1998

USING SLBMs FOR LAUNCHING SMALL SATELLITES

I.M. Ross, Associate Professor
C. Balwin, Visiting Assistant Professor
Space Systems Academic Group
Sponsor: Naval Space Command

OBJECTIVE: Space support to the warfighter may be enhanced significantly by providing a launch on demand capability to support the growing and dynamic C4ISR requirements. The purpose of this proposal is to study how SLBMs may be used to launch small communication satellites in Earth orbit. The proposal includes a conceptual design of a small communication satellite that can be launched using the Trident missile.

SUMMARY: A five-member team of three faculty member (Profs. Baldwin, Ross and Fahroo) and two student s(CDR Gleason and LT Molinari) was formed to solve the problem. The problem is divided into two major sub-problems: launch trajectory optimization to put the maximum payload in LEO, and orbital analysis (payload types, constellation requirements, mass constraints etc.). A computer code for the launch trajectory optimization ws written in MATLAB. It is based on discretizing a generic launch profile and optimizing the discrete points for the Triden data. We modeled the trident I (C4) data as a proof-of-concept.

The orbital analysis has progressed to the point of identifying potential orbits, payload ideas and lifetime requirements. Our students are trying out these ideas by means of the standard simulation package called the Satellite Tool Kit (STK). The launch and orbit analysis will be patched together at the end of this quarter. Preliminary small satellite design is underway and will be completed next quarter. The end of this analysis will help us identify the orbit and constellation requirements to achieve certain DoD objectives.

CURRICULUM DESIGN FOR CSMAD

I.M. Ross, Associate Professor
Department of Aeronautics and Astronautics
Sponsor: NASA-JPL

OBJECTIVE: The Jet Propulsion Laboratory (JPL) is in the process of setting up a center for Space Mission Architecture and design (CSMAD). One of the missions of CSMAD is the education and training of selected engineers. The primary focus of this education is to broaden the knowledge of technical experts in fields other than their own so that they can become "mission architects." The purpose of this proposal is to help JPL develop a curriculum that will accomplish their objectives.

SUMMARY: To accomplish the broad objectives, we identified the following questions: 1) What are the academic and professional credentials of the technical experts at JPL who are interested in becoming mission architects? 2) What are the necessary Educational Skill Requirements (ESRs) that must be met in order that JPL will declare someone is a Space Mission

Architect, and 3) What are the time-constraints (i.e. duration of the curriculum)? The first question was answered by preparing a questionnaire for distribution at JPL. Essentially, the objective of this survey was to identify potential students' experiences (in space projects) that may already contribute towards the goals of a mission architect. This data was used in the curriculum design. The second question was answered by defining the ESRs. These ESRs were obtained by iteration with a number of JPL technical staff through CSMAD. The final question is still being answered in an ongoing project. JPL has been provided with a tentative description of the curriculum (i.e., a matrix) and the ongoing project will flesh it out.

NEAR-EARTH-OBJECT INTERCEPTION

I.M. Ross, Associate Professor
Department of Aeronautics and Astronautics
Sponsor: JHU

OBJECTIVE: This proposal is for the purpose of analyzing certain problems associated with near-Earth-object interception. These problems need to be addressed today so that the United States and the world, at large, will be prepared to handle them when they occur tomorrow.

SUMMARY: We now have a computer code that can determine the minimum delta-V necessary to deflect an Earth-crossing asteroid (ECA). Given a warning time, we can now determine the location, the direction and the magnitude of the minimum impulse necessary to safety deflect an ECA. The results of the code yield some surprising results. The minimum point is the perihelion, but the direction is not parallel to the velocity vector as reported by other investigators. Also, when we include the gravitational effects of Earth, the delta-V is significantly higher for nearer ECAs than those that are further away. It thus appears that we may need to expend more energy to deflect an ECA than previously thought. All of these results are reported in the two papers described in the deliverables section below.

