THE USE OF THE TETHERED SATELLITE SYSTEM TO PERFORM LOW DENSITY AEROTHERMODYNAMICS STUDIES

Giovanni M. CARLOMAGNO - Luigi de LUCA*

Paul M. SIEMERS - George M. WOOD Jr.**

Abstract

The Tethered Satellite System (TSS) is a cooperative space system development activity being carried out by USA and Italy.

Within TSS, the Shuttle Tethered Aerothermodynamic Research Facility (STARFAC) concept has the potential to provide access to vast portions of the upper atmosphere for the purpose of atmospheric and aerothermodynamic research. The implementation of this capability will push Tether System (TS) state of the art to its limits; the primary problems being tether/satellite drag, heating, tension control, deployment/retrieval control. In this paper parametric studies are accomplished to assess some of these problems and to delineate the tradeoffs available to missions design to meet the engineering constraints. The utilization of aerodynamic rather than spherical shapes - (TSS) - as well as elementary satellite thrusting and lift are included in the present study.

1. Introduction

The recent growing interest of various aerospace vehicle programs has resulted in an urgent requirement for detailed studies related to the aerodynamics of very low density gas flows [1,2].

Modelling of rarefied gas flows may be basically based on the Boltzmann equation or on the Direct Simulation Monte Carlo (DSMC) method [3]. However, some analytical and/or numerical difficulties exist when such methods are applied to engineering problems. For example, presently there are serious deficiencies in the physical database required for the application of the DSMC method to aerothermodynamic studies, the major problem being the lack of information on gas-surface interactions under orbital conditions.

On the other hand, measurements of aerodynamic forces and heat fluxes carried out on models tested in hypersonic transitional wind tunnels, do not have full credibility because of: the inability to reproduce simultaneously Mach, Reynolds and Knudsen numbers; the short measurement time in the shock tunnels; the non real composition of the gas in the test section; the low resolution due to the size of test model. Similarly, direct measurements in the upper atmosphere, so far performed generally by use of a vehicle passing through the region of interest, are very difficult to carry out because of the cost of such instruments, the limited launch sites and the handicap of obtaining a single profile at a specific location in each survey.

To the end of overcoming the above limitations, detailed studies relative to aerothermodynamics of low density gas flows are the object of three experiments sponsored by Orbiter Experiments (OEX) Programs of NASA, the Shuttle Entry Air Data

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* Faculty of Engineering, University of Naples - P.le Tecchio, 80 80125 Naples (Italy)

** NASA Langley Research Center, Hampton, VA 23665 (USA)

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System (SEADS), the Shuttle Upper Atmospheric Mass Spectrometer (SUMS) and the High Resolution Accelerometer Package (HIRAP), as well as of three proposed flight programs, the AOTV Flight Experiment (AFE), the Entry Research Vehicle (ERV), and the Shuttle Tethered Aerothermodynamic Research Facility (STARFAC) [4], which makes use of the Tethered Satellite System (TSS).

2. The STARFAC program

The Tethered Satellite System is a cooperative space system deployer development activity being carried out by the United States and Italy. TSS is comprised of two major elements: the Tether Satellite (TS) and the deployer. TS, which is in the basic configuration a sphere, provides accomodations for scientific experiments to be performed up to 100 Km from the orbiter. The deployer will deploy, operate and retrieve the satellite in space utilizing a control system to maintain the system at selected orbital altitudes.

The United States'National Aeronautics and Space Administration (NASA) is responsible for deployer development and overall system integration. Italy's Piano Spaziale Nazionale (PSN) of the Consiglio Nazionale delle Ricerche (CNR) is responsible for development of the satellite. A joint U.S.A./Italian science program is planned which evolved from initial studies beginning in the sixties and is being designed as a reusable facility.

