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Satellite Meteorology
Model of the upper atmosphere from 130 through 1600 km, derived from satellite orbits
The Upper Atmosphere and Its Influence on Satellite Orbits
Prediction of Low Eccentricity Satellite Orbits Considering Earth Oblateness and Atmospheric Drag
Satellite Orbits

Secular Effect of Atmospheric Drag on Satellite Orbits
Derelict satellites, equipment and other debris orbiting Earth (aka space junk) have been accumulating for many decades and could damage or even possibly destroy satellites and human spacecraft if they collide. During the past 50 years, various National Aeronautics and Space Administration (NASA) communities have contributed significantly to maturing meteoroid and orbital debris (MMOD) programs to their current state. Satellites have been redesigned to protect critical components from MMOD damage by moving critical components from exterior surfaces to deep inside a satellite’s structure. Orbits are monitored and altered to minimize the risk of collision with tracked orbital debris. MMOD shielding added to the International Space Station (ISS) protects critical components and astronauts from potentially catastrophic damage that might result from smaller, untracked debris and meteoroid impacts. Limiting Future Collision Risk to Spacecraft: An Assessment of NASA's Meteoroid and Orbital Debris Program examines NASA's efforts to understand the meteoroid and orbital debris environment, identifies what NASA is and is not doing to mitigate the risks posed by this threat, and makes recommendations as to how they can improve their programs. While the report identified many positive aspects of NASA's MMOD programs and efforts including responsible use of resources, it recommends that the agency develop a formal strategic plan that provides the basis for prioritizing the allocation of funds and effort over various MMOD program needs. Other necessary steps include improvements in long-term modeling, better measurements, more regular updates of the debris environmental models, and other actions to better characterize the long-term evolution of the debris environment.

Upper-atmosphere Desity During the Years 1957 to 1961, Determined from Satellite Orbits
An Empirical Model of Long-term Thermospheric Density Change

Further Determination of Upper-atmosphere Rotational Speed from Analysis of Satellite Orbits

University Physics

Limiting Future Collision Risk to Spacecraft At last, a book that has what every atmospheric science and meteorology student should know about satellite meteorology: the orbits of satellites, the instruments they carry, the radiation they detect, and, most importantly, the fundamental atmospheric data that can be retrieved from their observations. Key Features * Of special interest are sections on: * Remote sensing of atmospheric temperature, trace gases, winds, cloud and aerosol data, precipitation, and radiation budget * Satellite image interpretation * Satellite orbits and navigation * Radiative transfer fundamentals

Satellite Orbits in an Atmosphere

Atmospheric Satellite Observations

Theory of Satellite Orbits in an Atmosphere Fifty years after Sputnik, artificial satellites have become indispensable monitors in many areas, such as economics, meteorology, telecommunications, navigation and remote sensing. The specific orbits are important for the proper functioning of the satellites. This book discusses the great variety of satellite orbits, both in shape (circular to highly elliptical) and properties (geostationary, Sun-synchronous, etc.). This volume starts with an introduction into geodesy. This is followed by a presentation of the fundamental equations of mechanics to explain and demonstrate the properties for all types of orbits. Numerous examples are included, obtained through IXION software developed by the author. The book also includes an exposition of the historical background that is necessary to help the reader understand the main stages of scientific thought from Kepler to GPS. This book is intended for researchers, teachers and students working in the field of satellite technology. Engineers, geographers and all those involved in space exploration will find this information valuable. Michel Capderou's book is an essential treatise in orbital mechanics for all students, lecturers and practitioners in this field, as well as other aerospace systems engineers. —Charles Elachi, Director, NASA Jet Propulsion Laboratory