1997

LAUNCH PERIOD ANALYSIS FOR PLUTO EXPRESS

I.M. Ross, Associate Professor
Department of Aeronautics and Astronautics
Sponsor: JPL

OBJECTIVE: This was a small exploratory research project whose objective was to perform a detailed analysis of the Jupiter Gravity Assist (JGA) trajectories for the Pluto Express spacecraft, now renamed the Pluto-Kuiper Express.

SUMMARY: The Jet Propulsion Laboratory (JPL) is designing a space mission that will conduct, for the first time, a reconnaissance of the Pluto/Charon system to determine their composition, atmosphere and geological characteristics among other things. The spacecraft will also be sent to the Kuiper Belt that is at the edge of the solar system. Using the JPL software MIDAS and CATO, an analysis was performed for two nominal launch period opportunities that occur in November 2003 and December 2004. Most of the analysis was performed by Michelle Reyes as part of her thesis required for the MS degree in Astronautical Engineering. Her results allow JPL to make the final decision for the most feasible arrangement for launch. Initially, the JGA was supposed to have been a "back-up" plan for the trajectory design. As of this writing, JPL is seriously considering the JGA as the baseline trajectory. Due to the success of this project, JPL has an ongoing partnership with NPS on the Advanced Mars Mission Project.

APPLICATION OF PERIOD OPTIMAL CONTROL TO SPACE MANEUVERS

I.M. Ross, Associate Professor
Department of Aeronautics and Astronautics
Sponsor: NPS

OBJECTIVE: The objective of this proposal was to develop a non-linear, fuel-optimal guidance algorithm by analyzing the necessary conditions of optimality for periodic stationkeeping of low-Earth-orbiting satellites. This was a collaborative proposal with Prof. Fahroo of the Mathematics Department.

SUMMARY: In the course of investigating the external solutions to the problem, a new type of orbital transfer was discovered. Collaborative work with Prof. Fahroo has resulted in advancing an algorithm to solve the optimization problem. The algorithm is based on a new spectral collocation method. The results show that the often-used Hohmann transfer is not the optimal maneuver for orbit maintenance. Further analysis performed by LT Karl Jensen has shown that we will be able to devise station keeping maneuvers that are fuel-optimal. These results could potentially change the orbit maintenance operations of future low-Earth-orbiting satellites. We intend to use these results to sell the research to potential RR sponsors such as NASA and NRO.

1996

ADSI AND MSTS SYSTEMS ANALYSIS

I.M. Ross, Assistant Professor of Aeronautics and Astronautics

Sponsor: Air Force Space Command

OBJECTIVE: This three-year project was aimed at analyzing the Air Defense System Integrator (ADSI) and the Multi-Source Tactical System (MSTS) in support of the warfighter.

SUMMARY: This year covers the final stage of a three-year contract. As in any multi-year contract, most of the work was performed in the prior years. The FY94 and FY95 Research Summaries outline these efforts. In compliance with the wishes of the sponsor, the tasks for FY96, were re-defined to investigate topics in space warfare, vis-à-vis their relationship to student participation by way of projects and theses. As a result, a space warfare research program home page was established in a cooperative effort with AFIT. The URL is given by http://dubhe.cc.nps.navy.mil/~swrp. This is also hot-lined to corresponding home pages at AFIT: http://www.afit.af.mil/Schools/EN/ENY/people/chall/course/seng63/project . A significant part of the effort was also directed towards the logistic problems pertaining to establishing a joint space warfare research program (with AFIT).

NEAR-EARTH-OBJECT INTERCEPTION

I.M. Ross, Assistant Professor of Aeronautics and Astronautics

Sponsor: APL/John Hopkins University & cost-shared by NPS

OBJECTIVE: This proposal is for the purpose of analyzing certain space warfighting problems associated with the threat from near-Earth-objects.

