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Low Thrust Propulsion Literature Survey

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TECHNICAL REPORT

The RICIS Concept

The University of Houston-Clear Lake established the Research Institute for Computing and Information Systems (RICIS) in 1986 to encourage the NASA Johnson Space Center (JSC) and local industry to actively support research in the computing and information sciences. As part of this endeavor, UHCL proposed a partnership with JSC to jointly define and manage an integrated program of research in advanced data processing technology needed for JSC's main missions, including administrative, engineering and science responsibilities. JSC agreed and entered into a continuing cooperative agreement with UHCL beginning in May 1986, to jointly plan and execute such research through RICIS. Additionally, under Cooperative Agreement NCC 9-16, computing and educational facilities are shared by the two institutions to conduct the research.

The UHCL/RICIS mission is to conduct, coordinate, and disseminate research and professional level education in computing and information systems to serve the needs of the government, industry, community and academia. RICIS combines resources of UHCL and its gateway affiliates to research and develop materials, prototypes and publications on topics of mutual interest to its sponsors and researchers. Within UHCL, the mission is being implemented through interdisciplinary involvement of faculty and students from each of the four schools: Business and Public Administration, Education, Human Sciences and Humanities, and Natural and Applied Sciences. RICIS also collaborates with industry in a companion program. This program is focused on serving the research and advanced development needs of industry.

Moreover, UHCL established relationships with other universities and research organizations, having common research interests, to provide additional sources of expertise to conduct needed research. For example, UHCL has entered into a special partnership with Texas A&M University to help oversee RICIS research and education programs, while other research organizations are involved via the "gateway" concept.

A major role of RICIS then is to find the best match of sponsors, researchers and research objectives to advance knowledge in the computing and information sciences. RICIS, working jointly with its sponsors, advises on research needs, recommends principals for conducting the research, provides technical and administrative support to coordinate the research and integrates technical results into the goals of UHCL, NASA/JSC and industry.

Low Thrust Propulsion Literature Survey

Preface

This research was conducted under auspices of the Research Institute for Computing and Information Systems by Inference Corporation. Dr. Charles McKay served as RICIS research coordinator.

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LOW THRUST PROPULSION LITERATURE SURVEY

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INTRODUCTION

Since the advent of space exploration in the late 1950's, research into different ways to reach our celestial neighbors has taken place. One particular area of research which has received a great deal of effort is the area of low thrust propulsion. Through the 1960's and early 1970's, much serious attention was focused on this area, and this interest has again revived in recent years. The purpose of this study has been to find out what literature is available. What follows is the result of this effort.

LITERATURE SURVEY

A literature survey was performed using NASA-RECON. From this, a great body of literature was revealed. After the search was performed, an effort was made to obtain as many of the referenced as possible. Approximately 100 papers were obtained in hard copy or microfiche. These articles were then examined and categorized according to their particular areas of analysis. A list of all articles found in the literature survey appears in two tables in Appendix A. Table 1 contains those articles of which hard copies were obtained and Table 2 contains those for which only abstracts were obtained. Abstracts for papers in Table 2 are found in Appendix B.

CATEGORIZATION

All articles which were obtained in hard copy were examined to determine more precisely what they were about, because many times the abstracts were not a very good picture of what the paper was really about, or of the detail of the analysis.

Table 3 of Appendix A contains the results of this catagorization. Several broad areas were determined, which break down into smaller categories. The first of these is what mission does the paper examine. This is further broken down into interplanetary, or more precisely, inter-solar system, and inter-orbit. For the solar system mission, there are those to the eight other planets, to the moon, to comets, and to the asteroids. The first 14 columns of Table 3 contain these missions. Some papers did not examine a particular mission, but rather looked at the more general problem of interplanetary transfers from object a to object b, and this in indicated by the column general interplanetary in the table. The second mission area is what could be called inter-orbit. These missions are basically orbit transfers between orbits influenced mainly by a single primary. These missions include LEO-GEO transfers, missions to the libration points, plane change, rendezvous, pursuit, and again a category of general inter-orbit transfers and maneuvers. These are indicated in columns 15 through 22 of Table 1.

The next area of categorization is the coordinate system model, which contains two divisions, two dimensional and three dimensional. Some articles specifically stated that a 2-d or 3-d model was used, and these are indicated as such. Some did not state. In general, most which did not state were fairly broad analysis and 3-d is accounted for.

The third area is optimization. Since space exploration is expensive, obtaining minimum fuel and/or minimum time trajectories is important. Columns 27 through 29 indicate if a paper optimizes, and if so, if it is optimized in time, energy, or mass. Cases where time is optimized and a constant thrust is used are also optimized in mass, since mass flow rate is constant, so minimum fuel corresponds to minimum time. Column 30 indicates if suboptimal rather than optimal control is used. This means that a paper is using parameter optimization to obtain an approximate optimal control. Column 31 gives the method of optimization if such is supplied. Most use the standard calculus of variations, but some use variants of this or other methods.

The next area relates to the guidance, navigation, and control of the vehicle. Columns 32 through 36 tell about the thrust or acceleration history of the vehicle. Some papers used constant thrust or acceleration levels while others used variable thrust or acceleration. Some utilized coast or ballistic arc segments, i.e. times of no thrusting. In terms of navigation, this is important, for it allows processing by the spacecraft of sensor data to estimate its true state and thus make appropriate guidance corrections. Column 37 indicates if gravity assists were used or examined. Gravity assists can be used quite effectively to lower mass requirements of the vehicle. Column 38, though not specifically about guidance, navigation, or control, indicates if hybrid propulsion systems were examined, i.e. if some combination of high and low thrust was used. Column 39 indicates if the paper examined the low thrust spiral in or out phase of flight around a primary. Column 42 verbally notes the method of guidance, navigation and control used if such was supplied in the paper. Backtracking, columns 40 and 41 give some indication as to how the analysis was performed. Some papers specifically indicated that an approximate analytical model was obtained and used. These have the advantage of being typically closed form solutions, but the disadvantage of being approximations and thus inherently containing errors. Column 41 indicates if a numeric method was specifically indicated as being used in the paper. Most articles, if neither is indicated, fall under the numerical subdivision. However, for some, it is unknown, because the article is not very detailed or only gives results.

Column 43 contains other comments, such as if perturbations were examined, or anything important about the paper but not reflected in the other columns. The last column is somewhat subjective. It is a rating as to the potential value of the article in future analysis. A scale of 1 to 4 was used, with 1 indicating an excellent paper, with much detail and substantial theoretical basis included, and 4 indicating a reference which might have some good information but which does not contain a detailed account of the theory or equation used in the analysis.

ASSESSMENT

Quite a lot of good research has been done in the area of low thrust propulsion. In particular, the 1960's provides a substantial increase in the understanding of low thrust trajectories. However, with the advances in computational capability, much of the analysis of these earlier years should be reexamined. One particular area which needs more attention is the development of practical guidance schemes. Though many papers examine optimal low thrust trajectories, the development of efficient and practical guidance schemes which will be easy to implement is sometimes not addressed. Advances in control theory would allow for better schemes. Another area which needs more attention is lunar trajectories. Though some work has been done, and currently is being done by Dave Korsmeyer at The University of Texas, a greater effort should be placed here, since after Space Station Freedom is realized, a lunar base is our next stop. Low thrust propulsion with its high specific impulse will be ideal for transportation from LEO to lunar orbit.

CONCLUSION

The results of this literature survey indicate that a wealth of information on low thrust propulsion exists. In an effort to evaluate this technology, a number of articles have been collected and categorized. The study indicates that although much has been done, particularly in the 1960's and 1970's, that more can be done, especially in the area of practical navigation and guidance utilizing new techniques. The older studies should be reinvestigated to see what potential there exists for future low thrust applications.

APPENDIX A

TABLE 1: REFERENCES FOR WHICH HARD COPIES WERE OBTAINED

Adams, C., Blissit, J., Jarrett, D., Sanner, R., and Yanagawa, K., Design Study for Asteroidal Exploitation, MIT, August 15, 1985.

Anderson, G.M., and Grazier, V.W., "Barrier in Pursuit-Evasion Problems between Two Low-Thrust Orbital Spacecraft", AIAA Journal, Vol. 14, No. 2, February, 1976, pp. 158-163.

Anthony, Maurice L., Orbit Adjust Maneuvers Using Very Small Tangential Thrust, IAF Paper #87-342, 38th IAF Congress, October 10-17, 1987.

Bahls, Daryl L, and Paris, Stephen W., A Mission Analysis Tool for Complex Low Thrust Interplanetary Missions, AIAA Paper #80-1674, AIAA/AAS Astrodynamics Conference, Aug. 11-13, 1980.

Bahls, Daryl L., and Paris, Stephen W., A Simplified Method for Obtaining Near Minimum Time Low Thrust Transfers, AAS Paper #79-166.

Bartholomew-Biggs, M.C., and Dixon, L.C.W., Preliminary Study of the Use of Laplace and Momentum Vectors in the Determination of Interplanetary Low Thrust Trajectories, July, 1985.

Bartholomew-Biggs, M.C., Dixon, L.C.W., Hersom, S.E., and Maany Z.A., "From High Thrust to Low Thrust: Application of Advanced Optimization Methods to Mission Analysis", ESA Journal, Vol. 11, No. 1, 1987, pp. 61-73.

Battin, R.H., and Miller, J.S., Trajectories and Guidance Theory for a Continuous Low Thrust Lunar Reconnaissance Vehicle, Sixth Symposium on Ballistic Missile and Aerospace Technology, 1961.

Bauer, Thomas P., Wood, Lincoln J., and Caughey, Thomas K., 'Gain Indexing Schemes for Low-Thrust Perturbation Guidance', Journal of Guidance and Control, Vol. 6, No. 6, November-December 1983, pp. 518-525.

Bauer, Thomas P., Wood, Lincoln J., and Caughey, Thomas K., Low-Thrust Perturbation Guidance, AIAA Paper #82-1430, AIAA/AAS Astrodynamics Conference August 9-11, 1982.

Belbruno, E.A., Lunar Capture Orbits, a Method of Constructing Earth Moon Trajectories and the Lunar Gas Mission, AIAA Paper #87-1054, 19th AIAA/DGLR/JSASS International Electric Propulsion Conference, May 11-13, 1987.

