliminate unnecessary redundancies among programs. However, a number of policy issues and challenges will influence how these efforts are executed. This report seeks to illuminate these policy issues and challenges, particularly those that will influence multi-mission space system concepts and programs conducted jointly by the National Reconnaissance Office (NRO) and the Air Force. Using case studies, this report examined five ways to conduct acquisition in an interagency setting—Executing Agent, System Integrator, Independent Agent, Confederation, and Joint Program Office. The report analyzed key elements inherent to interagency acquisition, including acquisition complexity, program management, program control, requirements management, funding stability, customer responsiveness, cultural alignment, and staffing. The report contained the following findings: 1) Interagency efforts such as those conducted by the NRO and the Air Force need to maintain high-level support, not only from agency leadership but also from key stakeholders, users, and the Congress, and consistency with national policy guidance and objectives. 2) Certain coordinating documents, such as the memorandum of agreement/memorandum of understanding, implementation plan and strategy, and program funding strategy are critical to ensuring commonality of purpose in

the early stages of an interagency effort. 3) Requirements management is critical, particularly in adjudicating among differing agency and user requirements to deter "requirements creep" by the partner agencies. 4) Ensuring funding stability is important, especially when coordinating between two (or more) very different budgetary processes and timetables. 5) Organizational culture can influence both operational capabilities and organizational structure and process, and its effects on interagency programs should not be underestimated.

MR-1469-DOC U.S. Commercial Remote Sensing Satellite Industry: An Analysis of Risks. K. M. O'Connell, J. C. Baker, B. E. Lachman, S. Berner, D. Frelinger, K. Gavin. 2001.

American firms have begun to operate their own imaging satellite systems, aiming to become an important part of the U.S. commercial remote sensing industry. To succeed over the long run, these new U.S. commercial remote sensing satellite firms need a combination of reliable technologies, government policies that encourage U.S. industry competitiveness, a strong international presence, and sound business plans to ensure their competitiveness in both the domestic and international marketplaces. The greatest risks for the these firms come from the challenge of transforming themselves from imagery data providers to strong competitors as information age companies; the need to master the technical risks of building and operating sophisticated imaging satellite systems; and the requirement to operate effectively in a complex international business environment. In addition, the government's policymaking process has yet to achieve the degree of predictability, timeliness, and transparency that the firms need if they are expected to operate effectively in a highly competitive and rapidly changing global marketplace. The authors conclude with six recommendations that the U.S. Department of Commerce should adopt to best fulfill its responsibilities for promoting the U.S. commercial remote sensing industry and for encouraging the competitiveness of new private imaging satellite firms.

MR-1649-AF Mastering the Ultimate High Ground: Next Steps in the Military Uses of Space. B. S. Lambeth. 2003.

The author assesses the military space challenges that face the Air Force and the nation in light of the findings and recommendations of the congressionally mandated Space Commission, released in January 2001. After reviewing the main milestones in the Air Force's involvement in space since its creation as an independent service in 1947, he examines the circumstances that occasioned the Space Commission's creation, as well as the conceptual and organizational roadblocks that have impeded a more rapid growth of U.S. military space capability. He concludes that the Air Force faces five basic challenges with respect to space: continuing the operational integration of space with the three terrestrial warfighting mediums while ensuring the organizational differentiation of space from Air Force air; effectively wielding its newly granted military space executive-agent status; realizing a transparent DoD-wide budget category for space; showing progress toward fielding a meaningful space control capability while decoupling that progress from any perceived taint of force-application involvement; and making further progress toward developing and nurturing a cadre of skilled space professionals within the Air Force.

REPORTS

R-2600-NASA Improved Coordinates of Features in the Vicinity of the Viking 1 Lander Site on Mars. M. E. Davies, S. H. Dole. 1980.

Data from a strip of 117 frames (principally Viking Orbiter photographs) joining the areas around Airy-O and the Viking 1 lander site were used in the GIANT computer program to improve the areographic coordinates of Mars surface features in this region. Airy-O defines the prime meridian on Mars, and thus this photogrammetric path permitted an independent and improved determination of the longitude of the Viking 1 lander site. The longitude remains the same as in prior measurements but the error is reduced by half. The report discusses the computer program used to make the analytical triangulations, describes the photogrammetric computation of the longitude of the Viking 1 lander site, and gives improved coordinates of features near the lander site.

R-2619-RC Standard Spacecraft Procurement Analysis: A Case Study in NASA-DOD Coordination in Space Programs. E. D. Harris. 1980.

Examines organizational and procurement issues surrounding NASA-DOD cooperation for a specific case study—DOD use of NASA standard spacecraft. Space shuttle operation, as the U.S. standard launch vehicle for both NASA and DOD payloads, refocuses attention on NASA-DOD cooperation. Use of standard spacecraft designs offers reduced operational costs, but intensifies the difficulty of determining agency needs and responsibilities while retaining mission responsiveness. A modified system-impact-assessment approach compares total costs of alternative procurement options and applies both sensitivity and a fortiori analyses to manage uncertainty. Principal conclusions are: use of a new standard spacecraft design, rather than any original NASA or DOD designs, provides the basis for minimizing the cost of the Air Force Test Program; factors essential to NASA-DOD

cooperation are a common subset of missions, a common organization responsibility, and an extensive period of time to develop the organizational mechanics; and the successful NASA-DOD cooperation model is not easily transferred to other situations.

R-3046-AF Techniques for the Analysis of Spectral and Orbital Congestion in Space Systems. A. L. Hiebert, W. Sollfrey. 1984.

This report is a compendium of the techniques available for analysis of spectral and orbital congestion in space systems. The expansion of signal transmissions and orbiting objects could severely affect the frequency spectrum allocations, orbit assignments, and related earth segments of space systems. The treatment of these problems requires a set of analytical procedures, computer programs to apply these procedures to specific configurations, and a database to provide inputs to the programs. The proposed Space System Data Base will consist of electromagnetic and operational characteristics of active and projected U.S. and international space systems including related earth and airborne segments. More than 20 analysis and computation codes are described, with the presentation pitched to an engineer's or user's level. The projected capabilities will provide an essential national resource for management decisionmaking and architectural planning on space-related programs.

R-3083-NASA A Development of Logistics Management Models for the Space Transportation System. M. J. Carrillo, T. Lippiatt, J. B. Abell, S. E. Jacobsen. 1983.

This report identifies the characteristics of logistics system capability assessment and stockage optimization methods that reflect the unique nature of the National Aeronautics and Space Administration's (NASA) Space Transportation System's (STS) launch and recovery cycle. It presents the mathematical foundations of approaches to such methods and demonstrates their feasibility in the context of NASA's and the U.S. Air Force's need to develop a sound, well-formulated logistics support strategy for the STS program.

R-3141-ARPA Radio Frequency Quadrupole and Alternating Phase Focusing Methods Used in Proton Linear Accelerator Technology in the USSR. N. Wells. 1985.

This report is part of an ongoing study of Soviet research and development of high-current, high-energy charged particle beams and their scientific and technological applications. It examines Soviet research on (1) the radio frequency quadrupole (RFQ) and (2) the alternating phase focusing (APF) methods of accelerating and focusing proton (and heavy ion) beams in linear accelerators, as reported in Soviet open-source technical publications. The author finds that Soviet work on optimizing the operating parameters in the RFQ and APF structures of the ion linear accelerator systems has kept abreast of corresponding developments in the United States.

R-3369-AF Strategic Defenses and the Transition to Assured Survival. G. A. Kent, R. J. DeValk. 1986.

