THE USEFULNESS OF AUXILIARY TRANSFER ORBIT MANOEUVRES FOR A NEAR NOMINAL GEOSTATIONARY MISSION

F. Hechler M. Rosengren M. Soop

European Space Operations Centre (ESOC), Darmstadt, W.-Germany

ABSTRACT

If the transfer orbit of a geostationary mission is in error due to an anomalous launcher performance there may be a possibility to save the mission by performing auxiliary orbit manoeuvres. Transfer orbit manoeuvres can be useful when the launcher dispersions lie outside the specified nominal range but still are not as high as to destroy the mission completely. We show here some examples where apogee and perigee raising manoeuvres during transfer orbit operations can save an otherwise degraded or lost mission.

Keywords : Geostationary, Transfer Orbit, Rescue Operations, Orbit Manoeuvres, Apogee Raising, Perigee Raising

1. INTRODUCTION

In the ESA geostationary missions the satellites are launched in inclined transfer orbits with perigee height around 200 km and apogee at the geosynchronous radius of 42165 km.

A fixed burn apogee boost motor is dimensioned such as to change the nominal transfer orbit inclination and perigee height into the desired geosynchronous values. Remaining orbit corrections are made with a hydrazine thruster system that is also used for orbit manoeuvres in the routine phase and for attitude manoeuvres.

The size of the hydrazine fuel loading is calculated on the basis of the nominal errors in launcher and apogee motor firing to yield the desired mission success probability plus a certain loading margin. The margin can be used to remedy the mission in case the launcher should underperform slightly outside the specified error range.

If an underperformance takes place such that the satellite is placed into an anomalous transfer orbit, the question arises how best to spend the available fuel margin in order to remedy or even recuperate the mission.

One way is to follow as closely as possible the original operational sequence by first firing the apogee boost motor and then correct the orbit with the hydrazine thrusters.

The other strategy is to first perform one or more orbit improvement burns with hydrazine in the transfer orbit, then fire the apogee boost motor and at last correct remaining orbit errors with hydrazine. A choice between the two methods can be made during the actual operations based upon the particular situation at hand.

2. MANOEUVRE TYPES

Errors in the transfer orbit parameters can endanger the mission in two ways : More hydrazine than planned must be spent after apogee motor firing to remove the residual orbit inclination, eccentricity and longitude drift; the spacecraft may be damaged by atmospheric friction heating when passing through a too low transfer orbit perigee.

The most likely recoverable launcher anomalies lead to a too low transfer orbit apogee height, possibly coupled with a too low perigee and a wrong inclination.

There are possibilities to remedy both the hydrazine fuel budget problem and the atmospheric friction problem by spending some of the fuel margin on transfer orbit manoeuvres instead of waiting until after the apogee motor firing.

Essentially three types of manoeuvres, approximately along track burns, can be useful in the transfer orbit, figure 1 :

1) at perigee to raise the apogee and improve fuel usage;

2) at apogee to raise the perigee in order to both improve fuel usage and decrease air drag;

3) between perigee and apogee to raise the perigee and reduce air drag.

Extra spin axis reorientation manoeuvres may be needed to align a radial or axial thruster to the desired burn direction, especially if there are

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thrusters only on one end of the spacecraft.

Some examples will show that there are possibilities to rescue an otherwise lost or degraded mission by performing extra transfer orbit manoeuvres. Apogee height deficiencies of the order of a few thousand km are mostly suitable in this respect. More severe anomalies in the mission can be at least partly remedied.

The examples in the following sections use spacecraft data from ESA's Orbital Test Satellite (OTS) It is spin-stabilised in the transfer orbit and has got hydrazine thrusters with radial and axial thrust directions.

The apogee boost motor gives an exhaust velocity of 2.88 km/sec and provides a velocity increment of 1.81 km/sec to the satellite when it is fired with the initial mass of 863.1 kg. After some of the hydrazine loading has been spent the spacecraft mass for the apogee motor firing is lower and the velocity increment is higher than planned for the nominal mission. The apogee velocity increment must, however, not be made too high such that the opposite apse of the orbit is raised not above the geosynchronous height.