Secular Effects of Atmospheric Drag on Satellite Orbits

Further Determinations of Upper-atmosphere Rotational Speed from Analysis of Satellite Orbits by D.G.King-Hele and Diana W.Scott We review and interpret the values of upper-atmosphere rotation rate (zonal winds) obtained by analysing satellite orbits determined from observations. The history of the method are answered, and three examples are given. Existing analyses of the atmospheric rotation rate, Lambda, are critically reviewed, and, after rejecting some and revising others, we are left with 85 values. These are divided according to local time and season, to give the variation of Lambda with height in nine situations: morning, evening and average local time, for summer, winter and average season. These observational results indicate that the value of (in rev/day), averaged over both local time and season, increases from 1.0 at 125 km to 1.22 at 325 km and then decreases to 1.0 at 430 km and 0.82 at 600 km. The value of Lambda is higher in the evening (18-24 h), with a maximum value (near 1.4) corresponding to a west-to-east wind of 150 m/s at heights near 300 km. The value of Lambda is lower in the morning (06-12 h), with east-to-west winds of order 50 m/s at heights of 200-400 km. There is also a consistent seasonal variation, the values of Lambda being on average 0.15 higher in winter and 0.1 lower in summer than the average seasonal value. No significant variation with solar activity is found, but there is a slight tendency for a greater rotation rate at lower latitudes for heights above 300 km.

The Rotational Speed of the Upper Atmosphere, Determined from Changes in Satellite Orbits
Thermospheric Density and Wind Determination from Satellite Dynamics This report describes a simple technique for determining the effects of air drag on a nearly circular satellite orbit. Over any single orbit, the change in orbital period and radius can be obtained as a function of $\text{sub D A/M}$. Several graphs are included where $\text{Sub D}$ with observations of the ANNA 1b Satellite.

The Contraction of Satellite Orbits Under the Influence of Air Drag This modern presentation guides readers through the theory and practice of satellite orbit prediction and determination. Starting from the basic principles of orbital mechanics, it covers elaborate force models as well as precise methods of satellite tracking. The accompanying CD-ROM includes source code in C++ and relevant data files for applications. The result is a powerful and unique spaceflight dynamics library, which allows users to easily create software extensions. An extensive collection of frequently updated Internet resources is provided through WWW hyperlinks.

Upper-atmosphere Density During the Years 1957 to 1961, Determined from Satellite Orbits

The Effect of the Earth's Oblateness and Atmosphere on a Satellite Orbit

The Decrease in Upper-atmosphere Density Between 1957 and 1963, as Revealed by Satellite Orbits

GPS-satellite Orbits and Atmospheric Effects The orbits of Earth satellites with perigee heights less than 600km are liable to be appreciably perturbed by the aerodynamic forces resulting from winds in the upper atmosphere, and analysis of the changes in the orbits provides a method of determining zonal (west-to-east) and meridional (north-to-south) winds. The theory hitherto used has been developed for orbits of eccentricity $e \leq 0.2$. Here we develop the theory for the effect of zonal and meridional winds on the inclination $i$ and right ascension of the node $\omega$ for satellites in orbits with $e > 0.2$ moving in an oblate atmosphere. The results are expressed in terms of the change in orbital period, which is accurately known for actual satellites, so that the equations are independent of variations in air density and satellite cross-sectional area.

Theory of Satellite Orbits in an Atmosphere The paper describes the method for determining the rotational speed of the Earth's upper atmosphere from the changes in the orbital inclinations of satellites, and briefly reviews the observational results so far obtained at heights above 180 km, both by this method and by measuring the movements of vapour trails. The results from satellite orbits indicate that the upper atmosphere at heights of 200-300 km is on average rotating 1.3 times faster than the Earth, corresponding to a mean west-to-east wind of about 100 m/s in mid latitudes. The physical processes which may control upper-atmosphere movements are outlined, and possible mechanisms for the observed motions are briefly discussed. It should be emphasized that the subject is full of uncertainties, and this paper is intended to draw attention to the difficulties, rather than to provide a coherent picture of the actual conditions. (Author).

A Tapestry of Orbits

Scale Height in the Upper Atmosphere, Derived from Changes in Satellite Orbits The rotation of the upper atmosphere subjects a satellite to an aerodynamic force normal to the orbit, which has the effect of slightly reducing the inclination of the orbit to the equator. The average rotational speed of the upper atmosphere at heights a little above that of perigee can be evaluated from the observed changes in orbital inclination. Since the change in inclination is small (less than 0.1 degree), the values generally have to be averaged over several months, and they can also be regarded as applying over latitudes up to about half the inclination, the effects being strongest at the equator. Recent results reviewed in the report confirm a previous finding that the upper atmosphere at heights of 200 to 350 km rotates on average faster than the Earth, and that the average rate of rotation increases with height from about 1.1 rev/day at 200 km to nearly 1.4 rev/day at 350 km. However, it appears that the rotation rate decreases above 350 km, to about 1.0 rev/day at 420 km and 0.7 rev/day at 500 km. (Author).