Breakwell, J.V., and Rauch, H.E., "Three-Dimensional Guidance for Low Thrust Escape From a Planet", XIXth International Astronautical Congress Proceedings: Vol. 2, Astrodynamics and Astrionics, New York, 1968, Astrodynamics, pp. 151-161.

Brock, Harvey T., and Johnson, Roger W., "Low-Thrust, Constant-Acceleration Trajectories for Solar Probe Missions", Journal of Spacecraft and Rockets, Vol. 6, No. 12, pp. 1462-1465, December, 1969.

Brown, William C., An All Electronic Transportation System from LEO to GEO and Beyond, Paper #LBS-88-122, Lunar Bases and Space Activities in the 21st Century, April 5-7, 1988.

Burrows, Roger R., and Wood, Gordon A., "Optimal Continuous Low-Thrust Trajectories for Co-Altitude Rendezvous", AIAA Journal, Vol. 7, No. 5, May, 1969, pp. 983-985.

Dazzo, Edward J., and Nagorski, Russell, P., Trajectory Analysis for Solar Electric Propulsion Stage (SEPS) Planetary Missions, AIAA Paper #73-1058, AIAA 10th Electric Propulsion Conference, October 31-November 2, 1973.

Dixon, L.C.W., et al., Low Thrust Orbit Optimization for Interplanetary Missions, Volume 1, December, 1983.

Eckstein, M., and Hechler, F., Station Acquisition and Station Keeping with Low-Thrust Systems, ESA Paper #SP-160, Proceedings of the International Symposium on Spacecraft Flight Dynamics, May 18-22, 1981.

Edelbaum, Theodore N., Sackett, Lester L., and Malchow, Harvey L., Optimal Low Thrust Geocentric Transfer, AIAA Paper #73-1074, AIAA 10th Electric Propulsion Conference, Oct. 31-Nov. 2, 1973.

Efimov, G.B., and Okhotsimskii, D.E., "On Optimum Acceleration in a Central Field", XVIth International Astronautical Congress Proceedings: Astrodynamics, Athens, 1965, Astrodynamics, pp. 209-227.

Flandro, G.A., "Solar Electric Low-Thrust Missions to Jupiter with Swingby Continuation to the Outer Planets", Journal of Spacecraft and Rockets, Vol. 5, No. 9, September, 1968, pp. 1029-1033.

Flury, W., Finite Thrust Transfers, 35th IAF Congress, October 8-13, 1984.

Free, Bernard A., "Satellite Raising to Synchronous Orbit: An Evaluation of the Hydrogen Resistance Jet and the Mercury Bombardment Ion Thruster", Journal of the British Interplanetary Society, Vol. 23, 1970, pp. 669-690.

Friedlander, Alan L., Analysis of an Optimal Celestial-Inertial Navigatinon Concept for Low-Thrust Interplanetary Vehicles, IIT Research Institute, NAS Contract #2-2401, August, 1965.

Friedlander, Alan L., Analytical Solution of Low-Thrust Trajectories by Time Series Approximation of Acceleration Functions, IIT Research Institute, Technical Memorandum T-24, September, 1970.

General Motors, "Performance Assessment of Low Thrust Space Guidance Systems: Version II", Interplanetary Guidance System Requirements Study, Vol. II, Computer Program Descriptions, Part 11, February, 1967.

General Motors-Castro, R.P., "Low Thrust Trajectory Design Using a Neighboring Optimum Iteration Process", Interplanetary Guidance System Requirements Study, Vol. II, Computer Program Descriptions, Part 9, January, 1967.

General Motors-Huckins, E.S., "Performance Assessment for Aided-Inertial Low Thrust Guidance Systems", Interplanetary Guidance System Requirements Study, Vol. II, Computer Program Descriptions, Part 10, January, 1967.

Glazkov, A.I., "Optimization of Flight with Low-Thrust Engine to Orbit of Artificial Satellite of Jupiter", USSR Report: Engineering and Equipment, March, 1987, pp. 16-19.

Gottlieb, Robert G., Universal Coast Equations and Their Application to Trajectory Optimization, Dynamics Research Corporation, AAR-1, 27 July, 1967.

Gurman, V.I., Popov, Yu. B., and Salmin, V.V., "Possibility of Achieving Trajectories with Low-Thrust Spacecraft, Accounting for Their Motion Around a Center of Mass", Cosmic Research, Vol. 8, 1971, pp. 628-635.

Hahn, D.W., Johnson, F.T., and Itzen, B.F., "Interplanetary Low-Thrust Mission Design Via Chebychev Optimization Methods", Proceedings of the 8th International

Symposium on Space Technology and Science, 1969, pp. 341-348.

Handelsman, Morris, "Optimal Free-Space Fixed-Thrust Trajectories Using Impulsive Trajectories as Starting Iteratives", AIAA Journal, Vol. 4, No. 6, June, 1966, pp. 1077-1082.

Hart, Jack D., and Fowler, Wallace T., "Further Results on Recurrent Lagrange Multipliers for the Low-Thrust Earth-Jupiter Transfer", AIAA Journal, Vol. 8, No. 11, November, 1970, pp. 2060-2062.

Hersom, S.E., and Maany, Z.A., Low Thrust Orbit Optimisation for Interplanetary Mission, Volume 2, ESA Paper #ESA-4774/81/D-JS(SC), December 1983.

Hersom, S.E., Maany, Z., Patel, K.D., and Dixon, L.C.W., Start Solution for Interplanetary Low Thrust Trajectory Optimisation and Model Refinement, Volume 1, Report #ESA-CR(P)-2175-Vol-1 ETN-86-97490, February, 1985.

Hersom, S.E., Maany, Z., and Patel, K.D., Start Solution for Interplanetary Low Thrust Trajectory Optimisation and Model Refinement, Volume 2, Report #ESA-CR(P)-2175-Vol-2 ETN-86-97491, November, 1984.

Hersom, S.E., and Maany, Z., Start Solution for Interplanetary Low Thrust Trajectory Optimisation and Model Refinement, Volume 3, Report #ESA-CR(P)-2175-Vol-3 ETN-86-97492, March, 1985.

Heusmann, Werner Andreas, General Mathematical Investigation of the Structure of Rendezvous and Transfer Maneuvers Under Low Thrust Constant and Variable Acceleration: 10 Statements of Reflection, 3rd IAF Student Conference, Baku, USSR, October 7-13, 1973.

Holdaway, R., and Jansson, R.E.W., Performance Analysis of a Solar Electric Tug, AIAA Paper #73-1070, AIAA 10th Electric Propulsion Conference Oct. 31-Nov. 2, 1973.

Horsewood, Jerry L., and Hipkins, Conrad, SWINGBY: A Low Thrust Interplanetary Swingby Trajectory Optimization Program, NASA Report #NASA-CR-119362, March, 1971.

Horsewood, Jerry L., and Mann, Frederick I., The Optimization of Low Thrust Heliocentric Trajectories with Large Launch Asymptote Declinations, AIAA Paper #74-803, AIAA Mecnanics and Control of Flight Conference, August 5-9, 1974

Horsewood, Jerry L., Interplanetary Trajectory Analysis for Combined High- and Low-Thrust Propulsion Systems, Douglas Paper # 3970, July, 1966.

Ilyutovich, A.E., "An Analysis of the Equations of Motion of a Low-Thrust Device", Cosmic Research, Vol. 6, 1969, pp. 579-592.

Jacobson, R.A., Guidance Strategies and Analysis for Low-Thrust Navigation, Jet Propulsion Laboratory Technical Memorandum 33-590, 1 February, 1973.

Jacobson, Robert A., and Powers, WIlliam F., "Optimal Low-Thrust from an Orbit about an Oblate Planet", Celestial Mechanics, Vol. 15, 1977, pp. 161-189.

Jacobson, Robert A., McDanell, James P., and Rinker, George C., Use of Ballistic Arcs for Low Thrust Navigation Enhancement in the 1980 Encke Slow Flyby, AIAA Paper #74-828, AIAA Mechanics of Control of Flight Conference, August 5-9, 1974.

Jasper, Thomas P., Low-Thrust Trajectory Analysis for the Geosynchronous Mission, AIAA Paper #73-1072, AIAA 10th Electric Propulsion Conference, Oct. 31-Nov. 2, 1973.

Johnson, Duane P., and Stumpf, Luis W., "Perturbation Solutions for Low-Thrust Rocket Trajectories", AIAA Journal, Vol. 3, No. 10, October, 1965, pp. 1934-1936.

Jordan, J.F., An Application of Low Thrust Guidance Methods, JPL Technical Memorandum 312-499, November 11, 1964.

Jordan, James F., and Rourke, Kenneth H., Guidance and Navigation for Solar Electric Interplanetary Missions, Jet Propulsion Laboratory.

Keaton, Paul W., Low-Thrust Rocket Trajectories, Los Alamos Paper # 10625-MS, January, 1986.

Korsmeyer, David J., Trajectory Determination and Characterization of Cislunar Low-Thrust Spacecraft, LBS Paper #88-080, 2nd Lunar Bases and Space Activities in the 21st Century, April 5-7, 1988.

Leondes, Cornelius T., and Smith, Frederick T., "Optimization of Interplanetary Orbit Transfers by Dynamic Programming", Journal of Spacecraft and Rockets, Vol. 7, No. 5, May, 1970, pp. 558-564.

Lewallen, Jay M., Sensitivity Study of Low Thrust Escape Spiral Trajectories, Jet Propulsion Laboratory, Technical Memorandum 312-478, 10 September, 1964.

Lion, P.M., A Primer on the Primer, Princeton University.

Lion, P.M., Kornhauser, A.L., and Hazelrigg, G.A., "Low-Thrust Mission Analysis Using an Analytical Trajectory Optimization Model", AIAA Journal.

MacKay, John S., and Mascey, Alfred C., "Some Three-Body Numerical Solutions for Low-Thrust Orbiter Missions", Journal of Spacecraft and Rockets, Vol. 8, No. 11, November, 1971, pp. 1143-1147.

Mainguy, A.M., Aumasson, C., and Donath, T., Interest of Functional Optimization Method for Orbital Manoeuvres Calculation, AAS/AIAA Astrodynamics Specialist Conference, 1986.

Marinescu, A., "Low-Thrust Maneuvers Near the Libration Points", Journal of Guidance and Control, Vol. 2, No. 2, March-April, 1979, pp. 119-122.

