Atmospheric Interface Reentry Point Targeting Using Aerodynamic Drag Control

Josep Virgili,* Peter C. E. Roberts,† and Nathan C. Hara‡
Cranfield University, Cranfield, England MK43 0AL, United Kingdom

DOI: 10.2514/1.G000884

The ability to control the location of a spacecraft atmospheric interface reentry has been traditionally accomplished using propulsion. A novel technique is presented here where a predefined point of atmospheric interface reentry is achieved by adjusting the aerodynamic drag of a spacecraft in a circular orbit. If this method is employed at a sufficiently high starting altitude, any ground-track point accessible by the orbit can be targeted. This method can be broken up into two different parts. The first consists of finding the decay profile that achieves the desired reentry location. The second consists of keeping the spacecraft within this nominal decay trajectory, given the atmospheric uncertainty and other perturbations. The two parts of this method are presented here in detail. Finally, a case study is provided to demonstrate how this method could work in a realistic scenario and to evaluate its performance. The case study shows that a reentry point can be targeted with a 3σ error of less than 200 km, using a typical Global Positioning System for navigation. Finally, a discussion of potential applications is provided.

Nomenclature

A_{ref}	=	spacecraft's reference area, m^2
a	=	semimajor axis, m
a_D	=	acceleration due to drag, m/s^2
C_B	=	ballistic coefficient, m^2/kg
C_D	=	drag coefficient
H	=	atmospheric scale height, m
h	=	altitude, m
i	=	orbit inclination, rad
J_2	=	Earth's oblateness coefficient
m	=	spacecraft mass, kg
n	=	mean motion, rad/s
q	=	dynamic pressure, N/m^2
t	=	time, s
u	=	argument of latitude, rad
V	=	relative velocity of the flow, m/s
$\boldsymbol{x}$	=	state vector
λ	=	longitude, rad
μ	=	gravitational constant of the Earth, m^3/s^2
ρ	=	atmospheric density, kg/m^3
Φ	=	state transition function
ϕ	=	latitude, rad
Ω	=	right ascension of the ascending node, rad

I. Introduction

THE aerodynamic forces experienced by spacecraft orbiting in low Earth orbit are usually considered perturbations that need to be avoided or compensated. Although this is generally the case, these aerodynamic forces can be controlled and exploited to achieve a useful purpose. Research has already been conducted to use aerodynamic drag to perform an aerocapture, control a spacecraft orbit, rendezvous with another vehicle, do formation flight, and do constellation maintenance [1–8]. Also, the use of aerodynamic forces has also been studied to control the attitude of a spacecraft [9–11].

Here a novel method is presented where the aerodynamic drag is used to target the atmospheric interface reentry point of a spacecraft's decaying orbit. The method presented here has been only applied to circular orbits and its extension to eccentric orbits is left for future studies. The assumption of circular orbits is not only applied to the initial orbit, but is also enforced as the orbit decays. It is also important to note that the method presented here only controls the location of the atmospheric interface reentry point and not the landing or impact point (if the spacecraft was to survive reentry). The atmospheric interface reentry point, also known as the entry interface in the literature, can be defined as the point where the interaction of the spacecraft with the atmosphere is so great, in terms of aerodynamic forces, that these forces completely dominate the flight dynamics. The altitude when this occurs depends on the vehicle aerodynamic properties and the atmospheric conditions, but it is usually set between 120–90 km [12]. Here an intermediate altitude of 100 km has been selected.

The control of the aerodynamic drag is assumed to be achieved through the control over the ballistic coefficient. Therefore, the drag is modulated to achieve the desired decay rate at all times. How to control the ballistic coefficient of a spacecraft and its practical considerations are outside the scope of this paper, but it is not difficult to envision simple ways to do so. For example, changing the cross-sectional area of the spacecraft by changing the attitude of the spacecraft or by altering the geometry of a drag sail would do.

Changing the ballistic coefficient, by changing the cross-sectional area, for example, is enough to alter the drag that the spacecraft creates, but it is not enough to have knowledge of this drag. The knowledge of the atmospheric properties (mainly density) is required to bridge the gap between controlling the ballistic coefficient and controlling the drag. This information of the atmospheric conditions can be obtained by using atmospheric models (estimation) or by using in situ measurements by onboard sensors. A detailed analysis of how to obtain this information has also been left outside the scope of this paper.