SUMMARY: This is a multi-year ongoing project. A comprehensive analysis was performed on the dynamics and control of deflecting near-Earth objects (i.e. those asteroids and comets that intersect the orbit of Earth). This analysis is contained in the Hall-Ross report that was delivered to SWC in March 96. Two new student these are currently being directed by the PI. An extensive numerical optimization of impulsive maneuvers has been performed leading to the conclusion that there may be alternative minimum-energy missions that might accomplish the task of planetary defense. This has lead to a more well-defined roadmap for the outyears. Plans are underway to investigate how this effort may complement the Clementine-II mission.

AEROBRAKING

I.M. Ross, Assistant Professor of Aeronautics and Astronautics

Sponsor: Falcon AFB

OBJECTIVE: This proposal is for the purpose of analyzing aerobraking maneuvers associated with the design of future spacecraft. These maneuvers will be analyzed for their tactical utility to the military, and the driving design parameters will be determined.

SUMMARY: A synergetic maneuver has the potential to enhance the tactical utility of military space. The maneuver requires a winged spacecraft. In CY96, new necessary conditions were obtained for the optimal synergetic maneuver. In addition, work on the singular thrust program shows that for flight occurring at orbital conditions, the optimal angle of attack is not at the maximum lift-to-drag ratio, but given by a transcendental equation, tan $a = \partial C_D / \partial C_L$. Numerical work performed elsewhere validates this conclusion to the extent that higher angles of attack yield larger synergetic efficiency.

1995

OPTIMAL PERIODIC CONTROL FOR LOW-EARTH-ORBIT MAINTENANCE

I.M. Ross, Assistant Professor of aeronautics and Astronautics
Sponsor: Naval Postgraduate School

OBJECTIVE: This proposal was aimed at analyzing fuel-optimal periodic maneuvers necessary to keep a large low-Earth-orbiting satellite within a prescribed altitude band. In particular, the utilization of optimal control theory to analyze the fuel-efficiency of a "forced Keplerian trajectory (FKT)"

SUMMARY: Extremal singular arcs for a low-Earth-orbiting spacecraft were derived and the results were used to formulate the fundamental problem of orbit maintenance. It was shown that nonoptimal steering induces singular control and this lead to the discovery of steering induced singular arcs. The fuel-efficiency of orbit raising by periodic Hohmann transfer was of the same order-of magnitude as that an FKT thus demonstrating at least two possibilities: (i) the propellant consumed by an FKT is close to the optimal if a periodic Hohmann maneuver is also close to the optimal, or (ii) since the propellant consumed by a Hohmann-type maneuver is close to the non-optimal FKT, the periodic optimal maneuver is quite different from the Hohmann maneuver possibly consisting of singular subarcs.

ADSI AND MSTS SYSTEMS ANALYSIS

I.M. Ross, Assistant Professor of Aeronautics and Astronautics
Sponsor: Air Force Space Command

OBJECTIVE: This three-year project was aimed at analyzing the Air Defense System Integrator (ADSI) and the Multi Source Tactical System (MSTS) in support of the warfighter.

SUMMARY: The project began in FY94, much of the work performed was in understanding these new systems, including travel tot he Air Force Space Command (AFSC). In FY95, the direction of the project was altered by the sponsor. Attention was focused on investigating advanced concepts that affect the future design on spacecraft. In addition, preliminary work was performed on simulating orbital perturbations on Earth-crossing asteroids.

NEAR-EARTH-OBJECT INTERCEPTION

I.M. Ross, Assistant Professor of Aeronautics and Astronautics
Sponsor: John Hopkins

OBJECTIVE: This proposal is for the purpose of analyzing certain space warfighting problems associated with the threat from near-Earth-objects.

SUMMARY: All of the work done in FY95 was in obtaining this grant. The research part of this proposal will be carried out in CY96 and beyond.

AEROBRAKING

I.M. Ross, Assistant Professor of Aeronautics and Astronautics

Sponsor: Falcon AFB

OBJECTIVE: This proposal is for the purpose of analyzed with the design of future spacecraft. These maneuvers will be analyzed for their tactical utility to the military, and the driving design parameters will be determined.