Satellite Communications Systems Engineering The Earth's atmosphere is often portrayed as a thin and finite blanket covering our planet, separate from the emptiness of
outer space. In reality, the transition is gradual and a tiny fraction of the atmosphere gases is still present at the altitude of low orbiting satellites. The very high velocities of these satellites ensure that their orbital motion can still be considerably affected by air density and wind. This influence can be measured using accelerometers and satellite tracking techniques. The opening chapters of this thesis provide an excellent introduction to the various disciplines that are involved in the interpretation of these observations: orbital mechanics, satellite aerodynamics and upper atmospheric physics. A subsequent chapter, at the heart of this work, covers advances in the algorithms used for processing satellite accelerometry and Two-Line Element (TLE) orbit data. The closing chapters provide an elaborate analysis of the resulting density and wind products, which are generating many opportunities for further research, to improve the modelling and understanding of the thermosphere system and its interactions with the lower atmosphere, the ionosphere-magnetosphere system and the Sun.

The Effect of Atmospheric Winds on Satellite Orbits of High Eccentricity The first edition of Satellite Communications Systems Engineering (Wiley 2008) was written for those concerned with the design and performance of satellite communications systems employed in fixed point to point, broadcasting, mobile, radio navigation, data relay, computer communications, and related satellite based applications. This welcome Second Edition continues the basic premise and enhances the publication with the latest updated information and new technologies developed since the publication of the first edition. The book is based on graduate level satellite communications course material and has served as the primary text for electrical engineering Masters and Doctoral level courses in satellite communications and related areas. Introductory to advanced engineering level students in electrical, communications and wireless network courses, and electrical engineers, communications engineers, systems engineers, and wireless network engineers looking for a refresher will find this essential text invaluable.

Satellite Orbits Under the Influence of Air Drag, Rotating Oblate Atmosphere, and Planet's Oblateness

The Rotational Speed of the Upper Atmosphere, Determined from Changes in Satellite Orbits by D.G. King-Hele

The Rotational Speed of the Upper Atmosphere: a Review The story of how small changes in satellite orbits have led to great changes in our views of the Earth and atmosphere is told in this narrative from the pioneer of this orbit analysis technique.

Handbook of Satellite Orbits Atmospheric Satellite Observations: Variation Assimilation and Quality Assurance provides an invaluable reference for satellite data assimilation. Topics covered include linear algebra, frequently used statistical methods, the interpolation role of function fitting, filtering when dealing with real observations, minimization in data assimilation systems, 3D-Var and the inverse problem it solves, 4D-Var and adjoint techniques, and much more. The book concludes with satellite observation of hurricanes. Contains mathematical concepts from several branches of study, including calculus, linear algebra, probability theory, functional analysis, and minimization illustrates quality assurance for satellite observations using real data examples. Includes a dedicated chapter on how different satellite instruments see hurricanes Reviews theory, system development, and the numerical experiments of three- and four-dimensional variational data assimilation (3D-Var/4D-Var)

Theory of Satellite Orbits in an Atmosphere

Satellite Orbit Considerations for a Global Change Technology Architecture Trade Study

Measurements of Upper-Atmosphere Rotational Speed from Changes in Satellite Orbits University Physics is designed for the two- or three-semester calculus-based physics course. The text has been developed to meet the scope and sequence of most university physics courses and provides a foundation for a career in mathematics, science, or engineering. The book provides an important opportunity for students to learn the core concepts of physics and understand how those concepts apply to their lives and to the world around them. Due to the comprehensive nature of the material, we are offering the book in three volumes for flexibility and efficiency. Coverage and Scope Our University Physics textbook adheres to the scope and sequence of most two- and three-semester physics courses nationwide. We have worked to make
physics interesting and accessible to students while maintaining the mathematical rigor inherent in the subject. With this objective in mind, the content of this textbook has been developed and arranged to provide a logical progression from fundamental to more advanced concepts, building upon what students have already learned and emphasizing connections between topics and between theory and applications. The goal of each section is to enable students not just to recognize concepts, but to work with them in ways that will be useful in later courses and future careers. The organization and pedagogical features were developed and vetted with feedback from science educators dedicated to the project.