This report details the anatomy and calculus of the ballistic missile portion of the transition to a robust nationwide strategic defense posture, as proposed by President Reagan on March 23, 1983. To provide insight into the policy issues surrounding the transition, the authors develop an analytic format based on ballistic missile "defense potential." The defense potential format demonstrates that, if highly survivable strategic defenses were deployed as an adjunct to current superpower ballistic missile forces, the United States could make the transition to the President's goal of assured survival from ballistic missile attack without having to pass through a period during which either the United States or the Soviet Union would have great incentive to launch a first strike against the other. However, if the defenses are vulnerable to attack and/or if both superpowers continue to deploy weapons capable of destroying hard targets but fail to adopt corresponding offensive force survivability measures, a stable transition would become less likely.

R-3412-FF/RC Strategic Defenses and First-Strike Stability. D. Wilkening, K. Watman. 1986.

The impact of strategic defenses on stability is a central theme in the Strategic Defense Initiative debate. This report examines the effects of defenses on first-strike stability. It is principally concerned with assessing first-strike stability during the transition from an offense-dominated strategic balance to a defense-dominated balance. It also examines the implications of various offensive and defensive force structures. The findings suggest that (1) first-strike instability during the defense transition can be minimized by careful force planning; (2) the most stable defense transition occurs when the ballistic missile defense transition is completed before significant levels of air defense are deployed; (3) arms control efforts will not necessarily reduce potential first-strike instabilities unless each side's counterforce capability is reduced; (4) asymmetries in each side's ability to suppress the opponent's defenses can lead to instabilities during, and after, the defense transition; and (5) biased perceptions make the defense transition either more or less stable, depending on the nature of the bias.

R-3692-RC RAND's Role in the Evolution of Balloon and Satellite Observation Systems and Related U.S. Space Technology. M. E. Davies, W. R. Harris. 1988.

This history commemorates the 40th anniversary of The RAND Corporation, 1948–1988. RAND research studies aided in development of concepts, system requirements, and development programs for space satellites operational in the 1960s. RAND research in 1946-1954 emphasized reconnaissance missions for balloons and electro-optical (TV) reconnaissance satellites with data relay. Thereafter, RAND proposed use of recoverable, film-storage satellite payloads with simple guidance systems so that reconnaissance satellites could aid in arms control verification when intercontinental ballistic missiles (ICBMs) were deployed. In the 1950s, RAND space technology studies dealt with scientific exploration of the moon and solar system, satellites for weather forecasting and for mapping, missile launch detection, and technology applications for the civil space program of the National Aeronautics and Space Administration. Innovative studies of balloon reconnaissance platforms, ICBMs, uses of panoramic cameras for remote observation of earth, and use of infrared satellites for missile launch warning resulted from researcher-initiated studies.

R-3820-AF U.S. Access to Space: Launch Vehicle Choices for 1990-2010. S. Pace. 1990.

Studies of space transportation in recent years have spanned a wide range of issues, from the pressing problems of recovering from specific failures and meeting budget limits to how the U.S. space program might develop over the next 50 years. However, there have been few studies that compare both means and ends. This report evaluates launch vehicle combinations capable of meeting a range of U.S. space traffic needs between 1990 and 2010. The evaluation aims to clarify alternatives available to the United States in pursuing potential national goals and to increase understanding of the implications of those alternatives. The study methodology involved six steps: (1) review the space transportation planning process, current issues, and political factors; (2) define alternative levels of U.S. space traffic demand for 1990–2010; (3) create various combinations of existing and proposed launch vehicles to fulfill each demand level; (4) calculate costs and uncertainties; (5) interview space transportation planners on institutional criteria for evaluating launch vehicle mixes; and (6) evaluate launch vehicle options and recommend preferred U.S. actions in space transportation planning and procurement.

R-4179-USDP Emerging National Space Launch Programs: Economics and Safeguards. B. G. Chow. 1993.

Most ballistic missile nonproliferation studies have focused on trends in the numbers and performance of missiles and the resulting security threats. This report concentrates on the economic viability and safeguard feasibility of Third World emerging space launch programs. The report finds that their costs cannot be recouped from space launch business. If the United States and other major launch providers give these programs technical assistance, the economic loss and technical difficulties will be reduced, enhancing their chances for continuing. This report also finds that it is not possible to safeguard space launch programs against technical transfers to ballistic missile development. Therefore, it concludes that if the United States and other nations wish to slow the proliferation of ballistic missiles, they should not assist these emerging launch programs. At the same time, if nations with only emerging launch programs at this time terminate their programs, they will not have missed an opportunity for lucrative profits.

NOTES

N-1260-AF A Preliminary Analysis of the Effect of Work-Arounds on Space System Performance and Procurement Requirements--a Proposal. A. G. Parish, W. Sollfrey. 1980.

This Note identifies a factor that appears to have been neglected in explaining the discrepancy between predicted and observed satellite lifetimes in orbit. This factor—extension of satellite life through ingenious "work-around" corrections—is not represented in current satellite replenishment models. The Note explores the effect of the omission on various measures of system performance, develops an analytical method of incorporating these work-arounds in replenishment models, and derives an initial estimate of the required parameters from a convenient database. Incorporating the effect of work-arounds dramatically improves system performance and lowers procurement requirements.

N-1528-AF Measuring the Impact of Launch Operations upon Satellite Effectiveness. B. E. Krell. 1980.

Procurement decisions regarding Department of Defense satellite systems are usually based upon the assumption of a reliable and dependable launch system. Attempts to relate disruptions of launch operations to numbers of satellites on-orbit are often in the form of discrete-event simulations (requiring many data inputs and large amounts of computer time). The approach which is adopted in this study is a form of continuous simulation (as opposed to discrete-event simulation), an approach which has traditionally been limited to analysis of systems in the physical sciences. The continuous simulation methodology requires significantly fewer inputs than discrete-event simulations and is amenable to implementation on a programmable, hand-held calculator,

saving expensive computer and data-gathering time. Several examples are provided which demonstrate how continuous simulation may be used to model disruptions in launch capability and various satellite operational philosophies.

N-1536-AF Transmission and Orbital Constraints in Space-Related Programs: Project Description. A. L. Hiebert, A. F. Brewer. 1980.

Future growth in commercial and military space systems is constrained by technical problems associated with the frequency spectrum, by orbital congestion, and by costs stemming from proliferated terminals. The authors outline an Air Force-sponsored research project to design and develop a capability for predicting and analyzing the spectrum/orbital geometry requirements of current and projected U.S. and international space-related systems. The two essential components of the project are a comprehensive space environment database and a computer analysis program. In combination, they will provide a resource for evaluating engineering and architectural designs, identifying and analyzing the impact of intentional and unintentional electromagnetic interference, and predicting probable saturation conditions in spectrum usage and satellite/orbital positions. The project will include assessments of ways to accommodate anticipated growth. It will be structured for a continuing analysis program, which will be accessible to the space community as operational capabilities are acquired.

N-1617-JPL/NASA Coordinates of Features on the Galilean Satellites. M. E. Davies, F. Y. Katayama. 1980.

Control nets of the four Galilean satellites have been established photogrammetrically from pictures taken by the two Voyager spacecraft during their flybys of Jupiter in 1979. Coordinates of 504 points on Io, 112 points on Europa, 1,547 points on Ganymede, and 439 points on Callisto are listed. Selected points are identified on USGS maps of the satellites. Measurements of these points were made on 234 pictures of Io, 115 pictures of Europa, 282 pictures of Ganymede, and 200 pictures of Callisto. The systems of longitude were defined by craters on Europa, Ganymede, and Callisto. Preliminary solutions have been found for the directions of the axes of rotation of the Galilean satellites. New mean radii have been determined as 1,815 plus or minus 5 km for Io, 1,569 plus or minus 10 km for Europa, 2,631 plus or minus 10 km for Ganymede, and 2,400 plus or minus 10 km for Callisto.

N-1761-1-AF Shuttle Fleet Operations: A Simulation Analysis. D. Leinweber. 1984.