The exhaust velocity of the hydrazine thrusters is 2.0 km/sec and the thrust force about 2 Newton. The satellite is launched in an attitude almost opposite to the desired apogee boost direction and with a transfer orbit inclination of 27°.

3. APOGEE RAISING

The most fuel effective transfer orbit manoeuvre is to raise the apogee height by a perigee burn with an axial thruster in continuous mode. A problem is the relatively low hydrazine thrust force which makes the burn quite long with a constant direction. The relative effect of the burn decreases with increasing length, but this can be improved by splitting the burn into several manoeuvres at successive perigee passes. Other problems come from eclipses and ground station contact difficulties near a perigee.

Figure 2 shows the result of a detailed simulation of four apogee raising manoeuvres on a transfer orbit with 1880 km too low apogee height. The burn direction is constant during the manoeuvres and is parallel to the perigee velocity direction. The start time is slightly different for the four burns in order to provide ground station visibility for the starting command. Burn end was provided by the on-board timer after between 30 and 48 minutes.

Figure 3 shows the hydrazine fuel usage until station acquisition without and with one, two, three or four apogee raising burns. The extra

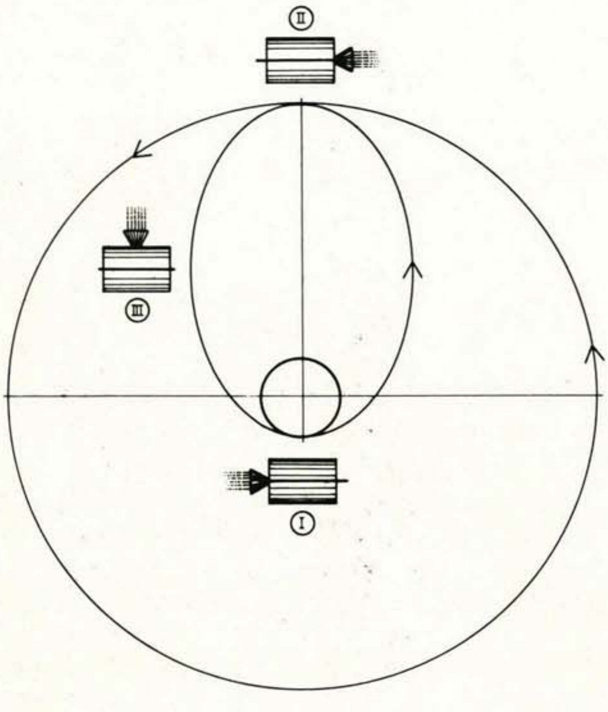

Figure 1. Hydrazine thruster burns in transfer orbit:

(I) at perigee to raise the apogee

(II) at apogee to raise the perigee

(III) between perigee and apogee to raise the perigee.

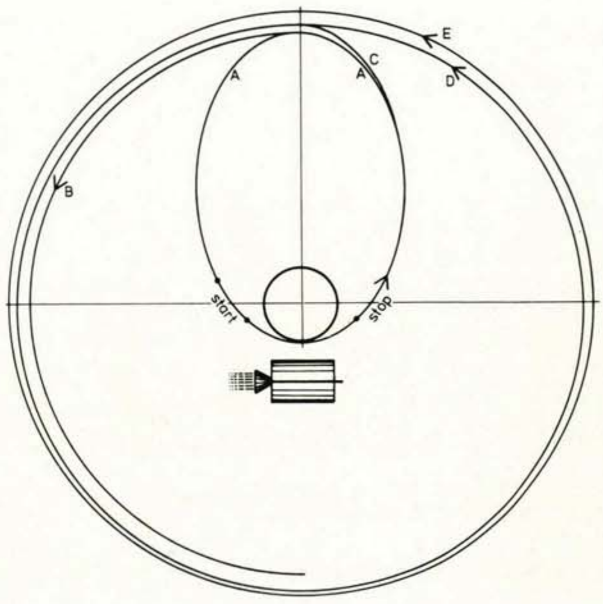

Figure 2. Four apogee raising manœuvres starting in the region labled "start" and stopping at "stop".

