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Operational Experience on OTS-2

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This paper outlines briefly the primary objectives of the OTS-2 mission and describes the means by which these objectives were successfully accomplished. The paper then concentrates on the orbit and attitude control aspects of OTS-2 describing the control subsystem, its operation, and its role in insuring the very high availability of OTS for its communication mission. Stationkeeping strategies are presented with details on the implementation and some of the results obtained.

Introduction

THE Orbital Test Satellite of the European Space Agency (ESA), OTS-2, was launched on May 11, 1978. OTS-2 is a communications satellite in the 11 and 14 GHz bands and is the forerunner of the European Communications Satellite (ECS) system which will beome operational in 1982. The OTS mission is primarily a test to assess the satellite technology and communications concept which will be used in the operational system.

Mission Objectives

The specific objectives of OTS may be listed as follows: 1) an in-orbit demonstration of the operational capabilities of the satellite and its constituent subsystems; 2) experimental validation of the communications concepts (reuse of the spectrum based on polarization discrimination, digital transmission and speech interpolation, and time division multiple access) and the propagation assumptions; 3) a study of the technical problems arising from the utilization of the system on a preoperational basis.

Mission Description and Operation

OTS is a three-axis stabilized satellite situated over the equator at 10°E and maintained within ±0.1 deg of that position in both the east-west and north-south directions. The general configuration of OTS is shown in Fig. 1. Six repeater channels are carried, two each of 10, 40, and 120 MHz bandwidths. This is shown diagrammatically in Fig. 2. The corresponding communication coverage zone as seen from the satellite is shown in Fig. 3.

The satellite is controlled from the European Space Operations Centre (ESOC) at Darmstadt, West Germany, via the telemetry, tracking and command (TTC) station located at Fucino, Italy. Large earth stations involved in the test program are located at Bercenay-en-Othe, France, Goonhilly, England, Usingen, West Germany, and Fucino, Italy. In addition, some 40 stations throughout Europe are involved in propagation measurements.

Routine support of OTS is not operationally demanding, consisting primarily of stationkeeping maneuvers, thermal control, and power management during eclipse seasons. However, due to the nature of the OTS mission, a large number of orbital test program (OTP) activities requiring active satellite operations were necessary. The majority of these tests involved special operation of the attitude and orbit control system (AOCS). The following may be used to illustrate this type of operation.

Antenna Pattern Measurement

To determine the actual in-orbit antenna pattern, it was necessary to slew the satellite in a raster scan formation to enable measurements to be made by the European ground stations. This was achieved by "rolling" OTS about ±2 deg to shift the coverage area north and south and, maintaining the selected roll position, to perform an east-west scan of similar magnitude.

Slew Maneuvers

Repointing OTS to a predefined point (again within a square of about 2° N-S/E-W) was utilized on several occasions for calibration of ground stations and transmission of TV signals from Europe to a 3 m dish in, for example, Cairo or Rabatt.

Solar Sailing

This technique of using the solar arrays to provide a controlled disturbance torque on OTS was found to be most successful. Reference 1 reports how roll/yaw control was disabled and control about these axes performed by periodic adjustment of the solar array axes with reference to the satellite body.

The Attitude and Orbit Control Subsystem

The attitude and orbit control subsystem (AOCS) is responsible for the following functions:

1) It provides attitude control and maneuvering capability during the transfer orbit to geosynchronous orbit altitude and for the transition from spin stabilization to a three-axis stabilization configuration.

2) It also provides attitude and orbit control of the spacecraft in the three-axis stabilized configuration so that the pointing accuracy requirements of ±0.08 deg in roll and pitch and ±0.35 deg in yaw are maintained.

Description of Equipment and Use

To maintain three-axis stabilization, the subsystem uses a fixed momentum wheel (FMW) to provide control torques about the pitch axis and gyroscopic stability about the roll and yaw axes. A two-axis infrared Earth sensor (IRES) provides roll and pitch attitude references and this sensor can be biased by ground command by up to ±2 deg about both axes. Figure 4 presents the sensor and thruster layout.