The idea of using drag to control certain parameters of the atmospheric interface reentry location is not completely new. Some work has been done to use a sudden drag increase in the last few hours of the decay to reduce the uncertainty of the time and location of the reentry interface [13]. The same approach is taken in [14] where a sudden increase in drag in the last few orbits is used to make the spacecraft reenter over an unpopulated area and reduce the risk to population and property that any surviving parts that reach the ground might pose. These two works, using the same method, only provide a limited capability to change the atmospheric interface reentry location in the along-track direction. Because this is done close to the reentry interface, the accessible targets are limited to the locations defined (approximately) by the last few orbits' ground track (along track). The method presented here starts modulating the drag at much

Received 7 July 2014; revision received 12 October 2014; accepted for publication 13 October 2014; published online 28 January 2015. Copyright © 2014 by the American Institute of Aeronautics and Astronautics, Inc. All rights reserved. Copies of this paper may be made for personal or internal use, on condition that the copier pay the $10.00 per-copy fee to the Copyright Clearance Center, Inc., 222 Rosewood Drive, Danvers, MA 01923; include the code 1533-3884/15 and $10.00 in correspondence with the CCC.

*Researcher, Space Research Centre; j.virgilillop@cranfield.ac.uk.

†Lecturer, Space Research Centre; currently Lecturer, University of Manchester, Manchester, England M13 9PL, United Kingdom; p.c.e.roberts@cranfield.ac.uk.

‡Postgraduate Student, Space Research Centre; n.c.hara@cranfield.ac.uk.

Atmospheric Interface Reentry Point Targeting Using

United States. Congress

Atmospheric Interface Reentry Point Targeting Using:

Hayabusa2 Asteroid Sample Return Mission Masatoshi Hirabayashi,Yuichi Tsuda,2022-04-14 Hayabusa2 Asteroid Sample Return Mission Technological Innovation and Advances covers the second Japanese asteroid sample return mission The purpose of the mission is to survey the asteroid Ryugu s surface features touch down on the asteroid form an artificial crater by shooting an impactor and collect sample materials This book covers these operations along with everything known about key technologies hardware and ground systems upon Hayabusa2 s return to Earth in 2020 This book is the definitive reference on the mission and provides space and planetary scientists with information on established technologies to further advance the knowledge and technologies in future space exploration missions 2023 PROSE Awards Winner Finalist Chemistry Physics Astronomy and Cosmology Association of American Publishers Broadly and comprehensively covers technologies necessary for space exploration missions Provides a unique focus on small body exploration missions Covers landing and impact experiments during the proximity operations of Hayabusa2 *U.S. Marines in Vietnam: The war that would not end, 1971-1973* United States. Marine Corps. History and Museums Division,1991 **U.S. Marines In Vietnam: The War That Would Not End, 1971-1973** Melson, Charles D.,2018-09-17 U S Marines In Vietnam The War That Would Not End 1971 1973Charles D Melson Curtis G Arnold United States Marine Corps History and Museums Division This is the eighth volume of a projected nine volume history of Marine Corps operations in the Vietnam War A separate functional series complements the operational histories This volume details the activities of Marine Corps units after the departure from Vietnam in 1971 of III Marine Amphibious Force through to the 1973 ceasefire and includes the return of Marine prisoners of war from North Vietnam Written from diverse views and sources the common thread in this narrative is the continued resistance of the South Vietnamese Armed Forces in particular the Vietnamese Marine Corps to Communist aggression This book is written from the perspective of the American Marines who assisted them in their efforts Someday the former South Vietnamese Marines will be able to tell their own story **Hearings, Reports and Prints of the Senate Committee on Armed Services** United States. Congress. Senate. Committee on Armed Services,1972 **U.S. Marines in Vietnam** Charles D. Melson,Curtis G. Arnold,1991 Fiscal Year 1973 Authorization for Military Procurement, Research and Development, Construction Authorization for the Safeguard ABM, and Active Duty and Selected Reserve Strengths, Hearings ..., 92-2 ... United States. Congress. Senate. Armed Services,1972 *Journal of the British Interplanetary Society* ,1975

Technical Information Indexes ,1974 **International Aerospace Abstracts** ,1997 *Aviation Week & Space Technology* ,1997 *44th Congress of the International Astronautical Federation* ,1993 **Guidance and Control** ,1998

Technical Abstract Bulletin ,1980 **Daily Report** ,1996-02 **Aerospace America** ,2000 **Congressional Record** United States. Congress,1977-02-08 Tech Notes ,1984 *Management Information Systems: Army Catalog of Automated Data Systems* United States. Dept. of the Army,1971 *NASA Patent Abstracts Bibliography: A Continuing*

Bibliography. Section 2: Indexes (supplement 20) ,1982 *Masters Theses in the Pure and Applied Sciences Accepted by Colleges and Universities of the United States and Canada* Wade H. Shafer,1984-02-01 This series lists applicable thesis titles published in the United States and Canada Volume 40 covers thesis year 1995 All back volumes are still available

This is likewise one of the factors by obtaining the soft documents of this **Atmospheric Interface Reentry Point Targeting Using** by online. You might not require more era to spend to go to the book establishment as competently as search for them. In some cases, you likewise pull off not discover the notice Atmospheric Interface Reentry Point Targeting Using that you are looking for. It will enormously squander the time.