A - original anomalous transfer orbit

B - after apogee motor firing in the original transfer orbit

C - improved transfer orbit after four apogee raising manœuvres

D - after apogee motor firing in the improved transfer orbit

E - ideal geostationary orbit

fuel spent in the transfer orbit is more than compensated for by the reduction in fuel after apogee motor firing.

Figure 4 shows the apogee radius of each intermediate transfer orbit and the radius of the opposite apse of the orbit that would have been the result after firing the apogee motor.

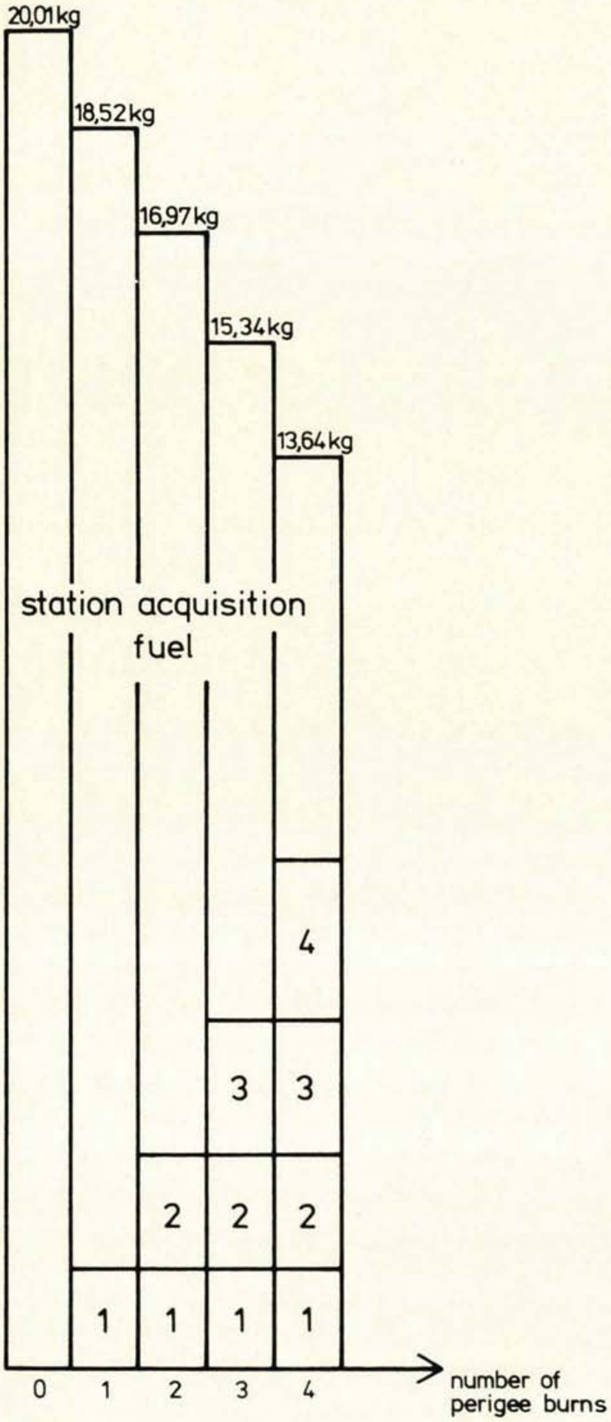

Figure 3: Total fuel until station acquisition with 0,1,2,3 and 4 perigee burns in transfer orbit.

4. PERIGEE RAISING FOR AIR DRAG

An obvious reason for a perigee raising manoeuvre is when an anomalous launcher performance has given a too low transfer orbit perigee.

If one has a situation such that the next perigee passage will be so low that the air drag may damage the satellite, the manoeuvre should be performed near apogee like number 2 in figure 1. If there is no thruster pointing in that direction one has another possibility to perform it by a radial thruster in pulsed mode like number 3 in figure 1, between apogee and perigee.