For normal mode operation, control torques are provided by a pair of dedicated hydrazine thrusters, numbered 17 (or 18 on the redundant branch) and 19 (or 20) in Fig. 4. These are offset from the yaw axis by some 20 deg and therefore when pulsed provide a torque about the roll and yaw axes

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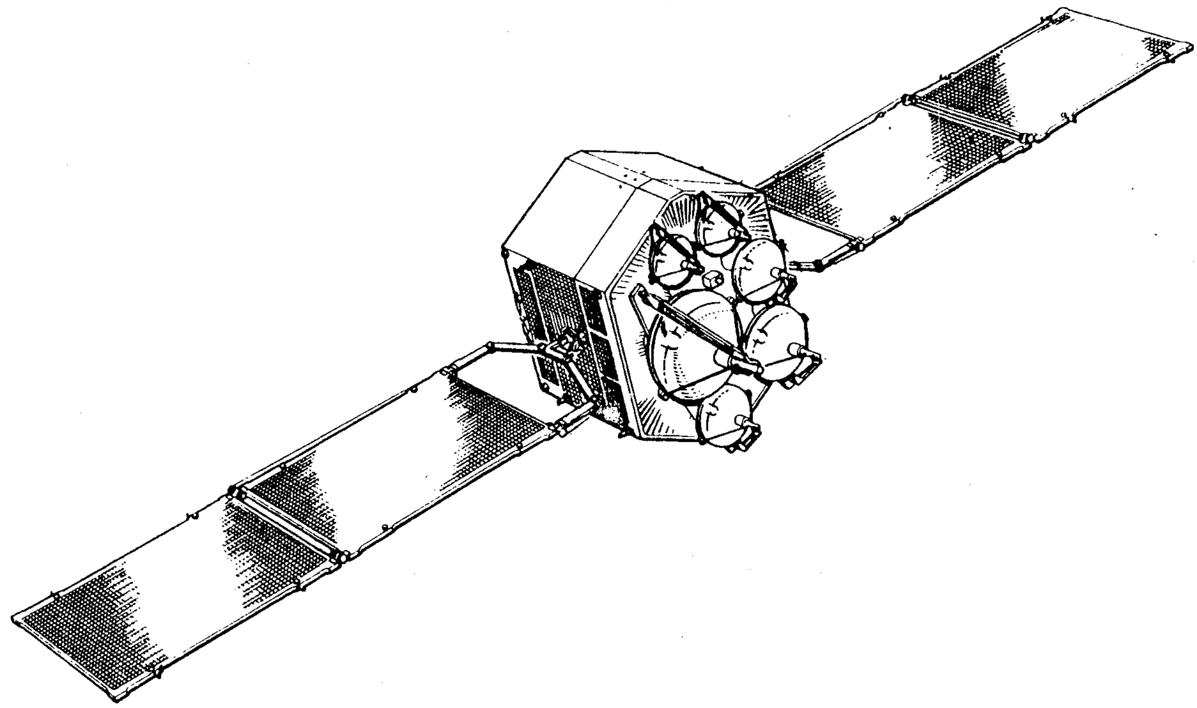

Fig. 1 OTS-2 in orbital configuration.

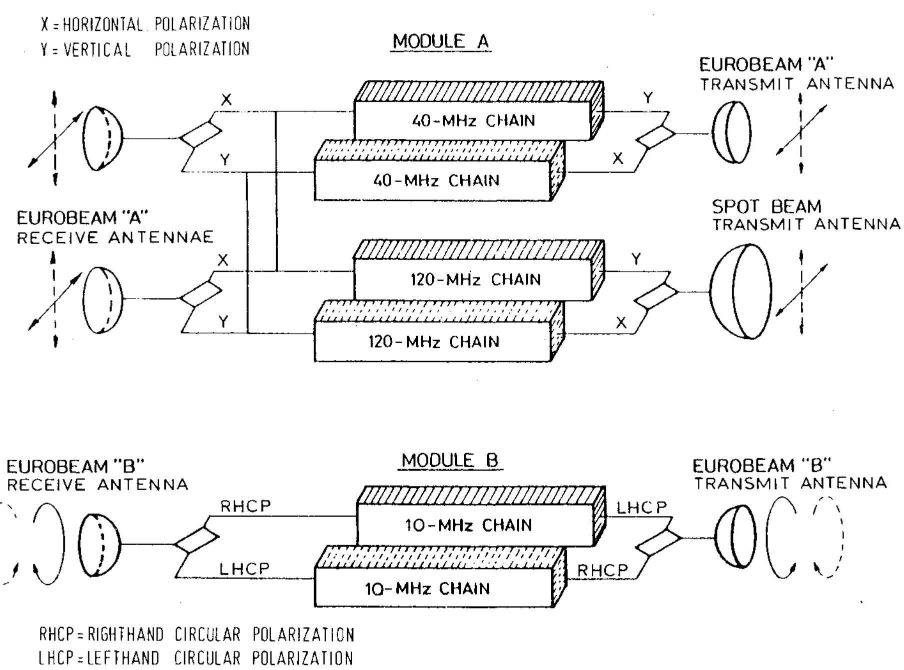

Fig. 2 Communications payload of OTS-2.