This Note documents a two-part analysis of the reliability of the Space Transportation System (STS). The first part is a statistical examination of the inherent bounds on reliability prediction based on accumulated mission experience as the shuttle program evolves. The results of this analysis suggest that it will take a long history of successes to firmly establish a high shuttle reliability, and that, therefore, some contingency provisions should be retained during the early part of the program at least. The second phase of the analysis is aimed at gaining some insight into operational consequences of less than perfect reliability. This analysis suggests that the risks from the uncertainties surrounding loss or retirement of orbiters, stand-down periods, and delays in refurbishment and turnaround can be reduced by supplementing the four-orbiter STS fleet with alternative launch systems and/or additional orbiters to minimize potential loss of access to space.

N-2093-SDIO The Geometry of a Satellite-Ballistic Missile Engagement. M. D. Miller. 1988.

This Note describes in mathematical terms the dynamic geometry between a constellation of satellites deployed for ballistic missile defense (BMD) and the missiles the satellites are engaging. Formulas, readily translatable into computer code, are given for such engagement parameters as slant range, closing velocity, and line-of-sight incidence angle in terms of satellite and missile position and velocity data. These formulas are the foundation of a model developed at Rand to support study of the BMD capability of various satellite armament concepts.

N-2315-NASA Potential Applications of Expert Systems and Operations Research to Space Station Logistics Functions. T. Lippiatt, D. A. Waterman. 1985.

This Note is the final report of an assessment study to determine the applicability of operations research, artificial intelligence, and expert systems to logistics problems for the space station, which must support multiple systems using only on-board resources. It recommends that the Space Station Program develop an integrated logistics decision support system to be used by all management levels during the design, development, and operational phases, and that three major logistics modeling capabilities be developed for a decision-support system: The first would provide on-orbit availability for each individual system; the second would compute the mix of on-orbit spares for each system; and the third would compute an optimum spares mix for each logistics module resupply mission. No existing models were found to be appropriate, but are probably within reach of current state-of-the-art operations research. The most promising area for expert systems in the space program is the area of fault detection and diagnosis. The authors recommend two applications within this area: troubleshooting RMS, the remote manipulator system for the shuttle, and developing an intelligent system for ground system communication

equipment in a way that will encourage a fault-tolerant design.

N-2432-FF/RC A Suggested Policy Framework for Strategic Defenses. G. A. Kent. 1986.

This study proposes a framework for considering U.S. policy with regard to the Strategic Defense Initiative (SDI). The framework takes account of the basic goals and strategies for the security of the United States and its allies, the reasons for the SDI technology program, the purposes and missions of strategic (or nationwide) defenses, and the relationship of these matters to arms control. It establishes national survival—a fundamental goal of the United States and its allies—as the central goal of strategic defenses. The framework relieves the tension between the advocacy of SDI on the one hand, and the basic U.S. strategy of deterrence and arms control on the other.

N-2478-AF Possible Soviet Responses to the Strategic Defense Initiative: A Functionally Organized Taxonomy. K. N. Lewis. 1986.

In the wake of the Strategic Defense Initiative (SDI), much effort has been devoted to estimating potential Soviet responses to it. There is general agreement that the Soviet response will (1) consist of attempts to stop, circumvent, emulate, and neutralize the SDI; (2) include political, military, and strategic efforts; and (3) vary over time, depending on several factors. Setting aside Soviet technological options, this Note considers various factors that might interest or influence senior Soviet decisionmakers as they consider a range of programmatic, strategic, and political options for responding to the SDI. Its goal is to identify generic categories of Soviet response options rather than the specific forms those options may take.

N-2482-AF The Soviet Union and the Strategic Defense Initiative: Preliminary Findings and Impressions. B. S. Lambeth. 1986.

This Note provides a background against which to evaluate possible Soviet alternatives for dealing with the Strategic Defense Initiative (SDI) in the decade ahead. Without speculating about what the Soviets will ultimately do in response to SDI, the Note (1) examines Moscow's statements on SDI to date, (2) reviews the highlights of Soviet doctrine and programs related to strategic defense, (3) considers the real concerns that may underlie the Kremlin's public posturing on SDI, and (4) outlines the key political and strategic factors that will constrain the Soviets' eventual response. The author suggests that, assuming SDI does lead to a deployable U.S. ballistic missile defense, the Soviets will be driven to counter that threat within the limits of their economic and technical resources. Forecasting the technical details of their response at this time, however, is complicated by uncertainty not only about Soviet concerns, motivations, and intentions, but also about what the United States will eventually do with SDI.

N-2551-AF New Weather Sensing and Forecasting Capabilities for Ground-to-Space Operations. C. Schutz, F. W. Murray. 1987.

Certain weather variables exercise an important control over space operations, either by making a launch infeasible or by adversely affecting the space vehicle and its trajectory. Climatological studies and standard National Weather Service observations show that the normal range of variability due to location and season, even from day to day, precludes the forecasting of these variables sufficiently accurately for precise trajectory control. Several new systems are now becoming available for measuring wind and density (or providing the variables from which density can be computed) continuously and automatically: VAS, PROFILER, WINDSAT, and the next generation of weather satellites. Together, these systems offer the promise of continuous real-time monitoring of winds and air density throughout the part of the atmosphere that exercises the greatest influence on space operations.

N-2664-NASA A Unified Lunar Control Network--the near Side. M. E. Davies, T. R. Colvin, D. Meyer. 1987.

The most important sources of information useful for positioning features on the surface of the Moon have been telescopic pictures; Lunar Orbiter pictures; Apollo 15, 16, and 17 mapping camera frames; and the Soviet Zond 6 and 8 pictures. This Note describes the combining of the Apollo mapping frames, telescopic pictures, and Mariner 10 pictures into a unified control network of the near side of the Moon with its origin at the center of mass. New coordinates of 1,156 points in the network are given, as are ten points from a Mariner 10 solution in the north polar region. The Lunar Orbiter and Zond 6 and 8 pictures must eventually be tied to the Apollo and telescopic networks to obtain a far-side control network in the same coordinate system.

N-2806-RC Whither SDI? Strategic Defenses in the Next Administration. A. Kanter. 1988.

This Note is a revised version of a paper prepared in spring 1988 for a Council on Foreign Relations study group on the "Arms Control Agenda of the Next Administration." Concentrating on the Strategic Defense Initiative (SDI), this Note describes the programmatic, budgetary, arms control, and political contours of the strategic defense agenda that the new president is likely to

confront. It considers the choices the next administration will face on strategic defenses from the perspective of both what it ought to do and what it is likely to do in light of the Reagan legacy it will inherit and the political forces that will operate on it.

N-2934-NASA Phoebe, a Preliminary Control Network and Rotational Elements. T. R. Colvin, M. E. Davies, P. G. Rogers. 1989.

This Note presents a preliminary control network and rotational elements for the Saturnian satellite Phoebe. The preliminary control network has been determined based upon six distinct albedo features mapped on sixteen Voyager 2 images.

N-2961-AF National Oceanic and Atmospheric Administration: Civil Assets for Department of Defense Use. J. J. Milanese, K. M. Poehlmann. 1990.

This Note describes the civil satellite and ground station assets owned by the National Oceanic and Atmospheric Administration (NOAA) and documents the existing relationship between NOAA and the Department of Defense (DoD) as a basis for DoD use of these assets during times of declared national emergency. NOAA is legally required to coordinate its programs with the DoD and provide peacetime assistance in planning for DoD's wartime duties. The authors discuss deficiencies in this relationship and make recommendations for improvements.

N-3103-A Apogee, Perigee, and Recovery: Chronology of Army Exploitation of Space. E. J. Mitchell. 1991.