**VOLUME I Unit 1: Mechanics**

- Chapter 1: Units and Measurement
- Chapter 2: Vectors
- Chapter 3: Motion Along a Straight Line
- Chapter 4: Motion in Two and Three Dimensions
- Chapter 5: Newton's Laws of Motion
- Chapter 6: Applications of Newton's Laws
- Chapter 7: Work and Kinetic Energy
- Chapter 8: Potential Energy and Conservation of Energy
- Chapter 9: Linear Momentum and Collisions
- Chapter 10: Fixed-Axis Rotation
- Chapter 11: Angular Momentum
- Chapter 12: Static Equilibrium and Elasticity
- Chapter 13: Gravitation
- Chapter 14: Fluid Mechanics

**Unit 2: Waves and Acoustics**

- Chapter 15: Oscillations
- Chapter 16: Waves
- Chapter 17: Sound

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**The Contraction of Satellite Orbits Under the Influence of Air Drag**

**Part 1: with Spherically Symmetrical Atmosphere**

**The Contraction of Satellite Orbits Under the Influence of Air Drag: With spherically symmetrical atmosphere**

**Atmospheric Perturbations on Nearly Circular Satellite Orbits**

**Average Rotational Speed of the Upper Atmosphere from Changes in Satellite Orbits**

**Satellite Meteorology** Predicting the positions of satellites in Low Earth Orbit (LEO) requires a comprehensive understanding of the dynamic nature of the atmosphere. For objects in LEO the most significant orbit perturbation is atmospheric drag, which is a function of the local atmospheric density from a layer in the atmosphere called the thermosphere. For long-term predictions of satellite orbits and ephemerides, any density trend in the thermosphere is a necessary consideration, not only for satellite operators, but also for studies of the future LEO environment in terms of space debris. Numerous studies of long-term thermospheric density change have been performed. Predictions by Roble & Ramesh (2002), along with evidence by Keating (2000), Emmert et al. (2004), Marcos et al. (2005), Qian et al. (2006) and Emmert et al. (2008), strongly suggest the existence of such a phenomenon. Therefore, the objective of the research presented in this thesis is to provide a novel method to evaluate quantitatively thermospheric density change. Satellite drag data is an effective medium through which one can investigate local thermospheric density and changes thereof. There are many ways of determining atmospheric density, but inferring thermospheric density from satellite drag data is a relatively cost-effective way of gathering in-situ measurements. To do this, knowledge about a satellite's physical properties that are intrinsic to atmospheric drag is required. A study by Saunders et al. (2009) highlighted problems with estimating a satellite's physical properties directly from data given explicitly by Two-Line Element (TLE) sets. This prompted an investigation into ways to estimate ballistic coefficients: a required satellite parameter associated with drag coefficient and area-to-mass ratio. A novel way of estimating satellite ballistic coefficients was derived and is presented in this thesis. Additionally, novel consideration of atmospheric chemical composition was applied on long-term drag coefficient variability. Using a quantitative estimate of a ballistic coefficient one can propagate numerically a satellite's orbit and predict the effects of atmospheric drag. Given an initial satellite orbit from TLE data, one approach is to use an orbital propagator to predict the satellite's state at some time ahead and then to compare that state with TLE data at the same epoch. The difference between the semi-major axes of the initial orbit and that after the orbit propagation is then integrated and can be used to estimate the global average density. The method employed in this study utilises this process. To achieve this, a specially developed, computer-based, numerical orbital propagator was written in the programming language C/C++. The underlying theories and implementation tests for this propagator are presented in this thesis.

**Model of the upper atmosphere from 130 through 1600 km, derived from satellite orbits**

**The Upper Atmosphere and Its Influence on Satellite Orbits** The chief variations in upper-atmosphere density are described, and it is shown how each of them affects the orbits of close Earth satellites. The main features discussed are: (1) the irregular variations in density dependent on solar activity, which may cause great changes in a
few days, as well as a 27-day recurrence tendency; (2) the day-to-night and semi-annual variations in density, which cause nearly-periodic changes in orbits: for the day-
to-night variation the period is usually between 2 months and 2 years, while the semi-annual effect leads to maxima of density in April and October, and minima in
January and July; and (3) the large changes in density during a sunspot cycle, which give rise to a 10- or 11-year recurrence tendency. The changes in orbital inclination
caused by the rotation of the atmosphere are also described. (Author).

Prediction of Low Eccentricity Satellite Orbits Considering Earth Oblateness and Atmospheric Drag

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