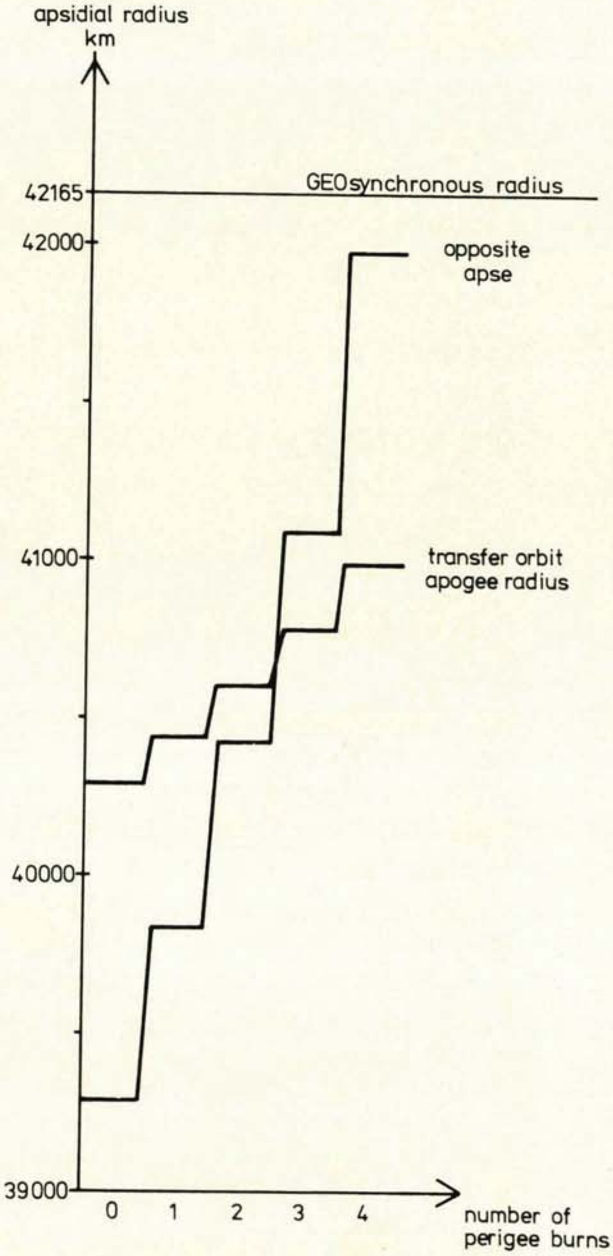

Figure 4: Transfer orbit apogee radius and corresponding radius of the opposite apse after apogee motor firing.

Figure 5 shows the perigee raising effect of a velocity increment parallel and perpendicular to the line of apses, respectively. A 1 m/sec velocity increment raises the perigee by 3.3 km when it is performed along-track about 1 1/2 hr before perigee but by 9.5 km when performed at apogee.

The former burn has also a certain apogee raising effect, but it does not essentially improve upon the total hydrazine consumption. The latter burn, on the other hand, can improve the total hydrazine budget, although it does not raise the apogee height. It is described in more detail in the next two sections.

5. PERIGEE RAISING TO SAVE HYDRAZINE

Perigee raising manoeuvres near the apogee of an anomalous transfer orbit can be used not only to decrease the air drag on the satellite. Under certain circumstances it can have a general saving effect as well on the total hydrazine fuel consumption until station acquisition.

A hydrazine burn like no. 2 in figure 1 near apogee in the same direction as later the apogee motor will fire into has, in principle, the same effect as an increase in the apogee motor size.

The saving effect comes from the fact that the rocket equation favours the burn of lower grade fuel, like hydrazine, before the higher grade fuel of the apogee motor is burned. The saving effect is, however, smaller than for the apogee raising, but it can be used when eclipse, ground visibility or thruster configuration makes it difficult to perform burns near perigee.

The angular velocity of the satellite near the apogee is relatively low, so even a long burn with a low thruster force has nearly the same effect as an impulsive velocity increment. For this reason fuel saving burns near apogee are relatively advantageous for low hydrazine thrust systems.

6. COMBINED MANOEUVRES

When hydrazine fuel saving manoeuvres are needed in an anomalous transfer orbit one must try to find the optimal combination of apogee and perigee burns that fit the actual operational circumstances.