simultaneously. The normal mode control loop demands a pulse from one of these thrusters whenever a preset roll pointing deadband is exceeded due to environmental disturbing torques. This pulse shifts the momentum vector to reduce the roll attitude error but also sets up a nutation of period 100 s. The nutation is canceled by a second pulse on the same thruster after a delay of about half a nutation period. The roll deadband is set at ± 0.042 deg which results in about five pairs of thruster pulses per day.

There is no yaw attitude reference in this mode. The satellite roll and yaw axes rotate in inertial space because of the orbital motion about the Earth. Thus, a component of attitude error along the yaw axis eventually becomes an error along the roll axis which is then removed by the control system. The offset of the thrusters used in this mode is incorporated to optimize this mechanism.

For stationkeeping maneuvers, when large attitude disturbance torques may occur due to thruster misalignment or mismatch, dedicated stationkeeping control loops are provided which maintain roll and yaw pointing via hydrazine thrusters [numbers 1, 3, 9, and 11 on Fig. 4 (2, 4, 10, and 12 for backup)]. Pitch control remains with the FMW. The attitude reference for pitch and roll is again the IRES but for yaw a rate-integrating gyro (RIG) is brought on-line and stabilized before maneuvers.

All equipment is redundant. As part of the test and evaluation objectives of OTS, the two IRES are made by different manufacturers (Sodern and Galileo) as are the two FMW's (Philips and Teldix). There are two complete sets of thrusters. Figure 4 shows the location of the individual thrusters. The odd-numbered thrusters are on the prime branch and the even-numbered on the redundant branch. The

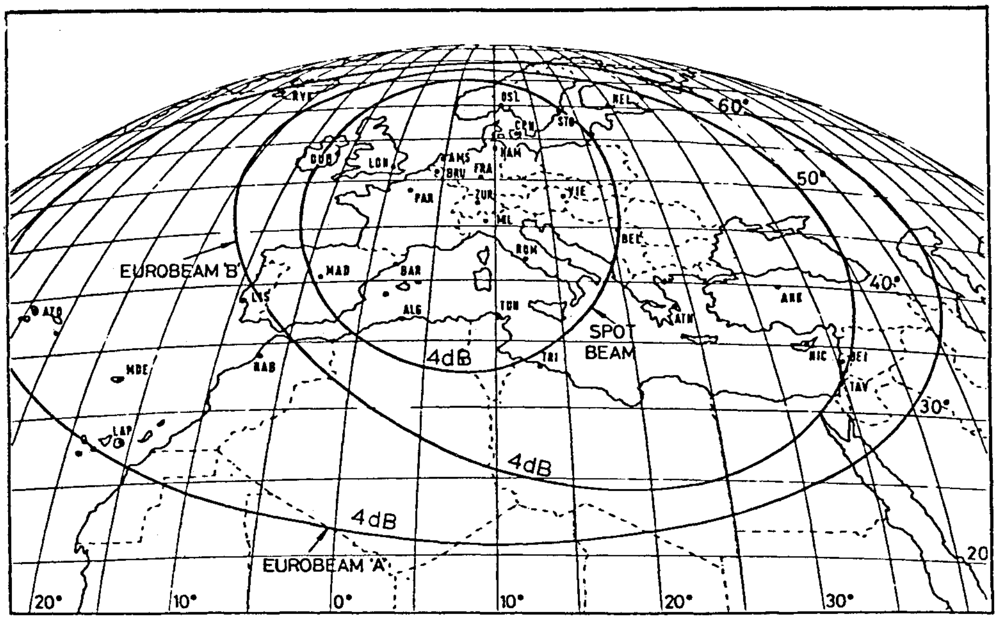

Fig. 3 OTS-antenna coverage zones 4 dB contours.

torque sense provided by each thruster is indicated, e.g., $x+$ denoting a positive torque about the roll axis.

