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Drag Compensation and Measurement With Manned Satellites: Feasibility Study[1]

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Even at low altitudes approximating those of manned earth-satellites it is feasible to use external jets to maintain a satellite in a purely gravitational orbit. With the jets off, it is possible to measure the drag, air density, and time of passage through perigee, by means of observations aboard the satellite. Intermittent operation of the jets should permit achievement of both objectives.

Many artificial satellites have had masses of about 10^6 gm and effective areas of some 5 m^2. At a height of 200 km the resulting drag amounts to some 6×10^4 dynes or about 6×10^{-5} of the weight. At 300 km the drag is one-tenth of this. Accurate knowledge of this drag is essential in determining the atmospheric density at high altitudes and in reducing the observed orbit to determine the figure of the earth. For the second purpose it would be better to be able to eliminate the drag than to correct for it.

So far drag measurement has been done only by difficult reductions of the orbits of unmanned satellites. Drag cancellation has not been done but a means has been discussed, involving automatic instrumentation. In this note we propose several methods for drag measurement or compensation that can be achieved either by automatic means in an unmanned satellite or by the astronaut in a manned satellite. The numerical values here presented may help to decide in different missions whether manning or automation is more appropriate. For greater vividness and conciseness, however, we now speak mostly in terms of a manned satellite.

First consider drag cancellation. To do so, we note that Pugh [1],[3] Lange [2], and others have suggested the use of external jets to neutralize the drag on an unmanned double satellite. This would require using a sensing device to detect approach of the inner satellite toward the outer one and a servomechanism to transmit the resulting signals to the external vernier jets. These jets in turn would produce enough acceleration of the outer satellite to keep the inner satellite centered. With neglect of very small gravitational interactions of the inner satellite with the outer and of small electromagnetic interactions of the inner satellite with the instrumentation, the outer satellite, and with the outside surroundings, the only force on the inner satellite would be external gravitation. Since the outer satellite is moving in the same orbit as the inner, the observed orbit is purely gravitational.

In place of this unmanned double satellite, if we use a manned space capsule, with the astronaut as sensing device and control system, we can eliminate certain difficulties. This procedure would be analogous to the use of a test pilot in a manned plane, while the automatic unmanned double satellite would correspond to an inertially guided unmanned plane, which came much later. The advantages of an automatic system will become important when one seeks prolonged, large scale, highly precise observations. Meanwhile we need not delay making some basic observations by means of astronauts' reports and data, which may be of great help in preparing elaborate space laboratories in the future.

To maintain a manned capsule in a gravitational orbit, the astronaut would continually or intermittently adjust some external jets, to keep a small test object within some tolerable distance from the capsule's center of mass. For protection against air currents and stray fields, the test object should be enclosed in an evacuated and electromagnetically shielded housing.

To examine the feasibility of such a procedure, consider a jet of compressed air escaping through a simple converging nozzle of 1 mm diameter from a chamber at 6 atmospheres. Producing 6×10^4 dynes thrust throughout a circular orbit at 200 km height would require 6.8 kg of air. For an elliptic orbit of eccentricity $e=0.03$ and the same perigee, it would take only 1.6 kg. For perigee at 300 km these figures would drop by more than a factor 10. Moreover, use of a divergent portion with the nozzle would also improve matters considerably.

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[3] Figures in brackets indicate the literature references at the end of this paper.

A chemical propellant giving the big rocket specific impulse of 300 kg force sec/kg mass (300 "sec"), if efficient micro-vernier jets become available, would be 6 times more economical of mass. Thus the satellite need not go very high to make man-controlled drag compensation feasible. At these relatively low altitudes all the appreciable harmonics of the earth's gravitational field will still be well represented, so that the resulting gravitational orbits should be very suitable for deducing the coefficients of the various harmonics. Furthermore, as will appear later, the relatively high drag can actually be used to improve the accuracy of determination of time of passage through perigee, by means of a separate experiment performed by the astronaut.

The astronaut may measure the drag at intervals between jet thrusts, having previously oriented the capsule so that it presents a constant projected area. To do this he may be furnished two identical torsion systems, with twist axes in the same plane but mounted at right angles to each other, each carrying a seismic mass of about 100 g about 1 cm off axis. He first rotates the torsion plane manually to produce maximum and equal twists for both torsion systems, whereupon it becomes normal to the drag force. He then orients the capsule for minimum drag by adjusting jets that rotate it until its long axis becomes perpendicular to the plane of the torsion axes and thus parallel to the drag.