However below, bearing in mind you visit this web page, it will be consequently very easy to acquire as without difficulty as download lead Atmospheric Interface Reentry Point Targeting Using

It will not take many period as we tell before. You can do it though fake something else at house and even in your workplace. appropriately easy! So, are you question? Just exercise just what we pay for under as capably as evaluation **Atmospheric Interface Reentry Point Targeting Using** what you bearing in mind to read!

https://socketapi.adit.com/data/uploaded-files/default.aspx/new_general_mathematics_for_ss1_answers.pdf

Table of Contents Atmospheric Interface Reentry Point Targeting Using

Atmospheric Interface Reentry Point Targeting Using Introduction

In todays digital age, the availability of Atmospheric Interface Reentry Point Targeting Using books and manuals for download has revolutionized the way we access information. Gone are the days of physically flipping through pages and carrying heavy textbooks or manuals. With just a few clicks, we can now access a wealth of knowledge from the comfort of our own homes or on the go. This article will explore the advantages of Atmospheric Interface Reentry Point Targeting Using books and manuals for download, along with some popular platforms that offer these resources. One of the significant advantages of Atmospheric Interface Reentry Point Targeting Using books and manuals for download is the cost-saving aspect. Traditional books and manuals can be costly, especially if you need to purchase several of them for educational or professional purposes. By accessing Atmospheric Interface Reentry Point Targeting Using versions, you eliminate the need to spend money on physical copies. This not only saves you money but also reduces the environmental impact associated with book production and transportation. Furthermore, Atmospheric Interface Reentry Point Targeting Using books and manuals for download are incredibly convenient. With just a computer or smartphone and an internet connection, you can access a vast library of resources on any subject imaginable. Whether youre a student looking for textbooks, a professional seeking industry-specific manuals, or someone interested in self-improvement, these digital resources provide an efficient and accessible means of acquiring knowledge. Moreover, PDF books and manuals offer a range of benefits compared to other digital formats. PDF files are designed to retain their formatting regardless of the device used to open them. This ensures that the content appears exactly as intended by the author, with no loss of formatting or missing graphics. Additionally, PDF files can be easily annotated, bookmarked, and searched for specific terms, making them highly practical for studying or referencing. When it comes to accessing Atmospheric Interface Reentry Point Targeting Using books and manuals, several platforms offer an extensive collection of resources. One such platform is Project Gutenberg, a nonprofit organization that provides over 60,000 free eBooks. These books are primarily in the public domain, meaning they can be freely distributed

and downloaded. Project Gutenberg offers a wide range of classic literature, making it an excellent resource for literature enthusiasts. Another popular platform for Atmospheric Interface Reentry Point Targeting Using books and manuals is Open Library. Open Library is an initiative of the Internet Archive, a non-profit organization dedicated to digitizing cultural artifacts and making them accessible to the public. Open Library hosts millions of books, including both public domain works and contemporary titles. It also allows users to borrow digital copies of certain books for a limited period, similar to a library lending system. Additionally, many universities and educational institutions have their own digital libraries that provide free access to PDF books and manuals. These libraries often offer academic texts, research papers, and technical manuals, making them invaluable resources for students and researchers. Some notable examples include MIT OpenCourseWare, which offers free access to course materials from the Massachusetts Institute of Technology, and the Digital Public Library of America, which provides a vast collection of digitized books and historical documents. In conclusion, Atmospheric Interface Reentry Point Targeting Using books and manuals for download have transformed the way we access information. They provide a cost-effective and convenient means of acquiring knowledge, offering the ability to access a vast library of resources at our fingertips. With platforms like Project Gutenberg, Open Library, and various digital libraries offered by educational institutions, we have access to an ever-expanding collection of books and manuals. Whether for educational, professional, or personal purposes, these digital resources serve as valuable tools for continuous learning and self-improvement. So why not take advantage of the vast world of Atmospheric Interface Reentry Point Targeting Using books and manuals for download and embark on your journey of knowledge?