The primary objective of STARFAC is to investigate the energy and momentum transfer between TS and its environmental medium within the range of the thermo-fluid-dynamic conditions experienced during TTS atmospheric flights. The research also includes characterization of the upper atmosphere. The uniqueness of STARFAC approach lies in the fact that it allows the accomplishment of a complete set of in-situ measurements within the extended range of flight conditions and the long operational time provided by TTS.

3. Simulation studies

In order to determine the feasibility of STARFAC concepts, a mission simulation technique which is based on the SKYHOOK program [5], has been employed. SKYHOOK, originally developed at the Smithsonian Astrophysical Observatory, evolved into a computer code of great generality and analytical sophistication with capabilities to analyze a broad range of tether related problems and missions. The Shuttle Orbiter and TS are modeled by mass points; the tether may be lumped in part into the orbiter and the satellite, or be represented independently by an arbitrary number of connected masspoints. If mass points are used, their number increases or decreases as the tether is deployed or recovered respectively. The state vector, and the temperature, of each element (orbiter, tether, satellite) is determined by integrating a set of differential equations, the equations of motion and energy equation. Both thermal and elastic expansions of tether are considered in the solution as TSS moves in a detailed model of Earth's gravity field which optionally includes gravity harmonics as well as solar and lunar pertubations. The Earth's magnetic field is modeled to account for electrodynamic forces and, more importantly for STARFAC simulation purposes, aerodynamic drag on TSS may be included.

Since SKYHOOK was not developed to accomplish system simulations at the altitudes required by the STARFAC feasibility studies, a low altitude capability and atmosphere model have been added to permit program operation for STARFAC simulations.

Data referring to a deployment from the Orbiter at 220 Km on a 28° inclined circular orbit to a satellite altitude of 100 Km are shown in Figs. 1-2. Fig. 1 presents the satellite radial displacement versus the satellite in-place displacement. The in-plane fore-and aft- oscillations of Fig. 1 occur during inclined orbits about an oblate Earth when a targeted or desired difference in geocentric altitudes of the Orbiter and TS is maintained precisely. The oscillations result from changes in altitudes due to the oblate Earth and consequently in variations in atmospheric density along the satellite's orbit, which result in a varying drag; Fig. 2 shows the out-of-plane displacements versus time at 30 Km locations along the tether. The out-of-plane oscillations, which increase moving from Orbiter to TS, are mainly due to the out-of-plane component of drag caused by the rotating atmosphere.

Note that, while the feasibility of deploying a tethered satellite up to an altitude of 100 Km seems established, techniques to extend the TSS operational range below 100 Km are presently being investigated. The main problems consist in the difficulty of entering the tethered satellite into the atmosphere below 100 Km. It has been shown |6| that much of the deployment time is consumed during the tether deployment at lower altitudes. This results in a significant difference between the target deployment lenght and the actual tether length, the latter being much longer than the former. Different techniques have been proposed to extend the TSS operational range below 100 Km, which make use of thrusting or lifting surfaces.

Satellite thrust could provide a capability to deploy satellite to altitudes below 100 Km. Numerical simulations have been carried on the basic configuration of the system for approximately seven orbits for mission completeness. Thrust vector is considered directed 33° below horizontal. The trusting ΔV manoeuvre has been estimated to be equal to 16.6 Km/s for deployment and 17.0 Km/s per orbit. In the case of the thrusting an attitude control is required to maintain thrust vector alignment. Fig. 3 shows the radial displacement versus the in-plane displacement attained by using a four body model. Fig. 4 presents the altitude versus time. As it may be seen , preliminary simulations indicate that deployment down to 70 Km is possible. Numerical results also show that in this case tether temperature near TS may rise up to about 2000 °K. Consequently, to accomplish any tethered mission below an altitude of 100 Km, a high temperature tether material and tether configuration must be developed.

The possibility of expanding the mission envelope to lower altitudes by using satellite lift has also been verified by SKYHOOK. A blunt cone configuration with L/D = 0.36 and 2800 Kg mass has been considered. As shown in Fig. 5 , satellite lift can provide a capability to deploy a tethered satellite to altitudes below 100 Km. Preliminary simulations indicate that it is reasonable to deploy satellite down to 80 Km; however, refined aerodynamics and alternate shape studies are required to define limits.

