Front Range Aerospace, Inc.

Title: Constellation of Atmospheric Density Research Experiments (CADRE)
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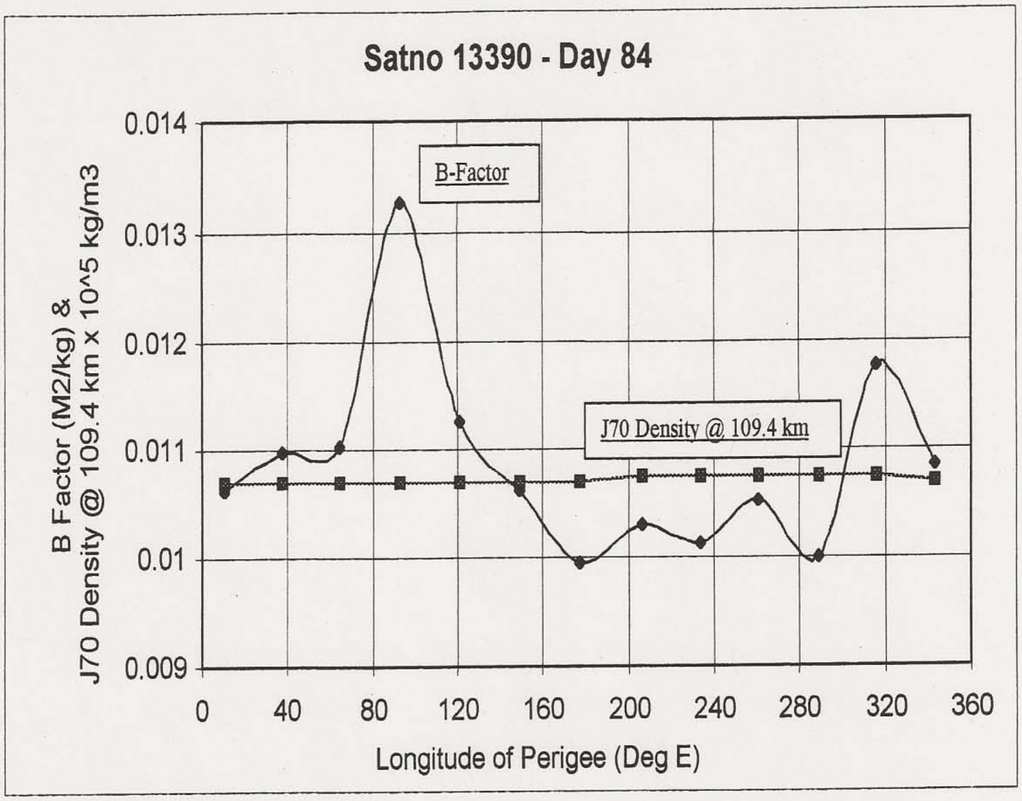
Need:

There are many issues encompassing the safe operation of satellite in low earth orbit. Orbital debris is an increasing problem in LEO (low earth orbit). Computation of potential debris impact with live satellites depend on accurate models of atmospheric drag. Current drag models are extremely poor as they lack timely data. The aerospace community needs near real time in situ estimates of atmospheric drag to improve orbit prediction models. The potential for collision has the highest downside consequences for manned missions or high-value payloads. To ensure safety from collision of objects in orbit and the ability to predict the re-entry of satellites that have ended their mission, the orbits of all satellite must be well determined. Satellite orbit determination accuracy can be characterized by four sets of parameters: the gravitational model used, the accuracy and span of the data used in the orbit fitting process and the (particularly for LEO satellites) knowledge of the atmospheric density across the fit span and the ability to predict density variations into the future.

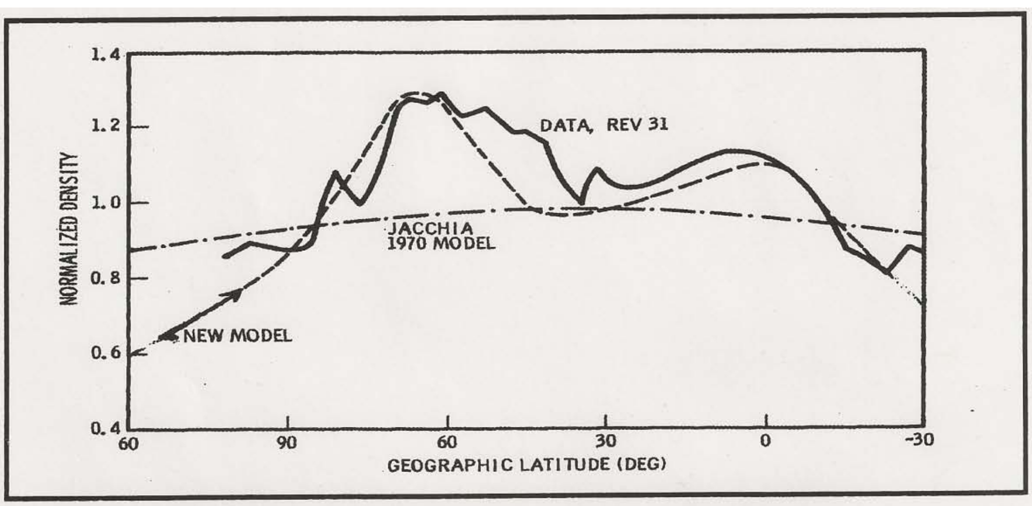
Mission Objectives:

To solve the orbital determination problem with accuracy, it is possible to use an earth gravitational model of degree and order of one's choosing and measurements of satellite position is a function of the orbit determination system requirements. Although the world has been launching and operating satellites in space for over 50 years, a better dynamic model of the atmospheric density has generally eluded us.[1] There are several reasons for this. There have been over 30 satellite missions flown with a mission to determine atmospheric density so that a model can be developed from the data. Some have been very sophisticated and hence expensive. Therefore only one density mission has flown at a time and the models developed from collected data are generally similar to spherical shells of varying density with density modulation provided by seasonal variations, sun activity estimates, day/night variations, etc. Evaluations of various atmospheric models over the past 30 years or so have shown that 10-30% errors still exist.[2] The first graph below was extracted from reference 2. It is intended to illustrate the difference between the models in popular use and the actual density experienced by the satellite. The data was taken on Spacetrack satellite number 13390 that decayed on 28 March 1995. The satellite was a beguine Molniya rocket body in a highly eccentric orbit (e ~ .7) with the perigee at the critical inclination (i = 63.4 deg) which held the argument of perigee angle constant throughout the decay. Luckily, the perigee was located at about 270 degrees argument of perigee so that the perigee passage went through the South geomagnetic pole during each pass. In the figure, it can be seen that the ballistic coefficient (which should be constant) varies widely when compared to what should be the average value. This effect is caused by the fact that during the orbit fitting process, the drag caused by the atmosphere (assumed known from the model) is forced to change the ballistic coefficient.

The second graph below is also extracted from reference 2 and illustrates actual accelerometer data taken by the LOGACS satellite further confirming the data shown in the first graph.



B-factor measured by satno 13390 and the Jacchia 1970 model versus geographic east longitude on day1995, 084. This shows that atmospheric variability near 108 km is much greater than indicated by the model.



Densities measured by the accelerometer on LOGACS near 180 km and the Jacchia 1970 model versus geographic latitude. This shows that models based on orbital decay measurements average out the atmospheric variability when the orbital eccentricity is moderate (which is the typical case).

We believe that the central issue in constructing better atmospheric models is the lack of *"global"* density measurements from a constellation of satellites making near simultaneous density measurements.

The expense of prior density sampling missions has dictated that only one is flown at a time but with the advent of better microelectronics (accelerometers, etc.) and smaller payloads, it is now possible to build and fly a constellation of nanosats that can routinely and constantly collect density data that will then be used to develop better models. Because the solar activity cycle is about 11 years duration, the constellations should be maintained for a decade or more to ensure that enough data is collected. This mission is ideal for Universities and other engineering groups that have a desire to build, launch and operate small satellites. Reducing the cost of these missions is central to being able to afford several in orbit at one time.

A microsatellite with a similar mission that has been successfully designed and tested is the DANDE satellite built by the University of Colorado (Boulder).[3] DANDE is currently anticipating launch in 2011/2012. The DANDE website can be found at: http://csmarts.colorado.edu/

To reiterate our mission objectives, we believe we must:
- Design/build an easily-reproducible density measurement payload useable on a variety of launch vehicles,
- Reduce ground operations to a minimum through innovative communications to lower cost of operation,
- Use existing equipment and designs where possible to reduce the overall cost of the mission,
- Establish a central repository of data for use by the atmospheric density modeling community,
- Provide a design that can accommodate other experiments within the weight and power budget.

Concept of Operations:

The CADRE satellite design will initially follow the general practice of a VHF uplink in the ~144 MHz band with a complementary UHF downlink channel (~430 MHz) for the purpose of initial operations and control. The satellites will also have a link that can communicate through IRIDIUM or similar low altitude communications constellation. The objective is to develop an alternative means of communications so that data can be collected and distributed potentially without use of ground stations devoted to this mission. There will be one central ground site that can communicate with all the satellites in this mission but that will eventually be intended for emergency or satellite re-programming use. The ground station will be connected to the internet for data distribution and/or use by groups cooperating in this endeavor to communicate with their satellite(s). The orbit of the satellites will be low altitude (<500 km) or eccentric (perigee 200-300 km and apogee ~1000 km) and of high inclination to cover the majority of the atmosphere with continuous measurements. The satellites will be spherical and the outer surface covered with solar cells to maximize power collection. The design will accommodate as many launch vehicles and deployment mechanisms as possible. These is no need of on-orbit maneuvering. Internal power for the satellite will be provided by batteries charged by the solar cells.