FAQs About Atmospheric Interface Reentry Point Targeting Using Books

What is a Atmospheric Interface Reentry Point Targeting Using PDF? A PDF (Portable Document Format) is a file format developed by Adobe that preserves the layout and formatting of a document, regardless of the software, hardware, or operating system used to view or print it. **How do I create a Atmospheric Interface Reentry Point Targeting Using PDF?** There are several ways to create a PDF: Use software like Adobe Acrobat, Microsoft Word, or Google Docs, which often have built-in PDF creation tools. Print to PDF: Many applications and operating systems have a "Print to PDF" option that allows you to save a document as a PDF file instead of printing it on paper. Online converters: There are various online tools that can convert different file types to PDF. **How do I edit a Atmospheric Interface Reentry Point Targeting Using PDF?** Editing a PDF can be done with software like Adobe Acrobat, which allows direct editing of text, images, and other elements within the PDF. Some free tools, like PDFescape or Smallpdf, also offer basic editing capabilities. **How do I convert a Atmospheric Interface Reentry Point Targeting Using PDF to another file format?** There are multiple ways

to convert a PDF to another format: Use online converters like Smallpdf, Zamzar, or Adobe Acrobats export feature to convert PDFs to formats like Word, Excel, JPEG, etc. Software like Adobe Acrobat, Microsoft Word, or other PDF editors may have options to export or save PDFs in different formats. **How do I password-protect a Atmospheric Interface Reentry Point Targeting Using PDF?** Most PDF editing software allows you to add password protection. In Adobe Acrobat, for instance, you can go to "File" -> "Properties" -> "Security" to set a password to restrict access or editing capabilities. Are there any free alternatives to Adobe Acrobat for working with PDFs? Yes, there are many free alternatives for working with PDFs, such as: LibreOffice: Offers PDF editing features. PDFsam: Allows splitting, merging, and editing PDFs. Foxit Reader: Provides basic PDF viewing and editing capabilities. How do I compress a PDF file? You can use online tools like Smallpdf, ILovePDF, or desktop software like Adobe Acrobat to compress PDF files without significant quality loss. Compression reduces the file size, making it easier to share and download. Can I fill out forms in a PDF file? Yes, most PDF viewers/editors like Adobe Acrobat, Preview (on Mac), or various online tools allow you to fill out forms in PDF files by selecting text fields and entering information. Are there any restrictions when working with PDFs? Some PDFs might have restrictions set by their creator, such as password protection, editing restrictions, or print restrictions. Breaking these restrictions might require specific software or tools, which may or may not be legal depending on the circumstances and local laws.

Find Atmospheric Interface Reentry Point Targeting Using :

new general mathematics for ss1 answers
modern physical organic chemistry student solutions manual
natural hazards disaster management cbse
nahmias production and operations analysis
~~n4 industrial electronics question paper and memorandum~~
network analysis synthesis semester iii electronics
n844 engine
moonchild aleister crowley
nana syaodih sukmadidinata metode penelitian pendidikan
~~multivariate statistics lecture notes mit opencourseware~~
msc zoology entrance previous question paper
nafasi za kazi halmashauri ya manispaa ya dodoma
multinational management cullen 5th edition test bank
modern standard arabic grammar a learners guide

my funny valentine solo chet baker transcription

Atmospheric Interface Reentry Point Targeting Using :