The possibility of utilizing the interaction between the Earth magnetic field and the tether wire is also being investigated.

4. Conclusions

The feasibility and capability of TSS to operate as a "Continuous Open Wind Tunnel" and to perform low density aerothermodynamic studies are investigated. The feasibility demonstration is accomplished through a modified version of the TS simulation program SKYHOOK. The results of the study indicate that STARFAC concept is both feasible and practical; however, some aspects have to be examined. In particular, TS can go below 100 Km but, if Thrust is used, large ΔV manoeuvres and an attitude control are required; if a satellite lift is considered, large tether tension is produced and an attitude control is required.

In future work multi-mass simulations incorporating transition aerodynamic models will be conducted. Furthermore, tether temperature and tension requirements have to be defined.

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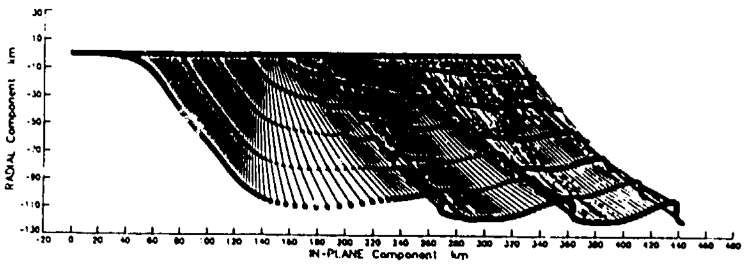

Fig. 1 - Satellite in-plane displacement

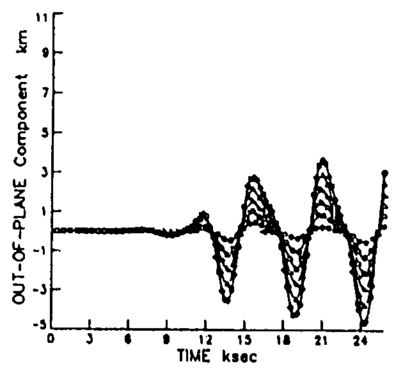

Fig. 2 - Out-of-plane displacement

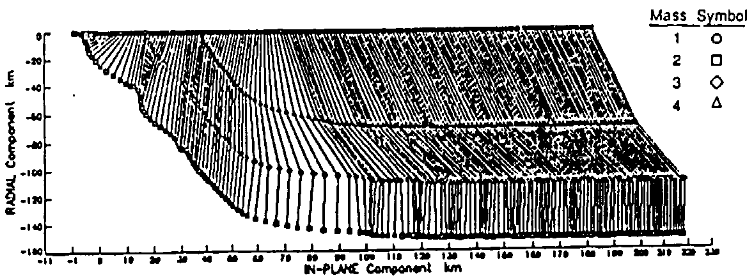

Fig. 3 - Satellite in-plane displacement in case of thrusting

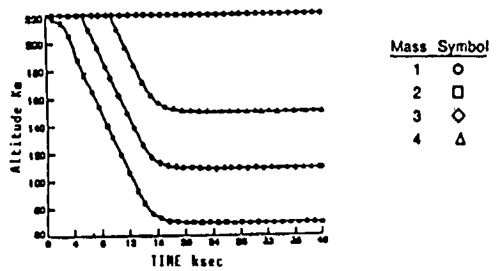

Fig. 4 - Tether and satellite altitude in case of thrusting

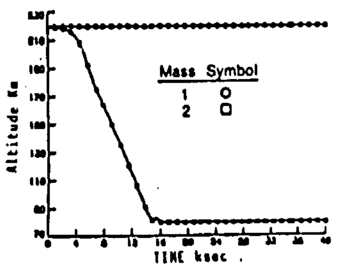

Fig. 5 - Satellite altitude in case of lifting