Since the mid-1980s, a debate has gone on within the Department of Defense (DOD) on whether it is appropriate for the Army to be increasingly involved in space and, if so, how the Army should exploit space. This Note (1) describes the evolution of the Army's exploitation of space in response to an emerging post-World War II Soviet threat while complying with national policy and organizational directives; (2) informs the current Army, DOD, students, and others of the full spectrum of the Army's past and current exploitation of space; and (3) provides a chronology of policy decisions and events, from 1907 through mid-1989, which have shaped the Army's exploitation in the technological areas of ballistic missiles, satellites, early-warning radars, ground stations, anti-satellite defenses, anti-ballistic missile defenses, theater missile defenses, and tactical missiles.

N-3221-JPL Radargrammetric Algorithms and Software for Use with Data from Magellan. T. R. Colvin. 1990.

The Magellan spacecraft is using its synthetic-aperture radar to map the entire surface of Venus. The resolution of these radar images is significantly better than that obtained by the Venera and Pioneer spacecraft. Magellan will orbit Venus every 3.26 hours during its nominal mapping mission of 243 days; there is enough reserve fuel for a lengthy extended mission. This Note describes algorithms and software the author developed to solve for control points, orbital parameters, the position of the north pole, and the rotation rate of Venus using Magellan radar images and their processing parameters. Ultimately, the results will aid in the mosaicking of individual radar strips into a unified cartographic product.

N-3250-AF Attitude Orientation Control for a Spinning Satellite. G. Frost. 1991.

The Department of the Air Force, Headquarters Space Systems Division, and the National Aeronautics and Space Administration (NASA) are currently involved in litigation with Hughes Aircraft Company over the alleged infringement of the "Williams patent," which describes a method for attitude control of a spin-stabilized vehicle. This Note summarizes pre-1960 RAND work on this subject and presents information obtained from RAND personnel who are knowledgeable in this area. The Note also reviews the TIROS II magnetic torque attitude control method.

N-3280-AF/NASA Space and Surface Power for the Space Exploration Initiative: Results from Project Outreach. C. Shipbaugh, K. A. Solomon, D. R. Gonzales, M. L. Juncosa, T. W. Bauer, R. M. Salter. 1992.

This Note describes the findings of the Space and Surface Power panel, one of eight project panels evaluating submissions to the Space Exploration Initiative (SEI) Outreach Program, or Project Outreach. The submissions screened by the Space and Surface Power panel proposed systems that can be classified into at least one of five technical areas: (1) power generation (solar power, nuclear power, fuel cells, batteries, and "other"), (2) power transmission, (3) energy storage, (4) thermal management, and (5) handling. The panel screened 167 submissions and selected the 22 highest-ranked ones for further analysis. The submissions that appeared to offer the best overall potential dealt with nuclear power sources, power beaming, the development of in-situ resources (including the use of solar dynamic power), and thermal management. Some lower-ranked submissions also contained interesting and potentially useful system concepts, and the authors evaluated some concepts not suggested in the submissions, including rechargeable high-energy density batteries, high-speed flywheels, and superconducting storage rings. A number of space and surface power issues became apparent and were examined by the panel members: (1) environmental implications of

SEI power systems, (2) use of in-situ materials, (3) nuclear vs. nonnuclear power, (4) start-up vs. evolutionary power needs, (5) manned vs. unmanned system requirements, and (6) development of new power transmission methods.

N-3283-AF/NASA Space Transportation Systems, Launch Systems, and Propulsion for the Space Exploration Initiative: Results from Project Outreach. T. B. Garber, J. R. Hiland, D. T. Orletsky, B. W. Augenstein, M. D. Miller. 1991.

This Note analyzes a number of transportation and propulsion options for Mars exploration missions. For space transportation options, the operational figures of merit that are of interest are (1) initial mass in low Earth orbit (IMLEO) and (2) transit times to and from the destination planet. It is desirable for both these parameters to have low values. Of the space transportation options examined, two approaches are most interesting: split missions, which use cargo spacecraft that follow low-energy trajectories to pre-position in Mars orbit the mass needed for Mars exploration and Earth return; and the use of in-situ propellants, which offer the potential for large reductions in IMLEO. To reduce IMLEO and trip time substantially, nuclear systems should be considered; a range of such systems is described. Almost all of the space transportation options evaluated would benefit from orbital transfer systems that can economically transfer large masses from low Earth orbit to high Earth orbits and Lunar space. In addition, all of these options would benefit from the development of propellant sources either on the Moon, on Martian systems, or both.

N-3284-AF/NASA Automation and Robotics for the Space Exploration Initiative: Results from Project Outreach. D. R. Gonzales, D. R. Criswell, E. Heer. 1991.

This Note describes the results of RAND's management of the direct solicitation component of the Space Exploration Initiative (SEI) Outreach Program, a program designed to solicit creative ideas from academia, research institutions, private enterprise, and the general public to help in defining promising technical areas and program paths for more detailed study. Eight panels were created to screen and analyze the submissions: space and surface power; space transportation systems, launch systems, and propulsion; automation and robotics; human support; structures, materials, mechanical systems, and in-situ processing; communications; information systems; and architectures and missions. Among the authors' recommendations are the following: (1) SEI robots, work environments, and systems should be systemically integrated; (2) structured-task robots should be developed for SEI; (3) NASA should adapt and develop advanced teleoperator robot control interfaces that enable telepresence; and (4) tradeoff studies must be done to select optimum mobility and navigational subsystems for SEI surface exploration robots.

N-3287-AF/NASA Human Support Issues and Systems for the Space Exploration Initiative: Results from Project Outreach. J. Aroesty, R. Zimmerman, J. Logan. 1991.

This Note describes the findings of the Human Support panel, one of eight project panels evaluating submissions to the Space Exploration Initiative (SEI) Outreach Program, or Project Outreach. Fundamental questions of crew adaptability, tolerance, performance, and survival must be confronted squarely and systematically to assure SEI feasibility, continued support, and eventual success. Human support issues should be incorporated by life scientists early in formulating preliminary requirements and guidelines, planning missions, and designing spacecraft. The authors performed issue-oriented analyses to evaluate Project Outreach submissions in a context of some critical problems: (1) radiation protection for Mars missions requires further research in active shielding techniques; (2) space-based microgravity research is needed to improve the quantitative assessment of long-term effects and possible countermeasures; (3) life-support systems for long-term missions and planetary settlement will require bioregenerative technologies incorporating both ecological and biotechnological approaches; (4) medical care and health maintenance may best be handled by a team approach; (5) human factors need emphasis, since human behavior under prolonged stress, isolation, and confinement could compromise mission success; and (6) EVA (extra-vehicular activity) suits are essential to productive work in space or on the Lunar or Martian surfaces.

N-3330-JPL Photogrammetric Algorithms and Software for Spacecraft Optical Imaging Systems. T. R. Colvin. 1992.

This Note describes photogrammetric algorithms and software that can be used with data obtained from spacecraft optical imaging systems. The algorithms and software solve for control point coordinates, camera orientation angles, the position of a target body's north pole, and the target body's rotation rate. This work can be used to generate control point networks and ancillary data for target bodies, which can then be used to mosaic individual photographs into unified cartographic products. The mathematics of the photogrammetric least-squares procedure is described in detail. It is presented in such a manner that readers wishing to make modifications are accommodated. Two FORTRAN programs are presented. The appropriate input and output files for these programs are discussed, and the programs themselves contain extensive comments. This Note is intended as a brief reference. The intended audience consists of planetary

scientists familiar with the data and possessing an intimate knowledge of FORTRAN.

N-3425-JPL A Control Network of Triton. M. E. Davies, P. G. Rogers, T. R. Colvin. 1991.