Miner, W.E., and Andrus, J.F., "Necessary Conditions for Optimal Lunar Trajectories with Discontinuous State Variables and Intermediate Point Constraints", AIAA Journal, Vol. 6, No. 11, November, 1968, pp. 2154-2159.

Miner, W.E., Tapley, Byron D., and Powers, W.F., "The Hamilton-Jacobi Method Applied to the Low-Thrust Trajectory Problem", pp. 293-305.

Moyer, H.G., and Kelley, H.J., "Conjugate Points on Extremal Rocket Paths", XIXth International Astronautical Congress Proceedings: Vol. 2, Astrodynamics and Astrionics, New York, 1968, Astrodynamics, pp. 163-172.

Mullin, J.P., Barber, T., and Zola, C., "Solar-Cell-Powered, Electric Propulsion for Automated Space Missions", Journal of Spacecraft and Rockets, Vol. 6, No. 11, November, 1969, pp. 1217-1225.

Nagorski, Russel P., A Solar Electric Spacecraft Trajectory and Performance Analysis for Area Target Missions, AIAA Paper #70-212, AIAA 8th Aerospace Sciences Meeting, January, 1970.

Nime, Edward J., and MacKay, John S., Low Variable Thrust Interplanetary Trajectory Data, Report #NASA-TN-D-4431, April, 1968.

Noton, M., and Salehi, S.V., Low-Thrust Navigation to Comets or Asteroids, Space and Communications Division, British Aerospace.

Noton, M., Salehi, S.V., and Elliott, C.A., Navigation for Low Thrust Interplanetary Missions, Report #ESA CR(P)-2375, October, 1986.

Palaszewski, Bryan, Electric Propulsion for Lunar Exploration and Lunar Base Development, LBS-88-005, Lunar Bases and Space Activities in the 21st Century Conference, April 5-7, 1988.

Parvez, S., and Holman, J.M.L., Low Thrust Insertion into Orbit Arount Mars, AIAA Paper #87-0093, January 12-15, 1987.

Penko, Paul F., Staiger, Peter J., and Bur, Michael J., An Analysis of Low-Thrust, Resistojet Reboost for the Space Station, AIAA Paper #85-2042, AIAA/DGLR/JSASS 18th Electric Propulsion Conference, Sept. 30-Oct 2, 1985.

Pines, S., Wolf, H., Horsewood, J., Lefton, L., and Hipkins, C., An N-Body Low-Thrust Trajectory Parameter Optimization Program, Report #NASA-CR-119377, March, 1971.

Pines, Samuel, Jazwinski, Andrew H., and Mann, Fred I., Low Thrust Interplanetary Trajectory Open Loop Error Analysis, Report #NASA-CR-119375, February, 1971.

Poole, Charles J., A Technique for Capture Analysis of Low Thrust Missions in a Planetary System, Masters Thesis, Air Force Institute of Technology, December, 1987.

Popescu, Mihai, Optimal Pursuit of Lagrangian Orbits, IAF Paper #84-351, 35th Congress of the IAF, October 7-13, 1984.

Ragsac, R.V., "Trajectory Requirements and Performance Comparisons of Single-Stage, Electrically Propelled Space Vehicles", Journal of Spacecraft and Rockets, Vol. 6, No. 4, April, 1969, pp. 370-375.

Ragsac, R.V., Trajectory Requirements and Performance Comparisons of Single-Stage Electrically Propelled Space Vehicles, AAS Paper #68-106, AAS/AIAA Astrodynamics Specialist Conference, September 3-5, 1968.

Rauch, H.E., "Low Thrust Swingby Trajectories", pp. 269-283.

Redding, David C., "Highly Efficient, Very Low-Thrust Transfer to Geosynchronous Orbit: Exact and Approximate Solutions", Journal of Guidance, Vol. 7, No. 2, March-April, 1984., pp. 141-147.

Redding, David C., and Breakwell, John V., "Optimal Low-Thrust Transfers to Synchronous Orbit", Journal of Guidance, Control, and Dynamics, Vol. 7, No. 2, March-April 1984, pp. 148-155.

Reidelhuber, Otto J., and Schwenzfenger, Klaus-J., Optimal Low Thrust Increase Spiral Expansion, 25th IAF Congress, October, 1974.

Rinker, George C., Wood, Lincoln J., and Jacobson, Robert A., Statistical Analysis of Trim Maneuvers in Low Thrust Interplanetary Navigation, AIAA Paper #75-85, AIAA 13th Aerospace Scineces Meeting, January 20-22, 1975.

Ross, D.J., Low-Thrust Alteration of Asteroidal Orbits, Fourth Princeton/AIAA Conference on Space Manufacturing Facilities, May 14-17, 1979.

Sackett, Lester L., Hastrup, R.C., Yen, C.L., and Wood, L.J., Comet Rendezvous Mission Design Using Solar Electric Propulsion, AIAA Paper #79-119, AAS/AIAA Astrodynamics Specialist Conference, June 25-27, 1979.

Sackett, Lester L., and Edelbaum, Theodore N., Optimal High and Low-Thrust Geocentric Transfer, AIAA Paper #74-801, AIAA Mechanics and Control of Flight Conference, August 5-9, 1974.

Salmin, V.V., "A Method of FInding an Approximately Optimal Control of a Space Vehicle with Low-Thrust Motor", Cosmic Research, Vol. 6, 1969, pp. 570-578.

Sauer, Carl G., "Optimization of Extended Propulsion Time Nuclear-Electric Propulsion Trajectories", AAS Paper #81-116, Advances in the Astronautical Sciences: Astrodynamics 1981, Vol. 46, Pt. 1, pp. 181-202.

Sauer, Carl G., On the Calculation of Low-Thrust Fail-Safe Trajectories, AAS Paper #75-033, AAS/AIAA Astrodynamics Specialist Conference, July 28-30, 1975.

Sauer, Carl G., Optimization of Multiple Target Electric Propulsion Trajectories, AIAA Paper #73-205, AIAA 11th Aerospace Sciences Meeting, January 10-12, 1973.

Sauer, Carl G., Optimum Solar-Sail Interplanetary Trajectories, AIAA Paper #76-792, AIAA/AAS Astrodynamics Conference, August 18-20, 1976.

Schwenzefeger, Klaus J., "Contribution to Regularization in Optimal Trajectory Problems", AIAA Journal, Vol. 12, No. 6, June, 1974, pp. 850-856.

Schwenzfeger, Klaus J., "Nonnumerical Tangential Low Thrust Energy Increase Trajectories Calculations", Z. Flugwiss.22, 1974, pp. 249-253.

Schwenzfenger, Klaus J., Analytical Approximate Calculation of Optimal Low-Thrust Energy Increase Trajectories, AIAA Paper #74-805, AIAA Mechanics of Control of Flight Conference, August 5-9, 1974.

Shen, C.N., and Lin, C.S., "Hohmann-Type Orbital Transfer by Constant Thrust", XVIth International Astronautical Congress Proceedings: Astrodynamics, Athens, 1965, Astrodynamics, pp. 193-207.

Spandoni, D.J., and Friendlander, A.L., Mars Surface Sample Return Missions Via Solar Electric Propulsion, IIT Research Institute, Report #T-29, August 1971.

Strack, William C., "Solar-Electric Propulsion System Performance for a Close Solar Probe Mission", Journal of Spacecraft and Rockets, Vol. 4, No. 4, April 1967, pp. 469-475.

Strack, William C., Some Numerical Comparisons of Three-Body Trajectories with Patched Two-Body Trajectories for Low Thrust Rockets, Lewis Research Center.

Tapley, Byron D., Low Thrust Guidance Methods, JPL Technical Memorandum 312-341, August 27, 1963.

Tapley, Byron D., Low-Thrust Guidance Methods.

Vasil'ev, V.V. and Salmin, V.V., "Optimal Acceleration of Spacecraft with Electroreactive Engine for Bounded Rate of Rotation of Thrust Vector", Cosmic Research, Vol. 14, No. 3, November, 1976, pp. 305-310.

Wallace, Richard A., "Uranus Mission Options", AAS Paper #79-145, Advances in the Astronautical Scineces: Astrodynamics 1979, Vol. 40, Pt. 1, pp. 443-474.

Yen, C.L., and Smith, D.B., Low-Thrust Mission Risk Analysis, With Application to a 1980 Rendezvous With the Comet Encke, Jet Propulsion Laboratory Technical Memorandum 33-593, 15 March, 1973.

Yen, C.L., Ion Drive Performance and Trajectories, 1978.

Zondervan, Keith P., Wood, Lincoln J., and Caughey, Thomas K., "Optimal Low-Thrust, Three-Burn Orbit Transfers with Large Plane Changes", The Journal of the Astronautical Sciences, Vol. 32, No. 3, July-September, 1984, pp. 407-427.

TABLE 2: REFERENCES FOR WHICH ONLY ABSTRACTS WERE COLLECTED

AIAA, American Institute of Aeronautics and Astronautics, Electric Propulsion Conference, 7th, Williamsburg, Va., March 3-5, 1969, Proceedings.

Barber, T.A., "Mission Analysis Model Requirements for Electric Propulsion", AIAA Electric Propulsion Conference, 7th, March 3-5, 1969, Proceedings.

Bezverbyi, V.K., Ivanov, R.K., Kuzmin, V.P., Petukhov, S.V., and Iaroshevskii, V.A., "Trajectory Control of a Space Vehicle with a Small Thrust on The Heliocentric Section of an Earth-Mars Flight", Cosmic Research, vol. 12, no. 5, May, 1975, pp. 744-756.

Breakwell, J.V. and Rauch, H.E., "Three-dimensional Guidance for Low Thrust Escape from a Planet", IAF Pater AD-131, AIAA/IAF, 19th Congress, October 13-19, 1968.

Cornelisse, J.W., Schoyer, H.F.R., anc Wakker, K.F., Rocket Propulsion and Spaceflight Dynamics, Pitman Publishing, Ltd., London, 1979.

Heusmann, W.A., "Low Thrust Constant Acceleration Trajectories for a Mercury Orbit", IAF International Astronautical Congress, 23rd, October 8-15, 1972.