Because of the large number of possible combinations, one must make a few simplifying assumptions to obtain a computer program that is feasible to use during critical satellite rescue operations.

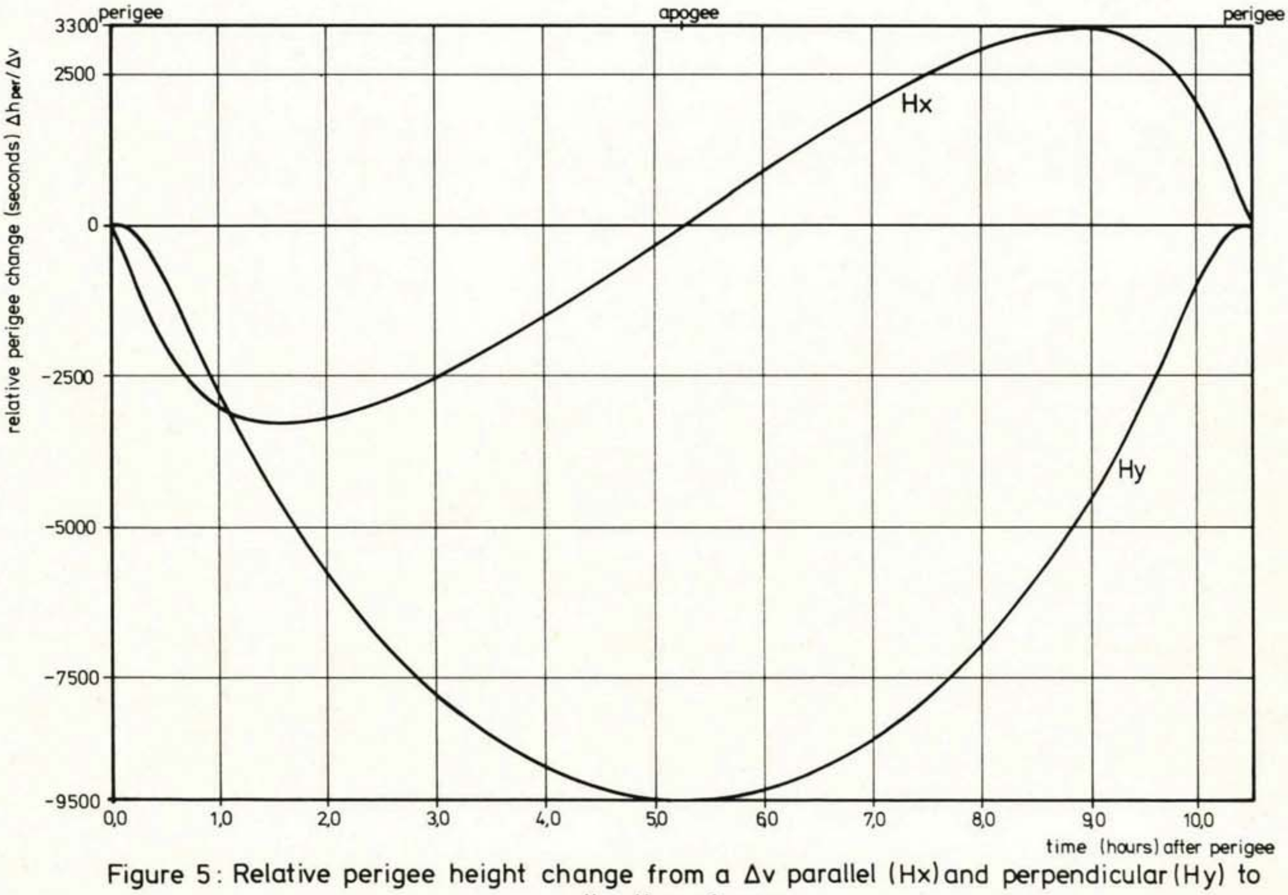

Figure 5: Relative perigee height change from a Δv parallel (Hx) and perpendicular (Hy) to the line of apses.