A control network for Triton has been computed using a bundle-type analytical triangulation program. The network contains 105 points that were measured on 57 Voyager 2 pictures. The adjustment contained 1,010 observation equations and 382 normal equations and resulted in a standard measurement error of 13.36 micrometers. The authors determined coordinates of the control points, the camera orientation angles at the times when the pictures were taken, and Triton's mean radius. A separate statistical analysis confirmed Triton's radius to be 1352.6, plus or minus 2.4 km. Attempts to tie the control network around the satellite were unsuccessful because discontinuities exist in high-resolution coverage between 66 degrees and 289 degrees longitude, north of 38 degrees latitude, and south of 78 degrees latitude.

N-3437-JPL The Preliminary Geodetic Control Network of Venus. M. E. Davies, P. G. Rogers. 1991.

This Note was written in preparation for the Magellan mission to Venus and presents the coordinate system adopted for the project. Control points have been identified on Venera 15, 16 pictures and 1983 Arecibo pictures, and their coordinates given in the Magellan coordinate system. Transformation matrices are presented. The control points are identified as craters, hills, or central peaks in craters.

N-3464-AF Aerospace-Plane Flights and Stratospheric Ozone: Review and Preliminary Assessment of the National Aerospace Plane (NASP) Operations. S. Liu. 1992.

The United States is engaged in a National Aerospace Plane program to develop an air-breathing single-stage-to-orbit vehicle, the X-30. This note provides estimates of stratospheric changes in water vapor and nitrogen oxide content in order to assess the effect on stratospheric ozone from an operational fleet of such vehicles. Assuming a fleet of 20, each making 10 flights a year, Liu finds that the effect on stratospheric ozone would be much smaller than other anthropogenic effects.

N-3535-A Recommended Strategy for the Army's Role in Space. E. D. Harris, K. P. Horn, E. Cesar, P. Steinberg. 1993.

This Note lays out a recommended strategy for the Army's role in space, drawing on research the Arroyo Center has performed in this area over the past seven years. The document argues that the Army should make supporting the battlefield commander its primary role in space, supplementing the argument with a discussion of how the Army used space to support the battlefield commander during Operations Desert Shield and Desert Storm. It then argues that implementing this role requires modifying the Army's organization so that it emphasizes space, which involves institutionalizing space in the Army's warfighting doctrine, establishing a high-ranking authority, and correcting the requirements and acquisition process. The document then proposes that the Army pursue a two-part investment strategy that involves exploiting existing space systems and participating in satellite requirement studies. Finally, it argues that the Army needs to modify its operational procedures for space to deal with such issues as training and information distribution.

N-3589-AF/A/OSD U.S. Space-Based Remote Sensing: Challenges and Prospects. D. J. Johnson, M. Nelson, R. J. Lempert. 1993.

This Note presents a survey of remote sensing policy issues for the 1990s. The study concludes that as the utility of remote sensing data is more widely understood and appreciated, greater efforts to exploit that data in unique ways will increase, thus blurring the distinctions among users in the federal agencies, state and local governments, and private entities. It will then be up to the owners and operators of remote sensing systems to justify why their particular systems should remain unique. The study recommends that the U.S. government develop remote sensing policies from a more comprehensive perspective, derived from U.S. remote sensing goals, user needs, and the diverse organizations that can participate in meeting those needs; determine where broadening needs or new technologies allow planned programs to be better coordinated or consolidated to avoid duplication of effort; determine what areas are best pursued as public endeavors and as commercial or private ones; and make remote sensing systems more responsive to user needs.

ISSUE PAPER

IP-139 Linking Space Exploration Programs to National Goals. E. D. Harris, J. M. Sollinger. 1994.

Space programs extend over long periods of time and require considerable financial investment. Thus the programs to be funded must be designed and evaluated for a probability of success. This issue paper describes a methodology for determining which programs have the best chance of success. The authors illustrate the approach using the Moon/Mars exploration program for which it was developed. The steps include defining national policy goals (e.g., enhancing national security, increasing scientific knowledge, and strengthening the economy),

identifying paths the program might take (e.g., early establishment of a Mars outpost, use of current technology only, involvement of the private sector to establish a lunar base), and evaluating how well the paths accomplish the goals.

REPRINTS

RP-243 Operational Issues for GPS-Aided Precision Missiles. G. Frost, B. P. Schweitzer. 1996.

This paper discusses the operational issues associated with combining the NAVSTAR Global Positioning System (GPS) with a low cost Inertial Navigation System (INS) as the primary means to obtain precision accuracy for air-to-ground missiles. The authors' goal is to achieve precision accuracy without the use of a terminal imaging sensor in the missile. Motivation for removing the homing sensor is to significantly reduce the cost of the entire guided missile system. The overall effectiveness of a GPS-aided air launched missile is a strong function of the method and accuracy in determining target coordinates. Methods for determining target coordinates in a relative GPS frame are presented which allow for removal of GPS related system bias errors. Missile accuracy also depends on the missile platform-target geometry and missile flight trajectory. Short range standoff trajectories can stress the time required for the missile's GPS receiver to acquire and track the satellite signals. In addition, the jamming vulnerability of the GPS receiver in an operational environment is of major concern. The paper presents a review of the major jamming parameters such as the defense's effective radiated jamming power, potential GPS anti-jam enhancements, and jamming range to break GPS signal track. Originally published in *1993 National Technical Meeting Conference Proceedings*, January 21, 1993.

RP-463 GPS-Guided Cruise Missiles and Weapons of Mass Destruction. I. Lachow. 1995.

Originally published in "Director's Series on Proliferation," Kathleen C. Bailey, ed., Lawrence Livermore National Laboratory, UCRL-LR-114070–8, June 1995.

RP-474-1 GPS-Aided Guidance for Ballistic Missile Applications: An Assessment. G. Frost, I. Lachow. 1996.

The proliferation of Third World ballistic missiles is a major concern for the U.S. government. These missiles can carry weapons of mass destruction, can reach targets quickly, and are difficult to intercept. To date, this concern has been somewhat mitigated because these missiles are relatively inaccurate. But the potential for improving the accuracy of these missiles by using the Global Positioning System makes them a greater threat. This paper evaluates the effectiveness of U.S. control policies as they pertain to ballistic missiles, focusing on those with ranges of 300–1000 km. It quantifies the errors that affect missile accuracy and assesses the improvement that could occur by using GPS-aided inertial guidance. The paper concludes that GPS-aiding can improve the accuracy of short- and medium-range missiles by approximately 20-25 percent and that Selective Availability has almost no effect on accuracy. Originally published in *50 Years of Navigation Progress from Art to Utility, Proceedings of the 51st Annual Meeting of the Institute of Navigation,* June 5-7 1995.

RP-543 Satellite Navigation-Aiding for Ballistic and Cruise Missiles. G. Frost, I. Lachow. 1996.

The proliferation of ballistic and cruise missiles to Third World countries is becoming a major concern for both the United States and the Russian Federation. These classes of missiles can carry weapons of mass destruction and are difficult to intercept. To date, this concern has been somewhat mitigated because these missiles are relatively inaccurate. But the potential of improving the accuracy of these missiles by using the Global Positioning System (GPS) or the Global Navigation Satellite System (GLONASS) makes them a greater threat. This paper evaluates the error sources that affect missile accuracy and assesses the improvement that could occur by using satellite navigation-aiding of the missile's inertial guidance system. The authors' analysis focuses on the U.S. GPS system; however, the findings would be similar if GLONASS were used. The paper concludes that satellite navigation-aiding can improve the accuracy of current short- and medium-range ballistic missiles by approximately 20–25 percent, and up to 70 percent for advanced ballistic missiles. It can also greatly improve the accuracy of cruise missiles with ranges greater than 50 km. In addition, the U.S. policy of Selective Availability has a marginal effect on controlling missile accuracy in most of the cases the authors examined. Originally published in *5th International Conference on Differential Satellite Navigation Systems,* St. Petersburg, Russia, May 20-24, 1996.