As the design phase progresses, a consortium will be formed that will include other programs that have interest in this type of spacecraft design and mission operations. This consortium will guide the future design efforts and help coordinate both current and future operations to the mutual interest of the group.

In addition, early design efforts will also define the data format and rates that can be supported by current ground facilities. If necessary, further expansion of ground site facilities will be provided. Front Range Aerospace has satellite ground station communications capability in place that has been used to communicate with amateur satellites AO-7, FO-29 and AO-51.

Key Performance Parameters:

Key to the initial design would be the ability to induce a known spin rate normal to the orbit plane on release from launch vehicle. The accelerometer suite must be able to measure atmospheric drag to the micro-g range and can be verified by matching measured decelerations provided through long term orbital analysis. It must be possible to communicate data through low altitude communications networks in order to pass data and reduce overall operational costs. Initial and backup operations will be through a central ground site with an objective of transitioning to other forms of data transfer as indicated above.

Space Segment Description:

The first two satellites will be the pathfinder for follow-on satellites where the basic concepts for density measurements, communications and ground site operations are proven. The payloads will be released in such a manner that they separate slowly and establish measurement locations well separated in time and location. This will also ease the burden on the ground site during early operations by separating the contact times. It is anticipated that acceleration measurements will be taken roughly every few seconds and stored in memory until a download can take place. Initial design for up and down link data rates are 9K6 bps which allows enough link margin for uplink commands and reprogramming to be accomplished during a typical pass over the ground site. Data processing on-board the satellite will be responsible for initial data reduction so that downlink data can be maintained at sufficient density to populate the modeling database. Payload performance data will be interleaved with payload data as required by uplink commands.

After the initial launch, subsequent launches will be deployed in pairs of payloads with different orbital inclinations and orbit plane orientations. This will ensure a more random distribution of positions and hence better data collected for modeling. The central ground site will be responsible for coordinating passes for data collection, programming with the various payload operations centers. If necessary, other operating locations could be added since the ground site operations equipment is COTS that is available at low cost.

While the DANDE satellite is less than 50 kg mass, some weight savings are anticipated from a critical design review early in the process. We anticipate the initial mass to be on the order of 30 kg. There will also be an effort to provide other space for programs that may want to include other scientific experiments.

Orbit/Constellation Description:

Because these missions will likely be secondary payloads on otherwise scheduled boosters, it is impossible at this time to describe the constellation requirements other than to say that high inclinations are preferred to gain the widest variety of sampling but low inclinations will provide useful data as well. Orbit plane separations that naturally occur with different launches will space the sampling satellites advantageously. As with previous dedicated density measurement missions, eccentric orbits were preferred so that various altitudes could be sampled. Eccentric orbits for the previous missions allowed the perigee to be placed at relatively low altitudes for better sampling and longer lifetime. The lifetime of the orbits can be regulated by choosing the initial perigee altitude.

Implementation Plan:

Our organization has worked for several years with the US Air Force Academy in support of their capstone satellite and rocket design course. We have supported the construction and maintenance of three ground sites used to operate the current FalconSAT 3 and 5 satellites. With authority to proceed, we would team with other organizations or groups to define the initial system requirements and conduct a selection process to identify how and by which organization the satellites get built, tested and prepared for launch. Early on, a users/developers group will be organized to guide the requirements and design efforts. Trade studies to evaluate alternatives will be conducted as the need dictates. Without having conducted the requirements generation and evaluation of alternatives, it is very difficult to project reasonable life cycle costs but our objective is to keep total and systems costs to a minimum. Our objective is to keep system costs for the first two satellites to approximately $5 M dollars (US) or less.

The design of the satellite and orbital parameters will ensure that the lifetime on orbit will be less than two years per vehicle and therefore no disposal plan other than natural orbital decay is planned.

References:

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2. Walters, L.G., Moe, K. G. Clark, J. B., "On the Macrostructure of the Earth's Atmosphere Near the Geomagnetic Pole(s), AIAA Paper 2000-3928, 14-17 August, 2000.

3. Young, Brady W., Masters Thesis, "Design and Specifications of an Attitude Control System for the DANDE Mission, University of Colorado, Department of Aerospace Engineering Sciences, 2008.