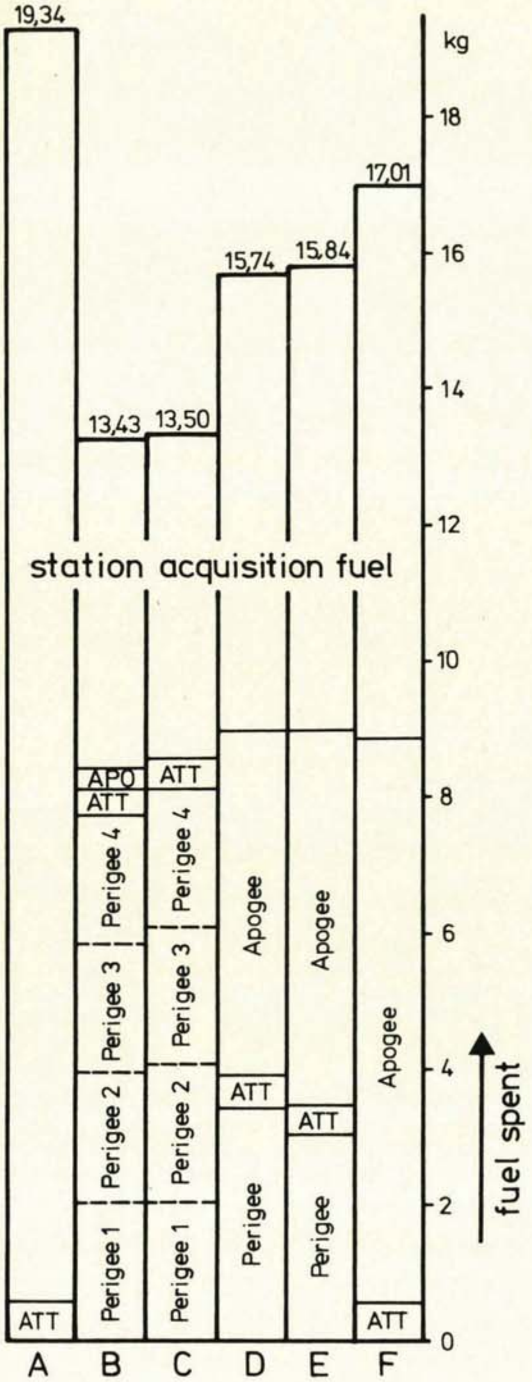

Figure 6: Fuel budget for different correction strategies.

The transfer orbit manoeuvre sequence to be considered is, in general, the following :

Manoeuvre	Purpose
Perigee	One or several identical burns at the same orbital position of several subsequent perigee passes to raise the apogee
Attitude	Re-orient the spin axis into the optimal apogee motor firing direction
Apogee	A burn near apogee to raise the perigee

Depending upon the various input parameters : Actual orbit anomaly, hydrazine thruster configuration, ground station visibility, time to perform the manoeuvres, etc., one or more of the above manoeuvres must be omitted. The effect on the orbital parameters of the attitude manoeuvre is taken into account in the optimisation.

In addition to the above manoeuvre sequence there is the possibility to insert an additional attitude reorientation before the perigee burns.

Figure 6 shows the hydrazine fuel consumption for each separate transfer orbit manoeuvre and the total consumption until station acquisition for six different transfer orbit sequences, namely :

a) no orbit manoeuvre
b) four perigee burns and one apogee burn
c) four perigee burns but no apogee burn
d and e) one perigee and one apogee burn
f) one apogee but no perigee burn

We can see that perigee raising burns at apogee has a certain fuel saving effect, but they are less effective than apogee raising burns at perigee.

7. CONCLUSIONS

Extra orbit manoeuvres can sometimes be useful to improve the total hydrazine fuel usage until station acquisition in case of an anomalous launcher performance. Depending on the amount of fuel on board the satellite, the execution of transfer orbit burns may save a mission that would not have been recuperated by the use of hydrazine burns only after firing the apogee boost motor.

In a similar way, extra orbit burns can alleviate the risk of air drag damage to an anomalously low transfer orbit perigee.