RP-630 Roles and Impacts of RAND in the Pre-Apollo Space Program of the United States. B. W. Augenstein. 1997.

RAND, in Santa Monica, California, performed a seminal function in the early years of the U.S. Space Program, not only in landmark science, technology, and operational/programmatic studies which helped to shape U.S. endeavors in space, but also by the diffusion of key study participants into industry and government, where

they helped reach many of the initial goals set. The salient RAND work now declassified is described here from the viewpoint of a deeply involved participant. Where possible, this work is discussed in the context of Former Soviet Union activities. Originally published in International Astronautical Federation, *46th International Astronautical Congress,* October 2–6, 1995, Oslo, Norway.

RP-718 The Synergy of Air and Space. B. S. Lambeth. 1998.

Until the Gulf War of 1991, Air Force aviators and space professionals worked in almost separate worlds, creating a divide between air and space components of the Air Force. The Gulf War became the crucible for a synergistic potential between air and space, between airmen and space professionals. In unexpected ways, space demonstrated what it could bring to the new face of air warfare in Operation Desert Storm. The exploitation of space by CENTCOM brought about a new awareness of space to the post-Gulf War era, permitting both air and space participants to "see beyond the horizon" and develop a joint space doctrine that could allow a rational allocation of resources for greater force integration. A space "roadmap" with clear concepts of operation that drive requirements (not a technology driver) will help ensure that this integration occurs. Originally published in *Airpower Journal,* v. XII, no. 2, AFRP 10–1, Summer 1998.

RP-740 Global Positioning System: Market Projections and Trends in the Newest Global Information Utility. S. Pace, J. E. Wilson. 1998.

The Global Positioning System (GPS) is a space-based signal providing precise timing, location, and velocity information. Just as any number of receivers can tune into a commercial TV or radio station, there is no limit on the number of people who can use GPS. With equipment ranging from small, hand-held receivers to large, rack-mounted electronics, anyone, anywhere, at any time can use the GPS signal. Initially, GPS applications were used for national defense; these remain in place today. The GPS signal has also become important commercially, from electric power distribution to land survey, car navigation, and management of telecommunications networks. In sponsoring this study, the U.S. Department of Commerce's Office of Telecommunications provides a current view of the commercial status and trends of the industry since its availability for civilian use in 1984, projects its development over the coming years, and identifies factors that will affect the growth of commercial GPS markets. Originally published in project report prepared for the International Trade Administration, Office of Telecommunications, U.S. Department of Commerce.

RP-787 Merchants and Guardians: Balancing U.S. Interests in Space Commerce. S. Pace. 1999.

Current challenges for space policy are examined in this study, particularly those derived from the growth of space commerce and resulting conflicts between public and private sector interests. After a review of old and new visions of space development, a model for policy conflict is introduced using the terms "Merchants" and "Guardians" to describe the differing objectives of public and private sector interests. Conflicts over dual-use technologies, such as space launch, remote sensing, satellite navigation, and communications are described, along with special implications for military space policy. The study concludes that various international organizations, such as the ITU and the WTO, will be of greater importance to space policy than in the past. While maintaining their separate roles, industry and government will have greater need to collaborate in shaping the international environment for space policy in order to achieve their economic and security objectives. Originally published in *Balancing National Interests in Space Development,* International Space Policy Forum, George Washington University's Elliott School of International Affairs.

RP-1076 Totem and Taboo: Depolarizing the Space Weaponization Debate. K. P. Mueller. 2003.

The debate over space weaponization is typically cast in simplistic, unidimensional terms, while many participants caricature their opponents as naive pacifists or rabid warmongers. This article redraws the subject more realistically. First, it surveys the question of what systems are truly space weapons and what developments would constitute weaponization. Second, it describes six distinct schools of thought regarding weaponization: idealist, internationalist and nationalist sanctuary theories, and preemptive, utilitarian and hegemonist pro-weaponization perspectives. Third, it analyzes and largely debunks the leading arguments which hold that space weaponization is inevitable. Finally, it suggests reforms to make the debate more sensible and productive. Originally published in *Astropolitics,* v. 1, no. 1, Summer 2003.

CONFERENCE PROCEEDINGS

CF-177-FIAS Toward Fusion of Air and Space: Surveying Developments and Assessing Choices for Small and Middle Powers. D. J. Johnson, A. Levite. 2003.

Accelerated technological change and the growing availability and proliferation of advanced commercial technologies and systems affect today's international

security environment and rethinking of military doctrine. What, for instance, is the wider application of these technologies and systems to operational exercises, and how does one address interoperability among coalition partners with differing technological capabilities? These developments assume special significance in the domain of space, and many nations are presently deciding how to proceed in their space activity. They must assess whether to acquire independent aerospace capabilities, whether to depend on other nations for aerospace support, whether potential costs and vulnerabilities are incurred for those relationships, and whether they are willing politically to accept both the benefits and the risks of dependence. A comprehensive understanding of what commercial and technological developments are occurring in the utilization of space as well as what is involved in integrating commercial and civil aerospace systems and technologies into military operations and organizations is required. RAND and the Fisher Institute for Air and Space Strategic Studies, in collaboration with the Israeli Air Force and the Israel Space Agency, held an international conference March 19–21, 2001, in Tel Aviv, focusing on the space activities and choices faced by small and medium powers. The papers presented should be of broad interest to government, military, and industry readers who follow international air and space issues and trends affecting global and national security.

TESTIMONY

CT-139 Promoting Commercial Space Activity. S. Pace. 1996.

PAPERS

P-6713 Transmission and Orbital Constraints in Space-Related Programs: Briefing Summary. A. L. Hiebert. 1981.

This paper is an addendum to RAND Note N-1536, *Transmission and Orbital Constraints in Space-Related Programs: Project Description* Essential components of the project include development of a comprehensive space environment database and analysis codes and computer programs. The paper describes how these databases and codes and computer programs will be organized and function. This capability will provide a resource for evaluating engineering and architectural designs, identifying and analyzing the impact of intentional and unintentional electromagnetic interference, and predicting probable saturation conditions in spectrum usage of space and earth segments, and satellite/orbital positions. Assessments of ways of accommodating anticipated growth are included in the program.

P-6725 Prospective Research and Development Areas for U.S. Cruise and Ballistic Missile Guidance Updating Systems. E. H. Conrow. 1982.

U.S. strategic missile forces require high guidance accuracies and reliability for mission effectiveness. A key component in achieving high accuracies is guidance updating. Guidance updating systems based on map-matching techniques are particularly useful in removing uncertainties or maneuvering errors in midcourse and terminal guidance. Map-matching systems compare a real-time sensor image with the prestored reference scene in the missile's computer to determine the along- and cross-track vehicle position error at the update location. This paper discusses potential areas of R&D funding that could improve the effectiveness of map-matching guidance updating systems, and estimates their potential payoff, technical risk, and required funding level. The R&D areas addressed are missile sensors, missile processing algorithms, scene modeling and simulation, system integration, fix quality evaluation, application of space assets, and advanced applications. Potential payoffs include increased vehicle survivability, operational coverage, update reliability, and force effectiveness.

P-6745 Crew Roles in Military Space Operations. D. Leinweber. 1982.

Discusses possible roles for military crews in space including research, maintenance of spacecraft, and direct participation in the operation of space systems. New vehicles, platforms, and tools proposed for manned operations in space (both military and civilian) are described. Evaluation criteria for these missiles are based on costs and advantages of new capabilities. We need to explore the possibilities, to experiment, and to acquire a sound knowledge base on which to make informed judgments on the future role of men in space.

P-6758 Space: A Sanctuary, the High Ground, or a Military Mission? J. E. Justin. 1982.