Horsewood, J.L., "The Optimization of Low Thrust Interplanetary Swingby Trajectories", AIAA Paper 70-1041, AIAA/AAS Astrodynamics Conference, August 19-21, 1970.

Ivanov, V., "Low-Thrust Engines for Spacecraft", Joint Publications Research Service, No. 2, Feb., 1982, pp. 42-43.

Lebedev, L.A., and Sakovskiy, S.A., "On the Necessary and Sufficient Conditions of a Functional Extremum in the Problem of Optimum Flight of a Vehicle with a Low-Thrust Drive", Air Force Systems Command, in its News of Schools of Highter Education, pp 25-33, 1967.

Lewallen, J.M., Szebehely, V., and Tapley, B.D., "Trajectory Optimization using Regularized Variables", AIAA Journal, Vol. 7, pp. 1010-1017.

MacPherson, D., "Characteristics of Low Thrust Interplanetary Trajectories", AIAA Papar 68-119, AIAA Aerospace Sciences Meeting, 6th, January 22-24, 1968.

MacPherson, D., "Mission Analysis Technology", AIAA Electric Propulsion Conference, 7th, March 3-5, 1969, Proceedings, p. 47-54.

Marchal, C, "Optimization of Space Trajectories", IAF Paper 76-010, IAF International Astronautical Congress, October 10-16, 1976.

Nishikawa, Y., "Optimum Control of Space Vehicle Orbital Elements", International Astronautical Federation, International Astronautical Contress, 18th, Proceedings Volume 1 - Astrodynamics, Guidance and Control, Miscellanea, September 24-30, 1967, pp. 361-378.

Oneill, P.M. and Fowler, W.T., "A Method for Handling Coast Arcs in Low-Thrust Interplanetary Trajectory Optimization --- Earth-Jupiter Trajectories", AIAA paper 75-062, AIAA Astrodynamics Specialist Conference, July 28-30, 1975.

Oneill, P.M., "A Modified Perturbation Method for Determining Minimum Fuel Low-Thrust Earth-Jupiter Trajectories", Nasa Report #NASA-CR-105634 TR-1003, 1969.

Popescu, Mihai, and Popescu, Tina, "Optimal Transfer from the Equilateral Libration Points", Acta Astronautica, vol. 15, April, 1987, pp 209-212.

Powers, W.F. and Tapley, B.D., "Canonical Transformation Applications to Optimal Trajectory Analysis", AIAA Journal, Vol. 7, p. 394-399.

Ragsac, R.V., "Trajectory Requirements and Performance Comparisons of Singl-Stage Electrically Propelled Space Vehicles", AAS Paper 68-106, AAS/AIAA Astrodynamics Specialist Converence, Sept. 3-5, 1968.

Salmin, V.V., "Optimization of Systems of Acceleration of a Rotating Spacecraft Having an Engine of Low Thrust", Cosmic Research, Vol. 11, no. 6, May, 1974, pp. 757-769.

Schwenzfeger, K.J., "Contribution to the Trajectory Optimization Problem of a Low Thrust Space Vehicle", AAS Paper 73-241, AAS/AIAA Astrodynamics Conference, July 16-18, 1973.

Stavro, W., "Low-Thrust Trajectories Using the Two-Variable Asymptotic Expansion Method", AIAA Paper 70-214, AIAA Aerospace Sciences Meeting, 8th, January 19-21, 1970.

Sugar, R.D., "Multilevel Optimization of Multiple Arc Trajectories", Control and Dynamic Systems, Academic Press, Inc, 1974.

Wesseling, P., "On Randomly Perturbed Spacecraft Trajectories", AIAA Paper 68-116, AIAA Aerospace Sciences Meeting, 6th, January 22-24, 1968.

Yevtushenko, Yu. G., "The Effect of Tangental Acceleration on the motion of a Satellite", RPT# ACIC-TC-1220, 1966.

Zakharov, Y.A., "Designing Intraorbital Spacecraft: Selection of Trajectories and rated parameters", 1984.

TABLE 3a

Rating	2	1	2	4	1	3	3	1	2	1	4	1	4	3	3	3	1	2	1	1	4	1	3	2	1	1	1
Other Comments	[illegible]	Applicable to intercept collision avoid.	Tangential Thrust		Near optimal mission planning	Mission to Vesta	Solar Elec	[illegible]			No Equations		Solar Probe No Eqns.	Beamed microwave power to S/C		Solar Elec. Upper Stage		Station acquisition & keeping	[illegible]		No Equations		Review of Thrust Techniques		Time Scales	[illegible]	[illegible]
Navitation/ Guidance Method		Linearization Closed Form				1) Feed-back 2) Pontryagin		Practical Scheme	1) Time to go guidance 2) Minimum distance	1) Time to go guid. 2) Minimum distance		Analytic spiral Numeric Helio.	Tangential Thrust											Linearized Nav. Model		[illegible]	[illegible]
Numerical												●								●							
Analytical		●	●									●													●		
Spiral In/Out								●			●	●								●							
Hybrid																											
Gravity Assist																					●						
Coast Arcs			●			●					●																
Var. Thrust																											
Var. Acc.																											
Const Thrust						●					●											●	●				
Const. Acc.			●										●						●								
Method					Shooting Method	[illegible] Vectors	Pontryagin Maximum Principle								Calculus of Variations					Max. Energy Appr. [illegible]		Pontryagin's Maximum Principle					
Suboptimal																						●					
Fuel/Mass												●						●				●					
Energy																											
Time					●										●			●	●	●	●						
3-D Model												●										●					
2-D Model			●																	●		●					
Transfers			●																								
Interorbit			●																	●		●					
Pursuit		●																									
Rendezvous															●												
Plane-Change					●																	●					
Libration Pts.																											
LEO-Molniya																											
LEO-GEO					●									●					●			●	●				
Moon								●			●																
Halley				●																							
Encke																●									●		
Kohoutek							●																				
Asteroids	●					●																					
General Interplanetary						●											●							●		●	
Pluto																											
Neptune																●					●						
Uranus																●					●						
Saturn				●												●					●						
Jupiter																●					●				●		
Mars									●	●		●												●	●		
Venus																●											
Mercury																●											
	Adams, et al (1985)	Anderson, & Grazier (1976)	Anthony (1987)	Bahls & Paris (1980)	Bahls & Paris$_2$	Bartholomew-Biggs & Dixon (1985)	Bartholomew-Biggs, et al (1987)	Battin, & Miller (1961)	Bauer, et al (1983)	Bauer, et al (1982)	Belbruno (1987)	Breakwell, & Rauch (1968)	Brock, & Johnson (1969)	Brown (1988)	Burrows, & Wood (1969)	Dazzo & Nagorski (1973)	Dixon, et al (1983)	Eckstein & Hechler (1981)	Edelbaum, et al (1973)	Efimov, & Okhotsimskii (1965)	Flandro (1968)	Flury (1984)	Free (1970)	Friedlander (1965)	Friedlander (1970)	GM Vol. II Part 9 (1967)	GM Vol. II Part 10 (1967)

Table 3b

	GM Vol. II Part II (1967)	Glazkov (1987)	Gottlieb (1967)	Gurman (1971)	Hahn, et al (1969)	Handelsman (1966)	Hart & Fowler (1970)	Herson, et al VII (1983)	Herson, et al V1 (1985)	Herson, et al V2 (1984)	Herson, et al V3 (1985)	Heusmann (1973)	Holdaway & Jansson (1973)	Horsewood & Hipkins (1971)	Horsewood & Mann (1974)	Horsewood (1966)	Ilyutovich (1969)	Jacobson (1973)	Jacobson & Powers (1977)	Jacobson, et al (1974)	Jasper (1973)	Johnson (1965)	Jordan (1964)$_1$	Jordan$_2$	Keaton (1986)	Korsmeyer (1988)	Leondes & Smith (1970)
Rating	1	4	2	2	3	2	2	2	2	2	2	3	3	1	1	2	2	1	1	3	1	3	1	2	1	2	2
Other Comments			Not about low thrust	Attitude control		Method to get initial Lagrange mult.		Computer program documentation	Comp. program theory	Program documentation	Program documentation		Solar elec. upper stage	Patched conic with low T.	Heliocentric plane change	High thrust escape & capture	Highly mathematical	Practical algorithm	J_2 effect 2-var acc exp.		Averaged Hamiltonian	2nd order perturbations		Solar electric	Simple model Ramp acc. to acc.	Restricted 3-body prob.	
Navitation/ Guidance Method	1) Lambda matrix 2) [illegible]								Finds an initial guess solution for more exact solution								Statistical method		Tangential thrust	Ballistic arcs for state estimation			1) Extremal field control 2) Lambda matrix control	1st order guidance linear filter		Jacobian / Battin	
Numerical																					●						
Analytical																											
Spiral In/Out																											
Hybrid																●											
Gravity Assist														●													
Coast Arcs			●																	●						●	
Var. Thrust					●							●															
Var. Acc.																									●		
Const Thrust						●						●		●					●							●	
Const. Acc.				●																		●			●		
Method						Variational calculus												Min. terminal constraint violations			Min-time Hamiltonian	Non optimal			Iaving's theory?	Non optimal	Dynamic programming
Suboptimal																									●		●
Fuel/Mass					●														●						●		
Energy		●																									
Time	●																		●		●		●				
3-D Model																											
2-D Model																●							●			●	
Transfers																											
Interorbit																											
Pursuit																											
Rendezvous																											
Plane-Change															●												
Libration Pts.																											
LEO-Molniya																											
LEO-GEO													●								●						
Moon																									●	●	
Halley																											
Encke															●			●		●							
Kohoutek																											
Asteroids									●																		
General Interplanetary	●				●			●	●	●	●			●		●							●				
Pluto																											
Neptune																											
Uranus																											
Saturn																											
Jupiter		●					●															●		●			
Mars					●	●								●									●		●		●
Venus																											
Mercury																											