SUMMARY: All of the work done in FY95 was in obtaining this grant. The research part of this proposal will be carried out in CY96 and beyond.

1994

ENDOATMOSPHERIC SPACE TRAJECTORY ANALYSIS AND OPTIMIZATION

I.M. ROSS, Assistant Professor of Aeronautics and Astronautics
Sponsor: Naval Psotgraduate School (RIP Program-2)

OBJECTIVE: This two-year project was underwritten at investigating three problems: (1) optimality of singular trajectories (2) development of a new synergetic orbital plane-change maneuver and (3) analysis of uncontrolled satellite re-entry and impact prediction mdoels.

SUMMARY: A state feedback solution to first-order singular arcs for a low-Earth-orbiting spacecraft was derived and the results were used to develop the problem of orbit maintenance. The results were also used to perform a preliminary investigation on nonlinear control; this analysis was used for writing an NSF Career Proposal. An analysis of uncontrolled satellite re-entry and impact prediction models was well received at the Air Force Space Command (AFSPACECOM) to the point that a 3-Year $1000K reimbursable research contract was initiated in FY94. A second contract is also being negotiated currently. Nearly half of the RIP labor funds were returned to the department as a result of securing reimbursable funding through the PANSAT project. Finally, an analysis of the synergetic maneuver has conclusively shown that the aerobang maneuver, designed by the PI, performs superior to the widely studied aerocruise maneuver. This maneuver holds the potential for significant fuel savings for a future transatmospheric vehicle.

1993

ENDOATMOSPHERIC SPACE TRAJECTORY ANAYSIS AND OPTIMIZATION

I.M. Ross, Assistant Professor of Aeronautics and Astronautics

Sponsor: Naval Postgraduate School (RIP Program)

OBJECTIVE: This project was (and continues to be) aimed at investigating three problems: (1) optimality of singular trajectories (2) development of a new synergetic orbital plane-change maneuver and (3) analysis of uncontrolled satellite re-entry and impact prediction models.

SUMMARY: First-order singular arcs for a low-Earth-orbiting spacecraft were derived and expressed in state variable feeedback form. A forced Keplerian trajectory was shown to be non-optimal in the Mayer sense and hence orbit maintenance fuel-budgeting was questioned. This lead to an energy-management guidance algorithm whose details are currently being worked out. In addition, the "aerobang maneuver" was further developed to the point of showing its superiority over the more traditional aerocruise maneuver. The fuel-optimality of the total synergetic maneuver is still under investigation. Finally, a thesis directed on a comprehensive literature review of uncontrolled satellite re-entry and impact prediction models was well received at the Air Force Space Command at Falcon (AFSPACECOM) and a "steering committee" is being formed to pursue a joint research venture whose details will be outlined in the coming weeks.

1992

TRANSONIC FAN DESIGN VALIDATION

R.P. Shreeve, Professor of Aeronautics and Astronautics
N.L. Sanger, NASA Lewis Research Center
Sponsor: Naval Air Warfare Center, Aircraft Division (Trenton)

OBJECTIVE: To replace the single-stage transonic fan currently installed in a test rig at the Turbopropulsion Laboratory with a prototype design recently completed by NASA, and to evaluate all aspects of the aerodynamic performance by the application of advanced intrusive and non-intrusive diagnostics. The project goals are to provide code vs. measurement comparisons to validate current design and analysis codes, to develop practical unsteady measurement diagnostics for use in advanced fan development testing, and to complete a design test and evaluation case study for instructional purposes.

SUMMARY: The aerodynamic design of a single stage compressor for the NPS test rig was completed and will be reported this year. The mechanical design is also completed and procurement is planned in 1994. The low aspect ratio (1.2) stage has a diameter of 11 inches and tip relative Mach number of 1.3. However, because of unusually high blade loading, the overall stage pressure ratio is projected to