From Prim to Improper (Harlequin Presents Extra Series ... Andreas will employ the unworldly beauty to work for him—where he can keep an eye on her! Only, Elizabeth's delectable curves keep getting in the way, and soon ... From Prim to Improper (eBook) Elizabeth Jones thought she was meeting her father for the first time. But ruthless tycoon Andreas Nicolaides has other plans for this frumpy arrival on his ... From Prim to Improper (Harlequin Presents Extra Andreas will employ the unworldly beauty to work for him—where he can keep an eye on her! Only, Elizabeth's delectable curves keep getting in the way, and soon ... Harlequin Presents Extra Series in Order From Prim to Improper by Cathy Williams, May-2012. 198, After the Greek Affair by Chantelle Shaw, May-2012. 199, First Time Lucky? by Natalie Anderson, May-2012. Harlequin Presents Extra Large Print Series in Order Harlequin Presents Extra Large Print Series in Order (44 Books) ; 196, The Ex Factor by Anne Oliver, Apr-2012 ; 197, From Prim to Improper by Cathy Williams, May- ... Publisher Series: Harlequin Presents Extra From Prim to Improper = Powerful Boss, Prim Miss Jones by Cathy Williams, 197. After the Greek Affair by Chantelle Shaw, 198. First Time Lucky? (Harlequin ... Harlequin – UNSUITABLE Harlequin continued to reject books with explicit sex even when other publishers had wild success selling and marketing books with sexier content than the prim ... Inherited by Her Enemy (Harlequin Presents) by Sara Craven She included a lot of little extras(some going nowhere) in the story that I think detracted from the romance that should have been there. There were quite a few ... From Prim To Improper Harlequin Presents Extra In a fast-paced digital era where connections and knowledge intertwine, the enigmatic realm of language reveals its inherent magic. Test Bank For Fundamentals of Anatomy & Physiology ... Nov 11, 2023 — This is a Test Bank (Study Questions) to help you study for your Tests. ... Martini, Judi Nath & Edwin Bartholomew 9780134396026 | Complete Guide ... Fundamentals of Anatomy & Physiology 11th Edition TEST ... Oct 28, 2023 — test bank by frederic martini author judi nath. author edwin bartholomew author latest. verified review 2023 practice questions and answer ... Fundamentals of Anatomy & Physiology 11th Edition ... Oct 5, 2023 — TEST BANK FOR FUNDAMENTALS OF ANATOMY & PHYSIOLOGY 11TH EDITION, MARTINI, NATH, BARTHOLOMEW Contents: Chapter 1. An Introduction to Anatomy ... Test Bank For Fundamentals Of Anatomy & Physiology ... ... martini-judi-l-nath-edwin-f-bartholomew. Fundamentals of Anatomy & Physiology, 11th edition Test Bank 2 Anatomy and physiology TB. The nervous tissue outside ... Fundamentals of Anatomy & Physiology 11th Edition by ... Jan 11, 2023 — ... Nath (Author), Edwin Bartholomew (Author), TEST BANK Latest Verified Review 2023 Practice Questions and Answers for Exam Preparation, 100 ... Test Bank for Fundamentals of Anatomy Physiology Global ... Test Bank for Fundamentals of Anatomy Physiology Global Edition 10 e Frederic h Martini Judi l Nath Edwin f Bartholomew - Free download as PDF File (.pdf), ... Fundamentals of Anatomy and Physiology 9th Edition ...

Fundamentals of Anatomy and Physiology 9th Edition Martini Test Bank ... Nath, Judi L., Bartholomew, Edwin F. (Hardc. 5,402 529 47KB Read more. Fundamentals Of ... Test Bank for Fundamentals of Anatomy Physiology 11th ... Use Figure 9-2 to answer the following questions: 67) Identify the type of joint at label "1." A) hinge. B) condylar. C) gliding Fundamentals of Anatomy and Physiology 11th Edition ... Aug 29, 2022 — Fundamentals of Anatomy and Physiology 11th Edition Martini Nath Bartholomew Test Bank, To clarify this is a test bank not a textbook . Test Bank for Visual Anatomy & Physiology 3rd Edition by ... View Assignment - Test Bank for Visual Anatomy & Physiology 3rd Edition by Frederic Martini.pdf from NURS 345 at Nursing College. New York, New York!: The Big Apple from A to Z From bestselling duo Laura Krauss Melmed and Frané Lessac comes an alphabetical picture book tour of one of the greatest cities in the world, New York! New York, New York!- The Big Apple from A to Z From bestselling duo Laura Krauss Melmed and Frané Lessac comes an alphabetical picture book tour of one of the greatest cities in the world, New York! New York, New York: The Big Apple from A to Z - YouTube New York, New York!: The Big Apple from A to Z The book includes an abundance of brightly colored, folk-art-style illustrations, and an excellent map locates each place mentioned. This book is certain to be ... New York, New York!: The Big Apple from A to Z - Hardcover From bestselling duo Laura Krauss Melmed and Frané Lessac comes an alphabetical picture book tour of one of the greatest cities in the world, New York! New York, New York!: The Big Apple from A to Z From bestselling duo Laura Krauss Melmed and Frané Lessac comes an alphabetical picture book tour of one of the greatest cities in the world, New York! The Big Apple from A to Z by Laura Krauss Melmed Synopsis: From bestselling duo Laura Krauss Melmed and Frané Lessac comes an alphabetical picture book tour of one of the greatest cities in the world, New York ... New York, New York!: The Big Apple from A to Z This book takes you on an alphabetical tour of New York City/the Big Apple. It is a whimsical guide to some of the city's most famous and historical attractions ... New York New York: The Big Apple from A to Z This city has something to offer everyone, from A to Z. Come visit the American Museum of Natural History and see prehistoric Animals, get a Bird's-eye view of ... New York, New York! The Big Apple from A to Z Annotation: An alphabetical picture book tour of New York City from the team that brought us Capital! Washington D.C. from A to Z.