A number of special operations required depointing of the spacecraft by up to 2.0 deg in pitch and roll. This was achieved by first disabling the roll/yaw thruster control loop and then pulsing the yaw thrusters by ground command to produce a component of angular momentum along the yaw axis; this effectively rotates the total momentum (pitch plus yaw) about the roll axis. Initially, the achieved offset in roll was maintained by biasing the IRES by the achieved roll angle and re-enabling the roll/yaw loops. However, the translation of the roll error into yaw due to orbital motion resulted in an inordinate number of thruster pulses with a consequent effect on the orbit and disruption of east-west stationkeeping. When this was realized, the procedure was modified to rely upon the gyroscopic stiffness to maintain the roll offset for the period of the operation, normally less than 2 h. Offset angles in pitch are easily achieved by biasing the IRES. The pitch control loop via the FMW immediately provides the required offset.

On-Board Protection Electronics

In addition to the equipment for normal mode and stationkeeping attitude control, there are electronics for on-board contingency protection. This protection operates at two levels. At the first level, detection of a potentially serious loss of pointing or an AOCS power supply anomaly will result in a switch from prime to redundant FMW, IRES, and control electronics plus disabling of the prime thruster branch by closing the main valves. Earth pointing is maintained and therefore full payload operation continues uninterrupted while diagnosis of the problem and subsequent reconfiguration take place. This is known as the automatic reconfiguration mode (ARM). The second level of protection is automatically implemented if this first level fails to maintain Earth pointing. After a pause of 15 min, all normal AOCS units are switched off and a basic sun acquisition loop is enabled with the redundant thruster branch to point the roll axis toward the sun. In this mode, known as emergency sun acquisition (ESA), payload operation is, of course, interrupted until a suitable point in the orbit is reached for reacquisition of the three-axis stabilized configuration.

The naturally confident opinion prior to launch was that these electronics would never be used and, indeed, a special test was planned for the end of the life of the OTS to check their operation. However, in fact ARM was achieved nine times and ESA twice in the first year of operation!

Some of the anomalies that led to these incidents are discussed in the following section. It is important to note that, except for the first and eighth ARM which were followed by ESA, operation of the payload continued without interruption and recovery to the normal configuration was straightforward.

Problems

There is always interest in problems. Fortunately, on OTS there have been few and none that have seriously interfered with the routine operation of the spacecraft, which continues to be very straightforward. The problems which have effected operation concern the IRES and the hydrazine thrusters.

Initially, the Galileo IRES was on-line. However, this sensor was found to be susceptible to random6 internal switching between its four bolometers, due to both electromagnetic interference and internal reflections of the sun's rays at certain times of the year. The sensor thus gave apparent depointing signals to the control logic which caused switching to the redundant equipment via the ARM on-board protection electronics. For these reasons the Sodern sensor was brought on-line and, although it is potentially less accurate than the Galileo, it has performed quite satisfactorily. It has been found, however, to be more sensitive than expected to the seasonal variations in the Earth's infrared profile, which introduces error about the roll axis as shown in Fig. 5. This error was detected by the unexpectedly large number of the roll/yaw thruster actuations which suggested that the spacecraft momentum vector was not perpendicular to the orbit plane. The solution has been to use the IRES bias unit to inject a correcting signal.

A second problem with this IRES is that when one of the four bolometers comprising the sensor has to be inhibited to prevent serious depointing when the sun or moon appears in its field of view, a large offset sometimes greater than 0.05 deg is apparent. The roll/yaw control loops are inhibited to prevent the actual roll attitude being affected but, in pitch, there is no such solution and the pitch attitude will suffer an actual offset for a period of about 2 h.

The hydrazine thrusters have exhibited two types of anomalous behavior. The first is the apparent generation of gas in the flow control valves and tubing close to the thruster. This is attributed to the interaction of the hydrazine with the materials used in the valve construction and has been repeated in the laboratory. Initial tests have shown the amount of gas generated to be strongly dependent on the type of materials