TABLE 3C

	Levallen (1964)	Lion$_1$	Lion$_2$	MacKay & Mascey (1971)	Mainguy, et al (1986)	Marinescu (1979)	Miner, et al$_1$	Moyer & Kelley (1968)	Mullin, et al (1969)	Nagorski (1970)	Nime (1968)	Noton, et al$_1$	Noton, et al (1986)$_2$	Palaszewski (1988)	Parvez (1987)	Penko, et al (1985)	Pines, et al (1971)	Pines (1971)	Poole (1987)	Popescu (1984)	Ragsac (1969)	Ragsac (1968)	Rauch	Redding (1984)	Redding & Breakwell (1984)	Reidelhuber & Schwenzfeger (1974)	Rinker, et al (1975)
Rating	1	1	4	4	2	2	1	2	3	3	1	1	2	3	4	4	1	1	1	4		2	1	2	2	1	1
Other Comments	J2 + Lunar Effects	Not specifically low-T but used as bounds		No Eqns. Some Graphs				Launch From Moon	Technology Review	No Eqns. Many Plots	Mission Tables From Earth to All Planets	Statistical		Many Tables		No Eqns. Space Station	N-Bodies	Closed Form Partial Derivatives	Low Thrust Capture of S/C by Moon of Ref.							2-Variable Series Expansion	
Navitation/ Guidance Method							Hamilton-Jacobi Method					Earth Based N/G Sequential Estimation	Comet Rendezvous Estimation of μ				Constant Control over Arcs	Error Analysis of Navigation Schemes Statistical	Tangential Thrust & Radial Thrust								Statistical Methods
Numerical				●				●																			
Analytical							●	●																●		●	
Spiral In/Out	●																					●				●	
Hybrid			●																								
Gravity Assist											●												●				
Coast Arcs													●									●					●
Var. Thrust											●																
Var. Acc.																											
Const Thrust							●	●														●		●	●		
Const. Acc.																								●	●	●	
Method		Primer Vector			Generalized Reduced Gradient			Check for Conjugate Points			Newton Raphson													Lawden's			
Suboptimal																	●										
Fuel/Mass			●		●	●		●			●											●	●	●			
Energy																											
Time							●													●						●	
3-D Model																	●							●	●		
2-D Model							●	●			●								●								
Transfers																											
Interorbit					●																					●	
Pursuit																				●							
Rendezvous													●														
Plane-Change																								●	●		
Libration Pts.						●														●							
LEO-Molniya																											
LEO-GEO																								●	●		
Moon														●													
Halley																											
Encke																											●
Kohoutek																											
Asteroids												●															
General Interplanetary											●		●					●	●				●				
Pluto											●																
Neptune				●							●																
Uranus				●							●											●					
Saturn				●							●											●					
Jupiter				●					●		●											●					
Mars											●				●								●				
Venus											●																
Mercury											●											●					

TABLE 3d

	Ross (1979)	Sackett & Edelbaum (1974)	Sacket, et al (1979)	Salmin (1969)	Sauer (1981)	Sauer (1975)	Sauer (1973)	Sauer (1976)	Schwenzfeger (1974)$_1$	Schwenzfeger (1974)$_2$	Schwenzfeger (1974)$_3$	Shen & Lin (1965)	Spandoni & Priendlander (1971)	Strack (1967)$_1$	Strack$_2$	Tapley (1963)$_1$	Tapley$_2$	Vasil'ev & Salmin (1976)	Wallace (1979)	Yen & Smith (1973)	Yen (1976)	Zondervan, et al (1984)
Rating	4	4	2	2	1	1	2	4	1	2	2	2	3	2	1	1	1	2	3	3	3	2
Other Comments	Asteroid Retrieval	No Equatovi	Halley/Tempel 2 Rendezvous Solar Elec.	Very Mathematical	Thruster Lifetime STS Payload			Solar Sail	Regularized Min. Time Esc.	2-Variable Asymptotic Exp.	Regularized 2-Var. Exp.		No Equations Many Figs & Tab.	Solar Elec. Upper Stage	N-Body 3-Body Patched 2-Body				Many Charts No Eqns.	Reliability Risk Anal.	Many Charts No Eqns	
Navitation/ Guidance Method			Ground Based Tracking			Fail Safe Guidance				Tangential Thrust						1) Lambda Matrix Cont. 2) Extremal Field Cont	1) Lambda Matrix Cont. 2) Extremal Field Cont.	Max. Rotation Rate of S/C Controlled				
Numerical															●							●
Analytical										●	●	●			●							
Spiral In/Out					●				●	●												
Hybrid		●																				
Gravity Assist							●												●		●	
Coast Arcs	●				●																	
Var. Thrust															●							
Var. Acc.																						
Const Thrust									●			●			●							
Const. Acc.	●									●	●						●					
Method				Min. Time in Radiation Belt			Calculus of Variation	Calculus of Variations						Max. Burn-out Vel.								Direct Shooting Method
Suboptimal																						
Fuel/Mass	●														●	●	●					
Energy												●										
Time				●					●		●					●	●					
3-D Model																						
2-D Model	●								●			●						●				
Transfers (G-∞)				●																		
Interorbit		●									●	●										●
Pursuit																						
Rendezvous			●																			
Plane-Change																						●
Libration Pts.																						
LEO-Molniya																						●
LEO-GEO																						
Moon																						
Halley			●																			
Encke						●	●													●		
Kohoutek																						
Asteroids	●						●	●													●	
General Interplanetary					●									●		●	●					
Pluto																						
Neptune					●																	
Uranus					●														●			
Saturn					●																	
Jupiter					●																	
Mars								●					●		●							
Venus								●														
Mercury								●														

APPENDIX B

69A21201 ISSUE 9 PAGE 1584 CATEGORY 30 69/00/00 70 PAGES
UNCLASSIFIED DOCUMENT

UTTL: American Institute of Aeronautics and Astronautics, Electric Propulsion Conference, 7th, Williamsburg, Va., March 3-5, 1969, Proceedings.

UNOC: Electric propulsion - AIAA Conference, Williamsburg, March 1969

SAP: MEMBERS, $5.00, NONMEMBERS, $7.50.

CIO: UNITED STATESNEW YORK, AMERICAN INST. OF AERONAUTICS AND ASTRONAUTICS, INC., AMERICAN INST. OF AERONAUTICS AND ASTRONAUTICS, ELECTRIC PROPULSION CONFERENCE, 7TH, WILLIAMSBURG, VA., MAR. 3-5, 1969, PROCEEDINGS.

MAJS: /*CONFERENCES/*ELECTRIC PROPULSION

MINS: / LOW THRUST PROPULSION/ MISSION PLANNING/ SPACECRAFT TRAJECTORIES

69A21202*# ISSUE 9 PAGE 1584 CATEGORY 30 69/00/00 5 PAGES
UNCLASSIFIED DOCUMENT

UTTL: Mission analysis model requirements for electric propulsion.

UNOC: Spacecraft electric propulsion parameters and launching vehicle characteristics in low thrust mission simulation, discussing spacecraft path

AUTH: A/BARBER, T. A. PAN: (AA/CALIFORNIA INST. OF TECH., JET PROPULSION LAB., PASADENA, CALIF./.)

CIO: UNITED STATESNEW YORK, AMERICAN INST. OF AERONAUTICS AND ASTRONAUTICS,INC., =IN- AMERICAN INST. OF AERONAUTICS AND ASTRONAUTICS, ELECTRIC PROPULSION CONFERENCE, 7TH, WILLIAMSBURG, VA., MAR. 3-5, 1969, PROCEEDINGS. P. 1-5. <A69-21201 09-30<

MAJS: /*ELECTRIC PROPULSION/*FLIGHT SIMULATION/*LOW THRUST PROPULSION/*SPACE MISSIONS/*SPACECRAFT MODELS

MINS: / CONFERENCES/ FLIGHT PATHS/ LAUNCH VEHICLES/ PAYLOADS/ PLANET EPHEMERIDES / ROCKET THRUST/ SPACECRAFT TRAJECTORIES

75A38678 ISSUE 18 PAGE 2637 CATEGORY 17 75/05/00 13 PAGES
UNCLASSIFIED DOCUMENT COPYRIGHT

UTTL: Trajectory control of a space vehicle with a small thrust on the heliocentric section of an earth-Mars flight

AUTH: A/BEZVERBYI, V. K.; B/IVANOV, R. K.; C/KUZMIN, V. P.; D/PETUKHOV, S. V. ; E/IAROSHEVSKII, V. A.

CIO: UNKNOWN (Kosmicheskie Issledovaniia, vol. 12, Nov.-Dec. 1974, p. 819-833.) Cosmic Research, vol. 12, no. 6, May 1975, p. 744-756. Translation.

MAJS: /*EARTH-MARS TRAJECTORIES/*ERROR CORRECTING CODES/*LOW THRUST PROPULSION/*TIME OPTIMAL CONTROL/*TRAJECTORY CONTROL/*TRAJECTORY OPTIMIZATION

MINS: / AIRBORNE/SPACEBORNE COMPUTERS/ ALGORITHMS/ ERROR ANALYSIS/ MONTE CARLO METHOD/ NUMERICAL CONTROL/ RANDOM ERRORS/ SPACECRAFT CONTROL/ SPACECRAFT TRAJECTORIES/ THRUST PROGRAMMING

ABS: (For abstract see issue 07, p. 919, Accession no. A75-19879)

68A45117 ISSUE 24 PAGE 4669 CATEGORY 30 RPT#: IAF PAPER
AD-131 68/10/00 19 PAGES
UNCLASSIFIED DOCUMENT COPYRIGHT
UTTL: Three-dimensional guidance for low thrust escape from a planet.
UNOC: Three dimensional guidance for low thrust interplanetary trajectory with planetary escape and arrival by nonplanar low thrust spiral
AUTH: A/BREAKWELL, J.V.; B/RAUCH, H.E. PAN: (AA/STANFORD U., DEPT. OF AERONAUTICS AND ASTRONAUTICS, STANFORD, CALIF./ AB/LOCKHEED AIRCRAFT CORP., LOCKHEED MISSILES AND SPACE CO., RESEARCH LABS., PALO ALTO, CALIF./.)
CIO: UNKNOWNNEW YORK AND PARIS, AMERICAN INST. OF AERONAUTICS AND ASTRONAUTICS AND INTERNATIONAL ASTRONAUTICAL FEDERATION, INTERNATIONAL ASTRONAUTICAL FEDERATION, CONGRESS, 19TH, NEW YORK, N.Y., OCT. 13-19, 1968.
MAJS: /*INTERPLANETARY TRAJECTORIES/*LOW THRUST PROPULSION/*SPACECRAFT GUIDANCE/*TRAJECTORY OPTIMIZATION
MINS: / BOUNDARY VALUE PROBLEMS/ CONFERENCES/ ORBITAL MECHANICS/ TRANSFER ORBITS

79A24529 ISSUE 9 PAGE 1539 CATEGORY 12 79/00/00 526 PAGES
UNCLASSIFIED DOCUMENT COPYRIGHT

UTTL: Rocket propulsion and spaceflight dynamics --- Book

AUTH: A/CORNELISSE, J. W.; B/SCHOYER, H. F. R.; C/WAKKER, K. F.
PAA: A/(ESA, European Space Research and Technology Centre, Noordwijk, Netherlands); C/(Delft, Technische Hogeschool, Delft, Netherlands)

SAP: $60.24

CIO: INTERNATIONAL ORGANIZATION
London, Pitman Publishing, Ltd., 1979. 526 p.