This paper discusses military strategy for space and how this strategy should be reflected in our decisions concerning the Soviet threat, the role of the military in space, the shuttle, military space programs, arms control negotiations for space, and military space organizations. Three general schools of thought are examined: space as a demilitarized sanctuary, space as the "high ground" for terrestrial force enhancement, and space as a unique military mission. The paper recommends that we should be wary of one-sided arguments. The United States needs a mixed fleet of launchers, a balanced military space

program, a goal of negotiating a realistic arms reduction agreement for space, and a major change in our military space organizations. Space should be viewed as a major military consideration requiring a major national commitment.

P-6814 Evolution of the U.S. Military Space Program, 1945-1960: Some Key Events in Study, Planning, and Program Development. B. W. Augenstein. 1982.

Discusses a number of aspects of the U.S. Space Program during the period 1945–1960. The seminal influence of early RAND work is highlighted, as is the way in which RAND research significantly set the stage for the undertaking of formal space programs in the United States in the mid-1950s. The rapid growth of these initial programs is then traced to 1960. The paper is written largely from the point of view of the writer's own involvement in many of the projects discussed.

P-6961 Interference Problems for Nongeostationary Satellites. W. Sollfrey. 1984.

The interference problems faced by nongeostationary satellites may be of major significance. A general discussion indicates the scope of the problems and describes several configurations of importance. Computer programs are described, which are employed by NASA/JPL and the U.S. Air Force Satellite Control Facility to provide interference-free scheduling of commands and data transmission. Satellite system mission planners are not concerned with the precise prediction of interference episodes, but rather with the expected total amount of interference, the mean and maximum duration of events, and the mean spacing between episodes. The procedures in the theory of probability developed by the author which permit calculation of such quantities are described and applied to several real cases. It may be anticipated that the problems will become steadily worse in the future as more and more data transmissions attempt to occupy the same frequency band.

P-6966 Overview, Techniques for the Analysis of Spectral and Orbital Congestion in Space Systems. A. L. Hiebert, W. Sollfrey. 1984.

Future growth in commercial and military space systems is constrained by technical problems associated with the frequency spectrum, by orbital congestion, and by costs stemming from proliferated terminals. The authors outline an Air Force-sponsored research project to design and develop a capability for predicting and analyzing the spectrum/orbital geometry requirements of current projected U.S. and international space-related systems. Two essential components of the project are a comprehensive space environment database and a computer analysis program. In combination, they will provide a resource for evaluating engineering and architectural designs, identifying and analyzing the impact of intentional and unintentional electromagnetic interference, and predicting probable saturation conditions in spectrum usage and satellite/orbital positions. The projected capabilities could provide an essential national resource for management decisionmaking and architectural planning on space-related programs. The U.S. Air Force Space Division is establishing a continuing project to utilize these capabilities.

P-7151 Remarks to the National Commission on Space. M. E. Davies. 1985.

This paper was originally presented at a Public Forum at the University of California, Los Angeles, on September 13, 1985. In it, the author suggests the time has come for the United States to announce that it intends to establish a permanent, self-sustaining colony on Mars. He outlines some of the technical difficulties to be considered, and then points out the following as some of the advantages of such a plan: (1) the engineering, planning, and designs for this program would support many near-term or parallel objectives, such as the space station, a lunar base, and space colonies; (2) there would be many opportunities for shared development with other countries, especially the Soviet Union; and (3) it will change man's view of himself and the world in which he lives.

P-7154 In Defense of Star Wars Research. R. A. Scheder. 1985.

This paper describes how, in the author's view, the central question in Strategic Defense Initiative (SDI) research has changed from "Is space-based defense feasible?" to "Can we counter an enemy's space-based defense?" The author explains how recent rapid advances in technology have made space-based defense a real possibility and points out that the Soviet Union is conducting extensive research into space-based defense. He concludes that if the United States does not pursue SDI research, it could become vulnerable to a Soviet space-based defense.

P-7274 Reference Coordinate Systems of the Moon and Planets. M. E. Davies. 1986.

This paper was originally presented in September 1986 at the Prague, Czechoslovakia, international symposium on Figure and Dynamics of the Earth, Moon, and Planets, and it will be published in a book containing papers from the meeting. The symposium was sponsored by the International Association of Geodesy (IAG), the Committee for Space Research (COSPAR), and the International Astronomical Union (IAU). The IAU/IAG/COSPAR Working Group on Cartographic Coordinates and Rotational Elements of the Planets and Satellites, which was established in 1976, publishes a

report every three years. This paper discusses the adopted definitions, conventions, and content of the 1985 report, and includes a brief note about those who use the data.

P-7288-RGS National Aerospace Plane Program: Principal Assumptions, Findings, and Policy Options. S. Pace. 1986.

This paper outlines key issues raised by the National AeroSpace Plane Program (NASP) and suggests policy options to be examined further. The need for routine space access and U.S. aeronautical leadership makes NASP a national priority. The costs and uncertainties of NASP, however, necessitate reducing its risks. The author raises the following points: (1) the rate of technical progress, cost projections, and potential applications of NASP technology are uncertain; (2) NASP development costs and possible increases may force tradeoffs with other research and development in subsonic aircraft and launch vehicle technology; and (3) the 1988–1989 fiscal year budget will require decisions on major funding increases for flying "technology demonstrators." The author suggests some policy options to be examined: (1) maintain NASP research efforts, but deemphasize operational applications; (2) hedge NASP research by expanding efforts in other space and aeronautical transport programs; and (3) increase National Aeronautics and Space Administration responsibility for NASP work and ease classification restrictions.

P-7323-RGS Spinoffs: Applying Historical Examples to the Present. K. W. Webb. 1986.

To begin to understand how to assess the spinoff potential of the Strategic Defense Initiative, this paper examines other research and development (R&D) programs, investigating both new products and new processes. Programs examined include Apollo and other National Aeronautics and Space Administration (NASA) programs, government demonstration projects, CERN, the Manhattan Project, and military R&D. The research results indicate that (1) industries that are closely involved in both government and commercial efforts seem more likely to transfer scientific research; (2) NASA has encouraged commercial spinoffs, but other benefits include management techniques and quality control procedures; (3) an important spinoff is the training of scientists and engineers; and (4) demonstration projects may lead to spinoffs even if the primary system is not adopted.

P-7350 The Star Wars Dilemma: A Speech Presented in the Newman Forum Lecture Series at the University of Minnesota, 12 November 1986. G. L. Donohue. 1987.

This paper is the text of a speech that was presented as part of the University of Minnesota's Newman Forum Lecture Series, which promotes the discussion of the moral and philosophical aspects of current social issues in the context of Catholic theology. The author discusses St. Augustine's Just War theory. He then reviews post-World War II history, and specifically the ways nuclear weapons and the theory of nuclear weapon employment have influenced both the military conflicts and the political thought of the United States, the Soviet Union, and Europe. Finally, against this background, he considers the Strategic Defense Initiative and the dilemmas surrounding it.

P-7351-RGS The Geostationary Platform 1976-1986: Evolution of an Advanced Space System Concept. S. Pace. 1987.

The geostationary platform is an instructive case study of the forces affecting the design and construction of space systems: Ten years after being proposed, the geostationary platform has not been built. This paper reviews the history of the geostationary platform, including the initial proposal, NASA and commercial studies of the concept, and competing concepts. It concludes with a review of the current status of the geoplatform program.

P-7396 The Army's Role in Space: Support for the Battlefield Commander. E. D. Harris, R. E. Darilek, K. P. Horn, M. Nelsen. 1988.

The potential role of the Army in space has long been the subject of extensive debate. Critics contend that the Army is ill-equipped to assume such a role, maintaining instead that the development of military space applications should be subordinated to other technological pursuits. The findings of an ongoing Arroyo Center research project, however, argue to the contrary. This assessment of over 100 potential space applications, which forms the basis of the present analysis, has uncovered an array of military functions that could be greatly enhanced by the application of space-based systems.