In our example the satellite of mass 10^6 g, moving at a height of 200 km, experiences a drag force of 6×10^4 dynes and a drag deceleration of 6×10^{-2} cm/sec^2. This leads to a torque of 6 dyne cm on each torsion system. If the sensitivity is 100 dyne cm per radian, the twist will be 3 deg, enough for easy measurement, although the systems will be rather sluggish, with response times from 6 to 10 sec. However, since 10 sec corresponds to only about 0.5 deg change in eccentric anomaly, such a torsion system should allow easy following of the changes in drag occurring in elliptic motion with small eccentricity. Such measurements of the drag should provide valuable information concerning both the orbit and the atmosphere. The astronaut can monitor height, eccentricity, and position in orbit with little dependence on terrestrial observers. Of greatest importance, he can determine accurately the time of passage through perigee, since the drag has a sharp maximum there even when the eccentricity is as small as 0.005.

Another method of measuring the drag would be simply to have the astronaut measure the distance $s=\frac{1}{2}a_Dt^2$ traversed in a short time t by a small test object as it drifts through the capsule under the influence of the effective gravitational field $\boldsymbol{a}_D$. Here $\boldsymbol{a}_D=\boldsymbol{F}_D/m_s$, the negative of the drag acceleration of the satellite. Thus in our above example, with $a_D=6\times10^{-2}$ cm/sec^2, we have $s=3$cm if $t=10$ sec.

Two difficulties arise. In order that $-\boldsymbol{F}_D/m_s$ should be the only field acting on the test object it is necessary to eliminate centrifugal and Coriolis forces arising from the changing orientation of the capsule. To do so one could orient the capsule inertially, relative to the fixed stars, by some method of attitude control. But then the projected area would keep changing, so that one could not readily deduce the atmospheric density from the drag.

If one orients the capsule tangentially, as proposed in the above paragraphs on the accelerometer, there arise the apparent forces. It is easy, however, to correct for them by purely kinematical calculations, since one knows the rotational motion of a capsule which is tangentially oriented. Moreover, their effect is small. In our above example, the centrifugal acceleration is negligible and the Coriolis acceleration does not exceed 1/50 of the drag acceleration.

A question arises about body motions of the astronaut or accelerations produced by automatic equipment on board. Four measures could be taken to reduce such effects: (a) balance the accelerations; (b) arrange them to be transverse to the satellite motion; (c) shock-mount and filter out these motions; (d) suspend the motions during observations of the drag. Even breathing could be suspended during the five or ten second duration of such a measurement, but it is not at all certain that this would be necessary. Thus the ballistocardiograms of Smith and Bryan [3] show no long-periodic accelerations attributable to breathing even though their system had as good a response at 0.1 c/s, where breathing would show up, as in the frequency range of 2 to 10 c/s important in recording accelerations produced by the heart beat.

Ballistocardiographic measurements by Smith [4], on the other hand, furnish reassuring statistics concerning the irremovable effects of the heart beat on drag measurements. Each of 50 normal persons was firmly attached to a platform free to swing in reaction to the heart beat. The double amplitudes of displacement ranged from 0.035 mm to 0.09 mm, with a most frequent double amplitude of about 0.06 mm. The normal peak displacement from mean position was thus about 0.03 mm.

Since the mass in these measurements was about 100 kg, the corresponding displacement in the case of an astronaut firmly attached to a 1000 kg capsule would be only 0.003 mm. Comparison of this figure with the 3-mm excursion of the test body inside a satellite at 300 km (Mercury at apogee) shows a possible error of only 1 part in 1000. Thus neither heart beat nor breathing need interfere with a drag measurement, even if we do not adopt the special measures a, b, and c listed above.

To recenter the test object, the astronaut has only to turn on and adjust the jets for drag compensation before the object collides with its housing. The orbit will then remain essentially gravitational. By combining all three of the methods here described, using intermittent drag compensation, one could obtain a gravitational orbit and take many measurements of the drag and thus of the air density, all in one flight. A manned satellite so instrumented should then provide valuable geophysical and bioastronautic data, along with experience in design and operation of a primordial zero-g laboratory.

To conclude, note that nothing we have said above is intended to discourage the use of automatic unmanned satellites. Our aim has rather been to find further important functions for astronauts in those manned flights that are now being planned or will be planned in the future. They in turn may lead both to better automatic and better manned space laboratories.

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