MAJS: /*ASTRODYNAMICS/*COMBUSTION PHYSICS/*PROPULSION SYSTEM CONFIGURATIONS/*ROCKET ENGINE DESIGN/*SPACECRAFT PROPULSION

MINS: / AEROSPACE ENGINEERING/ EQUATIONS OF MOTION/ INTERPLANETARY TRAJECTORIES/LOW THRUST PROPULSION/ MANY BODY PROBLEM/ PROPELLANT COMBUSTION/ ROCKET FLIGHT/ SATELLITE PERTURBATION/ THERMODYNAMICS/ TWO BODY PROBLEM

ABA: G.R.

ABS: Basic concepts in astronomy and geophysics are examined, taking into account the universe, the solar system, reference frames and coordinate systems, time and calendar, the earth, and the earth's atmosphere. The mechanics of particles, bodies and fluids are considered, giving attention to Newton's first and second law, noninertial frames, the dynamics of particle systems, gravitation, the motion of a particle in an inverse-square field, and the mechanics of fluids. The equations of motion of rigid rockets are discussed along with the chemical rocket motor, the characteristic coefficients and parameters of the rocket motor, the thermochemistry of the rocket motor, heat transfer in rocket motors,the solid-propellant rocket motor, the liquid-propellant rocket motor, two-dimensional rocket motion in vacuum, the multistage rocket, ballistiic missile trajectories, rocket motion in the atmosphere, the many-body problem, the two-body problem, the launching of a satellite, perturbed satellite orbits, interplanetary missions, and low-thrust trajectories.

72A45208# ISSUE 24 PAGE 3441 CATEGORY 30 72/10/00 26 PAGES
UNCLASSIFIED DOCUMENT

UTTL: Low thrust constant acceleration trajectories for a Mercury orbit.

AUTH: A/HEUSMANN, W. A.

CIO: UNKNOWN
International Astronautical Federation, International Astronautical Congress, 23rd, Vienna, Austria, Oct. 8-15, 1972, Paper. 26 p.

MAJS: /*COMPUTER PROGRAMS/*INTERPLANETARY TRAJECTORIES/*ION ENGINES/*LOW THRUST PROPULSION/*MERCURY (PLANET)/*TRAJECTORY OPTIMIZATION

MINS: / ACCELERATION (PHYSICS)/ EQUATIONS OF MOTION/ FLIGHT TIME/ INTERPLANETARY TRANSFER ORBITS/ MISSION PLANNING/ SPACECRAFT LAUNCHING/ SPACECRAFT TRAJECTORIES

ABA: V.Z.

ABS: Theory and technical data are given for an interplanetary probe to be placed in orbit around Mercury. Specifications and performance characteristics for the probe are discussed. The application of ion thrusters is indicated as necessary to provide the high performance and power for the orbital transfer of the probe. Details are given on the parameters and specifications of the three German ion thrusters designed to optimize the transition of the interplanetary trajectories of the probe into a circumplanetary orbit. The planned launching data, flight durations, and mission objectives are described. Computations are made for trajectories under tangential, radial and constant accelerations. The computer programs to be used are discussed.

70A38856*# ISSUE 19 PAGE 3527 CATEGORY 30 RPT#: AIAA PAPER 70-1041 CNT#: NAS5-11193 70/08/00 15 PAGES UNCLASSIFIED DOCUMENT COPYRIGHT

UTTL: The optimization of low thrust interplanetary swingby trajectories

UNOC: Low thrust interplanetary swingby trajectories optimization, considering thrusting and coasting within sphere of influence

AUTH: A/HORSEWOOD, J. L. PAN: (AA/ANALYTICAL MECHANICS ASSOCIATES, INC., SEABROOK, MD./.)

SAP: MEMBERS, $1.25, NONMEMBERS, $2.00.

CIO: UNITED STATESNEW YORK, AMERICAN INST. OF AERONAUTICS AND ASTRONAUTICS, AMERICAN ASTRONAUTICAL SOCIETY AND AMERICAN INST. OF AERONAUTICS AND ASTRONAUTICS, ASTRODYNAMICS CONFERENCE, SANTA BARBARA, CALIF., AUG. 19-21, 1970.

MAJS: /*INTERPLANETARY TRAJECTORIES/*LOW THRUST PROPULSION/*SWINGBY TECHNIQUE/* TRAJECTORY OPTIMIZATION

MINS: / CONFERENCES/ ELECTRIC PROPULSION/ GRAVITATIONAL EFFECTS/ NUCLEAR PROPULSION/ SOLAR SYSTEM/ SPACECRAFT ENVIRONMENTS

82N32286# ISSUE 22 PAGE 3226 CATEGORY 20 82/08/17 4 PAGES
UNCLASSIFIED DOCUMENT

UTTL: Low-thrust engines for spacecraft

AUTH: A/IVANOV, V.

CORP: Joint Publications Research Service, Arlington, VA.

SAP: Avail: Issuing Activity
In its USSR Rept.: Space, No. 17 (JPRS-81552) p 58-61
(SEE N82-32275 22-99)

CIO: U.S.S.R. Transl. into ENGLISH from Aviat. Kosmonavt. (USSR), no. 2, Feb. 1982 p 42-43

MAJS: /*LOW THRUST PROPULSION/*PROPULSION SYSTEM PERFORMANCE/ *SPACECRAFT PROPULSION

MINS: / INTERORBITAL TRAJECTORIES/ INTERPLANETARY TRAJECTORIES/ SPACECRAFT POWER SUPPLIES/ THRUST LOADS

ABA: M.G.

ABS: The advantages of low thrust engines for spacecraft are outlined and orbit transfer and interplanetary trajectory strategies are discussed. An Earth-Mars flight is given as an example. Constraining factors effecting the characteristics of an electric propulsion spacecraft such as the carrier vehicle design and electric power source are also addressed.

68N13844   ISSUE 4 PAGE 580 CATEGORY 30   67/03/21   9 PAGES
UNCLASSIFIED DOCUMENT

UTTL: On the necessary and sufficient conditions of a functional extremum in the problem of optimum flight of a vehicle with a low-thrust drive

UNOC: Calculus of variations method for flight optimization of low thrust interplanetary spacecraft between sun and planet

AUTH: A/LEBEDEV, L. A.; B/SAKOVSKIY, S. A.

CORP: Air Force Systems Command, Wright-Patterson AFB, OH.   CSS: (FOREIGN TECHNOLOGY DIV.)
IN ITS NEWS OF SCHOOLS OF HIGHER EDUC. AERON. ENGR. 21 MAR. 1967 /SEE N68-13841 04-28/ P 25-33

CIO: U.S.S.R.

MAJS: /*CALCULUS OF VARIATIONS/*FLIGHT OPTIMIZATION/*INTERPLANETARY SPACECRAFT

MINS: / EQUATIONS OF MOTION/ LOW THRUST/ PLANETS/ SPACECRAFT TRAJECTORIES/ SUN

69A37173*# ISSUE 20 PAGE 3595 CATEGORY 30 RPT#: AAS PAPER
CNT#: NGR-44-012-046 NAS9-6963 69/06/00 8 PAGES
UNCLASSIFIED DOCUMENT/FOR ABSTRACT SEE ISSUE 20, PAGE
3853, ACCESSION NO. A68-38687/
UTTL: Trajectory optimization using regularized variables.
UNOC: Trajectory optimization of space vehicle with continuous
thrust based on regularized equations, comparing
perturbation method for earth-Jupiter rendezvous transfer
AUTH: A/LEWALLEN, J. M.; B/SZEBEHELY, V.; C/TAPLEY, B. D. PAN:
(AB/TEXAS, U., DEPT. OF AEROSPACE ENGINEERING AND MECHANICS,
AUSTIN, TEX./. AA/NASA, MANNED SPACECRAFT CENTER,COMPUTATION
AND ANALYSIS DIV., HOUSTON, TEX./.)
AIAA JOURNAL, VOL. 7, P. 1010-1017.
CIO: UNITED STATESNEW YORK, /AMERICAN ASTRONAUTICAL SOCIETY AND
AMERICAN INST. OF AERONAUTICS AND ASTRONAUTICS,
ASTRODYNAMICS SPECIALIST CONFERENCE, JACKSON, WYO., SEP. 3-
5, 1968./
MAJS: /*INTERPLANETARY TRAJECTORIES/*ORBITAL RENDEZVOUS/
*PERTURBATION THEORY/*TRAJECTORY OPTIMIZATION
MINS: / BOUNDARY VALUE PROBLEMS/ CONFERENCES/ DIFFERENTIAL
EQUATIONS/ GRAVITATIONAL FIELDS/ JUPITER (PLANET)/ LOW
THRUST/ SINGULARITY (MATHEMATICS)/ TRANSFER ORBITS

68A17537# ISSUE 6 PAGE 1089 CATEGORY 30 RPT#: AIAA PAPER 68-119 68/00/00 12 PAGES UNCLASSIFIED DOCUMENT

UTTL: Characteristics of low thrust interplanetary trajectories.

UNOC: Low thrust interplanetary trajectory characteristics illustrated by n-body three dimensional trajectory simulations of various space missions

AUTH: A/MAC PHERSON, D. PAN: (AA/HUGHES AIRCRAFT CO., EL SEGUNDO, CALIF./.)

SAP: MEMBERS, $1.00, NONMEMBERS, $1.50.

CIO: UNKNOWNNEW YORK, AMERICAN INST. OF AERONAUTICS AND ASTRONAUTICS. AMERICAN INST. OF AERONAUTICS AND ASTRONAUTICS, AEROSPACE SCIENCES MEETING, 6TH, NEW YORK, N.Y., JAN. 22-24, 1968.