P-7404 An Agenda for the Strategic Defense Initiative: Presentation to a Colloquium of the American Association for the Advancement of Science, May 14, 1987. G. A. Kent. 1988.

This paper suggests that the United States has two broad choices regarding the Strategic Defense Initiative (SDI): to continue its relationship with the Soviet Union in an offense-dominant world, or to cooperate with the Soviets on a transition to a defense-dominant world where each side deploys ballistic missile defenses and ballistic missiles are reduced to near zero. If the United States is serious about making such a transition, it must do so according to a well-defined agenda, rather than piecemeal. The author recommends that, for the short term, the United States should adhere to the 1972 ABM Treaty, explore a cooperative transition with the Soviets, continue to debate

the pros and cons of such a shift, and proceed with the SDI technology program.

P-7635 Trends in Space Control Capabilities and Ballistic Missile Threats: Implications for ASAT Arms Control. D. J. Johnson. 1990.

Several emerging trends in global affairs will have an impact on U.S. military space policy and the acquisition of space control capabilities. These trends include the uncertainty of NATO's future and the role of U.S. forces in Europe, the growing potential for U.S. involvement in Third World conflicts, and ballistic missile proliferation among nations ostensibly developing space launch capabilities. This paper examines U.S. national space policy and military space policy, focusing on the space control debate. It considers the status of space control-related capabilities, such as the antisatellite (ASAT) and national aerospace plane (NASP) programs. The author discusses the "operationalization" of space control; examines the growing sophistication of the European Space Agency, and Japanese and other space programs; and evaluates three near-term ASAT "regimes." Finally, the author presents a range of policy choices for the United States.

P-7768 Power Systems for Space Exploration. C. Shipbaugh, K. A. Solomon. 1992.

Concepts submitted to Project Outreach for Space Exploration and Extended Habitation serve to highlight a number of important research areas, and in particular, the importance of broad-based support for research into power and propulsion technologies. Nuclear energy sources emerge as very strong candidates for both space and surface power systems. Recent interest includes NERVA-like nuclear thermal rockets, the SP-100 reactor, and Topaz II and nuclear rocket technology from the former Soviet Union. Power beaming also has long-term potential for enormous utility.

P-7849 Space Launch Policies and Systems: A Presentation to SPACECAST 2020. D. J. Johnson. 1993.

This paper presents an overview of the status of U.S. space launch policies and initiatives dealing with the U.S. space transportation infrastructure and with enhancing economic competitiveness of the U.S. commercial launch industry. It also identifies a number of emerging issues and challenges for the U.S. space community in the future. The United States finds itself facing a number of challenges in the space launch arena that are affecting U.S. space activities both in the short and long terms. These challenges have been shaped by the Challenger loss in 1986 and the demise of the Soviet Union. In addition, U.S. economic competitiveness is challenged by the activities of our European, Russian, and Chinese commercial space competitors. The Bush Administration laid the policy foundation for addressing space transportation problems by enacting a number of policies to improve the space transportation infrastructure and improve commercial competitiveness. In addition, a number of national commissions and advisory groups from 1986 on have all pointed to the critical need to address the fragility of the space launch infrastructure, arguing that a robust space transportation system is key to undertaking any future long-term space programs. This paper argues that it is not the absence of a policy framework nor a lack of technology options that lies at the heart of the problem, but rather, the absence of a broadly accepted, performance-based process that allows for a choice among technology options, and the absence of a mechanism to break the current political-budgetary impasse concerning space launch.

P-7858 The National Aerospace Plane: Cost Considerations for the Follow-on Vehicle. E. D. Harris. 1994.

The United States and other countries have been pursuing the development of hypersonic technologies and experimental vehicles to demonstrate technical feasibility of aircraft-like operations for future space launch vehicles. Ultimately, the usefulness of these vehicles will depend as much on their economics as on their operational utility. If they are relatively cheap, they will find a number of roles and missions, but if they are expensive, they will have a hard time finding a niche. This paper examines one of the critical cost aspects of a U.S. National Aerospace Plane (NASP) derived vehicle (NDV) program—the acquisition cost of a fleet of single-stage-to-orbit (SSTO) vehicles. The paper places the vehicle acquisition costs within the context of future U.S. space launch demand. It deals with the uncertainty of the cost-estimative relationships for NASP-type experimental technologies required to perform a SSTO space launch mission—high performance materials, multimode propulsion systems, and sophisticated avionics. A sensitivity analysis is used to portray the impact of launch costs (dollars per pound in orbit) of a number of operational considerations, notably, total number of flights per vehicle, launch demand, fleet size, research, development, testing, and evaluation (RDT&E) cost, uncertainty in cost estimating relationships (CER), and investment cost. The NDV launch costs are compared with current U.S. launch costs that are based on the use of expendable launch vehicles and the shuttle. This analysis concludes that it is highly unlikely that U.S. space launch costs will decrease dramatically by the development of a single-stage-to-orbit, fully reusable NASP-derived vehicle. This conclusion was reached without considering operating and service costs, which would only increase the launch costs even more.

P-8041-1 An Executive Guide to Space: A Starting Point for Understanding Space in the New Millennium. S. Carey. 2000.

This paper is a starting point for those not schooled in space, space terminology, and space issues. It provides a brief history of space technology, explains orbit fundamentals, and gives an overview of commands, agencies, and national organizations. It then takes up U.S. policy toward space and the commercialization of space systems. Finally, it highlights some of the more relevant military questions: Does the United States need a separate service for space? Has the space arms race already begun, and what space weapons should be employed? Is the country vulnerable to space attacks and ready to fight in space? The author concludes that space control is probably the single greatest military space issue facing the country in the next several decades.

DOCUMENTED BRIEFINGS

DB-135-A Assessing the Future Role and Conduct of the Army Space Exploitation Demonstration Program (ASEDP). J. R. Hiland, G. Huth, S. J. Pond. 1996.

The Army Space Exploitation Demonstration Program (ASEDP) has been conducted for the past seven years as an important part of the Army's overall efforts to effectively utilize and integrate space assets and capabilities into its operations and other activities. This annotated briefing presents the results of an effort to review the current process used to select candidate space demonstrations, as well as the emerging interfaces with other new internal Army program initiatives that will shape the future context for this program. Improvements to the current selection process are suggested, and alternative future program directions are assessed. The document also presents some viewpoints, gleaned from a series of interviews with 16 key Army people, on the ASEDP and Army space efforts in general.

DB-176-CIRA Emerging Markets of the Information Age: A Case Study in Remote Sensing Data and Technology. C. B. Gabbard, K. O'Connell, G. S. Park, P. J. E. Stan. 1996.

High-resolution imagery data and technology are among the products that may have a dramatic effect on international, foreign policy, commercial, and security issues in the information age. U.S. firms, under a 1994 Presidential Decision Directive, are allowed to compete for a growing international marketplace in remote sensing products, in which they hold a distinct technological lead due to decades of investment by the U.S. government. This CIRA documented briefing presents an in-progress report for research on the marketplace dynamics, including government-industry relations, the strategies of U.S. firms and other entities entering this arena, and international perspectives on and activities in the market. This DB also includes a brief tutorial on remote sensing, including the dual-use nature of remote sensing data and technology.

DRAFTS

DRU-1219-RC Problems of Radio Frequency Allocation. R. H. Coase, W. H. Meckling, J. R. Minasian. 1995.

DRU-1494-OSTP Federal Investments in Small Spacecraft: An Interim Report. L. Sarsfield. 1996.

WORKING PAPER

WR-105-OSTP National Space Transportation Policy: Issues for the Future. T. Hogan, V. Villhard. 2003.

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