MAJS: /*INTERPLANETARY TRAJECTORIES/*LOW THRUST PROPULSION/*SPACE MISSIONS/* TRAJECTORY ANALYSIS

MINS: / CELESTIAL MECHANICS/ CONFERENCES/ FLIGHT SIMULATION/ ORBITAL MECHANICS

69A21209# ISSUE 9 PAGE 1585 CATEGORY 30 69/00/00 8 PAGES
UNCLASSIFIED DOCUMENT
UTTL: Mission analysis technology.
UNOC: Low thrust interplanetary trajectories optimization, discussing hardware design considerations
AUTH: A/MACPHERSON, D.PAN:(AA/HUGHES AIRCRAFT CO.,EL SEGUNDO CALIF./.)
CIO: UNKNOWNNEW YORK, AMERICAN INST. OF AERONAUTICS AND ASTRONAUTICS, INC., IN- AMERICAN INST. OF AERONAUTICS AND ASTRONAUTICS, ELECTRIC PROPULSION CONFERENCE, 7TH, WILLIAMSBURG, VA., MAR. 3-5, 1969, PROCEEDINGS. P. 47-54. <A69-21201 09-30<
MAJS: /*INTERPLANETARY TRAJECTORIES/*LOW THRUST PROPULSION/*TRAJECTORY OPTIMIZATION
MINS: / CONFERENCES/ ELECTRIC PROPULSION/ INDEPENDENT VARIABLES/ MATHEMATICAL MODELS/ MISSION PLANNING/ SOLAR PROPULSION

76A46029# ISSUE 23 PAGE 3586 CATEGORY 13 RPT#: IAF PAPER 76-010 ONERA, TP NO. 1976-107 76/10/00 12 PAGES UNCLASSIFIED DOCUMENT

UTTL: Optimization of space trajectories /Survey paper/

AUTH: A/MARCHAL, C. PAA: A/(ONERA, Chatillon-sous-Bagneux, Hauts-de-Seine, France)

CIO: FRANCE International Astronautical Federation, International Astronautical Congress, 27th, Anaheim, Calif., Oct. 10-16, 1976, 12 p.

MAJS: /*ASTRODYNAMICS/*OPTIMAL CONTROL/*SPACECRAFT TRAJECTORIES/*THRUST PROGRAMMING/*TRAJECTORY OPTIMIZATION/*TRANSFER ORBITS

MINS: / ELLIPTICAL ORBITS/ KEPLER LAWS/ LOW THRUST PROPULSION/ NUMERICAL ANALYSIS/ STOCHASTIC PROCESSES

ABA: (Author)

ABS: Optimization of space trajectories is the major factor in the birth of modern theories of optimization and of corresponding numerical methods (used to-day in all domains). The case of optimal time-free transfers between Keplerian orbits in a central field is on the way to be completely investigated, but the other cases remain difficult especially because of the different kinds of singular arcs. Stochastic optimization is much less investigated and remains very difficult.

69A17579 ISSUE 6 PAGE 955 CATEGORY 21 68/00/00 18 PAGES
UNCLASSIFIED DOCUMENT COPYRIGHT
UTTL: Optimum control of space-vehicle orbital elements.
UNOC: Minimum fuel control of spacecraft orbital elements for transfers between elliptial orbits by low variable thrust propulsion, noting interplanetary trajectory optimization
AUTH: A/NISHIKAWA, Y.; B/SANNOMIYA, N. PAN: (AA/CALIFORNIA, U., LOS ANGELES, CALIF./ AB/KYOTO U., DEPT. OF ELECTRICAL ENGINEERING, KYOTO, JAPAN/.)
CIO: JAPANOXFORD AND WARSAW, PERGAMON PRESS, LTD. AND PANSTWOWE WYDAWNICTWO NAUKOWE, IN- INTERNATIONAL ASTRONAUTICAL FEDERATION, INTERNATIONAL ASTRONAUTICAL CONGRESS, 18TH, BELGRADE, YUGOSLAVIA, SEP. 24- 30, 1967, PROCEEDINGS. VOLUME 1 - ASTRODYNAMICS, GUIDANCE AND CONTROL, MISCELLANEA. P. 361-378. 9 REFS. <A69-17560 06-30.
MAJS: /*FUEL CONSUMPTION/*INTERPLANETARY TRAJECTORIES/*OPTIMAL CONTROL/*ORBITAL ELEMENTS/*TRANSFER ORBITS
MINS: / CONFERENCES/ ELLIPTICAL ORBITS/ LOW THRUST PROPULSION/ MARS PROBES/ SPACECRAFT TRAJECTORIES/ TRAJECTORY OPTIMIZATION/ VARIABLE THRUST

87A40232 ISSUE 17 PAGE 2633 CATEGORY 13 87/04/00 4 PAGES
UNCLASSIFIED DOCUMENT COPYRIGHT

UTTL: Optimal transfer from the equilateral libration points

AUTH: A/POPESCU, MIHAI; B/POPESCU, TINA PAA: B/(Institutul National pentru Creatie Stiintifica si Tehnica, Bucharest, Rumania)

CIO: ROMANIA (RUMANIA)

Acta Astronautica (ISSN 0094-5765), vol. 15, April 1987, p. 209-212.

MAJS: /*EARTH-MOON SYSTEM/*LAGRANGIAN EQUILIBRIUM POINTS/*SPACECRAFT TRAJECTORIES/*TRAJECTORY OPTIMIZATION/*TRANSFER ORBITS

MINS: / ACCELERATION (PHYSICS)/ EULER-LAGRANGE EQUATION/ LOW THRUST PROPULSION

ABA: Author

ABS: This paper analyzes the motion of a space vehicle which starts from the equilateral libration points of the earth-moon system to its orbit in a prescribed time. Considering the vehicle position at the end of the evolution time as being unspecified, the trajectory of the space vehicle is determined so that its final speed is maximized. The results are shown in a numerical application.

69A28202*# ISSUE 13 PAGE 2353 CATEGORY 30 CNT#: NGR-44-012-046 69/03/00 6 PAGES
UNCLASSIFIED DOCUMENT

UTTL: Canonical transformation applications to optimal trajectory analysis.

UNOC: Canonical transformation and Hamilton-Jacobi theories applied to space vehicle trajectory analysis, discussing elliptical coast arc and optimal low thrust problems

AUTH: A/POWERS, W. F.; B/TAPLEY, B. D. PAN: (AB/TEXAS, U., AUSTIN, TEX./.) AIAA JOURNAL, VOL. 7, P. 394-399.

CIO: UNITED STATES

MAJS: /*CANONICAL FORMS/*HAMILTON-JACOBI EQUATION/*SPACECRAFT TRAJECTORIES/* TRAJECTORY ANALYSIS/*TRAJECTORY OPTIMIZATION

MINS: / ARCS/ COASTING FLIGHT/ EQUATIONS OF MOTION/ HAMILTONIAN FUNCTIONS/ LAGRANGE MULTIPLIERS/ LOW THRUST/ PERTURBATION THEORY/ SPACECRAFT PROPULSION

69X18359*# ISSUE 20 PAGE 1565 CATEGORY 30 RPT#: NASA-CR-105634 TR-1003 CNT#: NGR-44-012-008 69/04/00 96 PAGES
UNCLASSIFIED DOCUMENT US GOV AGENCIES AND CONTRACTORS
UTTL: A modified perturbation method for determining minimum fuel low-thrust Earth-Jupiter trajectories
UNOC: Modified perturbation method for determining minimum fuel low thrust Earth-Jupiter trajectories
AUTH: A/ONEILL, P. M.
CORP: Texas Univ., Austin. CSS: (APPLIED MECHANICS RESEARCH LAB.)
CIO: UNITED STATES
MAJS: /*EARTH (PLANET)/*FUEL CONSUMPTION/*JUPITER (PLANET)/*LOW THRUSTm PROPULSION/*PERTURBATION/*TRAJECTORY OPTIMIZATION
MINS: / ALGORITHMS/ BOUNDARY VALUE PROBLEMS/ CALCULUS OF VARIATIONS/ EQUATIONs OF MOTION/ INTERPLANETARY TRAJECTORIES/ MASS FLOW RATE

76A11296# ISSUE 1 PAGE 19 CATEGORY 13 RPT#: AAS PAPER 75-062 75/07/00 22 PAGES UNCLASSIFIED DOCUMENT

UTTL: A method for handling coast arcs in low-thrust interplanetary trajectory optimization --- earth-Jupiter trajectories

AUTH: A/ONEILL, P. M.; B/FOWLER, W. T. PAA: A/(McDonnell-Douglas Astronautics Co., Houston, Tex.); B/(Texas, University, Austin, Tex.)

CIO: UNITED STATES
American Astronautical Society and American Institute of Aeronautics and Astronautics, Astrodynamics Specialist Conference, Nassau, Bahamas, July 28-30, 1975, AAS 22 p.

MAJS: /*COASTING FLIGHT/*INTERPLANETARY TRAJECTORIES/*JUPITER PROBES/*LOW THRUST PROPULSION/*TIME OPTIMAL CONTROL/ *TRAJECTORY OPTIMIZATION/*TRANSFER ORBITSMINS: / ALGORITHMS/ ARCS/ BOUNDARY VALUE PROBLEMS/ PERTURBATION THEORY/ SWITCHING

ABA: (Author)

ABS: A method for handling coast arcs for low-thrust interplanetary trajectory optimization is presented. The method combines a switching function with the guessing of the length and center point of the coast arc. The center point of the coast arc is shifted while its length is held constant while the values of the switching function at the start and end of the coast arc are made equal. Then the length of the coast arc is found directly through a linear extrapolation procedure. Then the optimal center point for the coast arc is found. Examples of the procedure based on low-thrust earth-Jupiter trajectories are presented.

68A38694# ISSUE 20 PAGE 3853 CATEGORY 30 RPT#: AAS PAPER
68-106 68/09/00 12 PAGES UNCLASSIFIED DOCUMENT
UTTL: Trajectory requirements and performance comparisons of
single-stage electrically propelled space vehicles.
UNOC: Trajectory requirements and performance comparisons of
single stage electrically propelled space vehicles
AUTH: A/RAGSAC, R. V. PAN: (AA/UNITED AIRCRAFT CORP., UNITED
AIRCRAFT RESEARCH LABS., EAST HARTFORD, CONN./.)
CIO: UNKNOWNNEW YORK, AMERICAN ASTRONAUTICAL SOCIETY,
AMERICAN ASTRONAUTICAL SOCIETY AND AMERICAN INST. OF
AERONAUTICS AND ASTRONAUTICS, ASTRODYNAMICS SPECIALIST
CONFERENCE, JACKSON, WYO., SEP. 3-5, 1968.
MAJS: /*ELECTRIC PROPULSION/*PROPULSION SYSTEM
PERFORMANCE/*SPACECRAFT PROPULSION/*TRAJECTORY OPTIMIZATION
MINS: / CONFERENCES/ LOW THRUST PROPULSION/ ORBITAL MECHANICS/
PAYLOADS/ SPACE MISSIONS/ SPACECRAFT TRAJECTORIES/
TRAJECTORY ANALYSIS

74A34555 ISSUE 16 PAGE 2346 CATEGORY 31 74/05/00 13 PAGES
UNCLASSIFIED DOCUMENT COPYRIGHT

UTTL: Optimization of systems of acceleration of a rotating spacecraft having an engine of low thrust

AUTH: A/SALMIN, V. V.

CIO: UNKNOWN (Kosmicheskie Issledovaniia, vol. 11, Nov.-Dec. 1973, p. 842-854.) Cosmic Research, vol. 11, no. 6, May 1974, p. 757-769. Translation.

MAJS: /*ACCELERATION (PHYSICS)/*ARTIFICIAL GRAVITY/*LOW THRUST PROPULSION/* ROTATING BODIES/*SPACECRAFT MOTION/*TRAJECTORY OPTIMIZATION

MINS: / AXES OF ROTATION/ CALCULUS OF VARIATIONS/ EQUATIONS OF MOTION/ SPACECRAFT TRAJECTORIES

ABS: (For abstract see issue 07, p. 1012, Accession no. A74-19605)

74A17610 ISSUE 5 PAGE 707 CATEGORY 30 RPT#: AAS PAPER 73-241 73/07/00 27 PAGES
UNCLASSIFIED DOCUMENT COPYRIGHT

UTTL: Contribution to the trajectory optimization problem of a low thrust space vehicle

AUTH: A/SCHWENZFEGER, K. J. PAA: A/(Muenchen, Technische Universitaet, Munich, West Germany)

CIO: GERMANY,FEDERAL REPUBLIC OF
American Astronautical Society and American Institute of Aeronautics and Astronautics, Astrodynamics Conference, Vail, Colo., July 16-18, 1973, AAS 27 p.

MAJS: /*BOUNDARY VALUE PROBLEMS/*LOW THRUST PROPULSION/*RUN TIME (COMPUTERS)/* SPACECRAFT TRAJECTORIES/*TRAJECTORY OPTIMIZATION

MINS: / CELESTIAL MECHANICS/ CONVERGENCE/ EQUATIONS OF MOTION/ ERROR ANALYSIS/ KEPLER LAWS/ LAGRANGE MULTIPLIERS

ABA: A.B.K.

ABS: Development of an improved formulation of the set of differential equations describing the motion and optimality conditions of a low-thrust space vehicle. The equations for the optimal trajectory of a space vehicle with a continuous low-thrust propulsion system are derived using regularized variables. In this case the regularization for both the state equations and the Lagrange multiplier equations is obtained by using only the classical Sundman (1912) time transformation. The numerical behavior of the derived system is investigated in two examples, in one of which numerical calculations are made of Keplerian orbits, while in the other two-dimensional minimum-time earth escape trajectories are calculated, starting from various orbits and using various vehicle characteristics.

70A18064*#   ISSUE 6   PAGE 1145   CATEGORY 30   RPT#: AIAA PAPER
70-214 70/01/00   16 PAGES
UNCLASSIFIED DOCUMENT

UTTL: Low-thrust trajectories using the two-variable asymptotic expansion methodUNOC: Heliocentric low thrust spacecraft trajectory analysis using two-variable asymptotic expansion method

AUTH: A/STAVRO, W.   PAN: (AA/CALIFORNIA INST. OF TECH., JET PROPULSION LAB.,PASADENA, CALIF./.)

SAP: MEMBERS, $1.00, NONMEMBERS, $1.50.

CIO: UNITED STATESNEW YORK, AMERICAN INST. OF AERONAUTICS AND ASTRONAUTICS, AMERICAN INST. OF AERONAUTICS AND ASTRONAUTICS, AEROSPACE SCIENCES MEETING, 8TH, NEW YORK, N.Y., JAN. 19-21, 1970.

MAJS: /*LOW THRUST PROPULSION/*SOLAR ORBITS/*SPACECRAFT TRAJECTORIES/*TRAJECTORY ANALYSIS

MINS: / APPROXIMATION/ ASYMPTOTIC METHODS/ COMPUTER PROGRAMS/ CONFERENCES/ ORBIT CALCULATION

74A42990 ISSUE 22 PAGE 3220 CATEGORY 30 74/00/00 110 PAGES
UNCLASSIFIED DOCUMENT COPYRIGHT

UTTL: Multilevel optimization of multiple arc trajectories

AUTH: A/SUGAR, R. D. PAA: A/(Hughes Aircraft Co., Space and Communications Group, El Segundo, Calif.)

CIO: UNITED STATES

In: Control and dynamic systems. (A74-42987 22-19) New York, Academic Press, Inc., 1974, p. 145-254.

MAJS: /*COMPLEX SYSTEMS/*CONTROL THEORY/*INTERPLANETARY TRAJECTORIES/*OPTIMAL CONTROL/*OUTER PLANETS EXPLORERS/*TRAJECTORY OPTIMIZATION

MINS: / ARCS/ DIFFERENTIAL EQUATIONS/ EQUATIONS OF MOTION/ FLIGHT PATHS/ HIERARCHIES/ LOW THRUST/ NUMERICAL ANALYSIS/ STATE VECTORS/ SWINGBY TECHNIQUE/ THRUST PROGRAMMING

ABA: G.R.

ABS: Attention is given to the numerical optimization of multiple arc trajectories by means of a technique developed from multilevel control theory. A multiple arc trajectory is the solution of a set of ordinary differential equations subject to discontinuities and constraints. A new computational technique for treating multiple arc problems is presented. The technique is an extension of a two-level trajectory decomposition algorithm originally developed as an application of multilevel control theory. The application of the new technique is demonstrated with the aid of an example involving the formulation and the numerical investigation of a multiple arc trajectory optimization problem. The problem is concerned with the flight of a continuously thrusting interplanetary probe on an Earth-Jupiter-Saturn swingby trajectory.

68A17534*# ISSUE 6 PAGE 1088 CATEGORY 30 RPT#: AIAA PAPER 68-116
68/01/00 17 PAGES UNCLASSIFIED DOCUMENT
UTTL: On randomly perturbed spacecraft trajectories.
UNOC: Statistics of spacecraft trajectories perturbed by random
forces
AUTH: A/WESSELING, P. PAN: (AA/CALIFORNIA INST. OF TECH., JET
PROPULSION LAB., PASADENA, CALIF./.)
SAP: MEMBERS, $1.00, NONMEMBERS, $1.50.
CIO: UNITED STATESNEW YORK, AMERICAN INST. OF AERONAUTICS AND
ASTRONAUTICS. AMERICAN INST.OF AERONAUTICS AND ASTRONAUTICS,
AEROSPACE SCIENCES MEETING, 6TH, NEW YORK, N.Y., JAN. 22-24,
1968,
MAJS: /*PERTURBATION THEORY/*RANDOM PROCESSES/*SPACECRAFT
TRAJECTORIES/*STATISTICAL ANALYSIS
MINS: / APPLICATIONS OF MATHEMATICS/ CONFERENCES/ LOW THRUST
PROPULSION/ MARKOV PROCESSES

68N10151# ISSUE 1 PAGE 134 CATEGORY 30 RPT#: ACIC-TC-1220
AD-656989 67/08/00 14 PAGES UNCLASSIFIED DOCUMENT
UTTL: The effect of tangential acceleration on the motion of a satellite
UNOC: Effect of tangential acceleration, created by low thrust engines, on satellite motion
AUTH: A/YEVTUSHENKO, YU. G.
CORP: Aeronautical Chart and Information Center, Saint Louis, MO.
CSS: (LINGUISTIC SECTION.)
CIO: U.S.S.R. TRANSL. INTO ENGLISH FROM PRIKL. MAT. I MEKH. /MOSCOW)/ ISSUE 3, 1966 P 594-598
MAJS: /*ACCELERATION (PHYSICS)/*EQUATIONS OF MOTION/*LOW THRUST PROPULSION
MINS: / ANALYSIS (MATHEMATICS)/ APPROXIMATION/ CIRCULAR ORBITS/ ORBITAL ELEMENTS / OSCILLATIONS/ SATELLITE ORIENTATION/ SPACECRAFT TRAJECTORIES

86X10297*# ISSUE 8 CATEGORY 13 RPT#: NASA-TM-88003 NAS 1.15:88003
CNT#: NASW-4004 86/03/00 259 PAGES
UNCLASSIFIED DOCUMENT US GOV AGENCIES AND CONTRACTORS

UTTL: Designing intraorbital spacecraft: Selection of trajectories and rated parameters

AUTH: A/ZAKHAROV, Y. A.

CORP: National Aeronautics and Space Administration, Washington, DC. MFC: E3

CIO: U.S.S.R. Transl. by Scientific Translation Service, Inc., Santa Barbara,Calif. Transl. into ENGLISH of ""Proyektirovaniye mezhorbital'nykh kosmicheskikh apparatov'' Moscow, USSR, Mashinostroyeniye Press, 1984 p 1-174

MAJS: /*INTRAORBIT TRANSFER VEHICLES/*ROCKET THRUST/*SPACECRAFT DESIGN/*SPACECRAFT TRAJECTORIES

MINS: / HIGH THRUST/ LOW THRUST

ABA: Author

ABS: Fundamentals are presented for the theory of designing intraorbital spacecraft (ISC) with high and low thrust engines. Methods are discussed for selecting the optimal rated parameters of the ISC, control of its engine and flight trajectory.