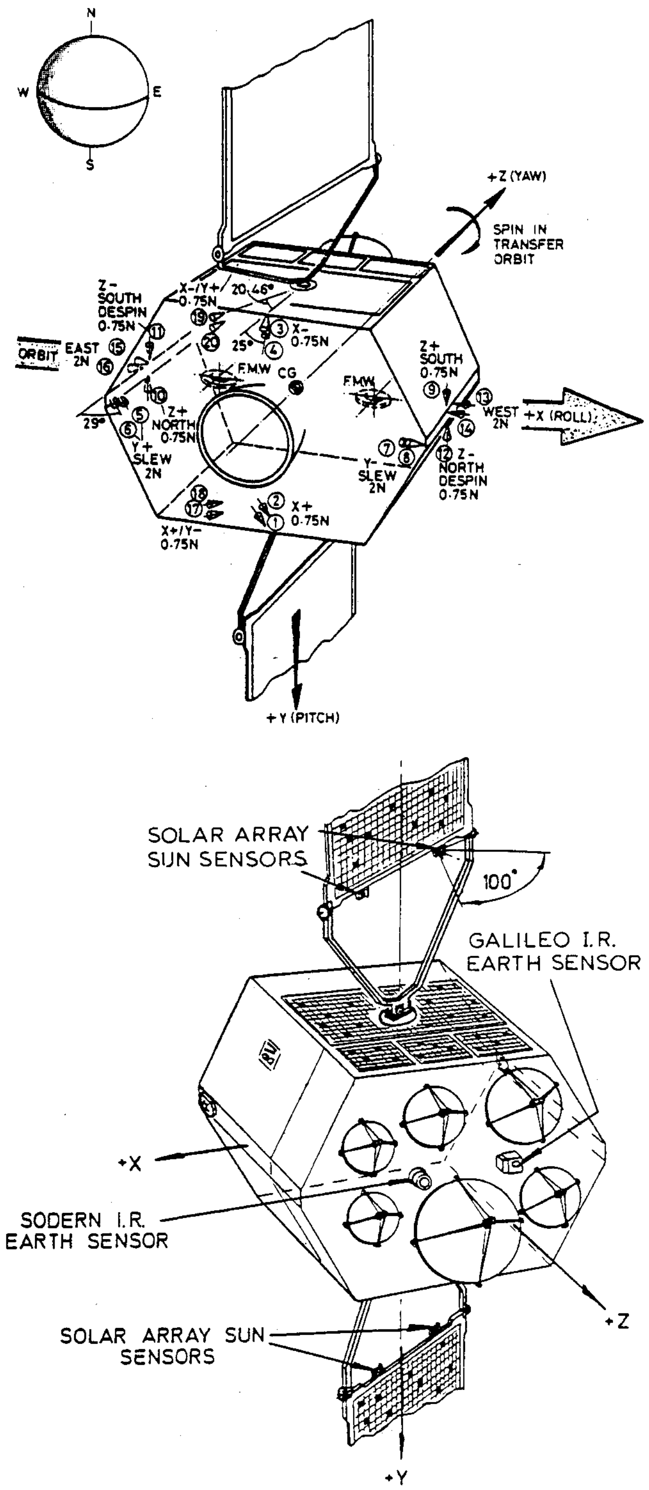

Fig. 4 OTS-2 thruster and sensor layout.

used and on the temperature of the valve. On the satellite the result is "missing pulses" or degraded performance when the thruster is operated after a period of inactivity, which is of particular consequence for stationkeeping maneuvers (see below).

The second thruster anomaly has been on a yaw thruster on the prime thruster branch. This has produced an impulse where none has been commanded which has, on several occassions, resulted in depointing sufficient to cause reconfiguration via the ARM protection logic. This is tentatively attributed to a faulty valve seat which allowed hydrazine to trickle into the catalyst bed. All thrusters are provided with heaters so that this catalyst bed can be heated before use in order to prolong its useful life. The hypothesis is that when

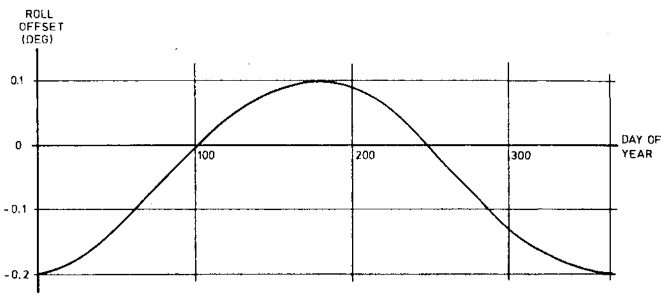

Fig. 5 Seasonal variation of roll offset (Sodern sensor).

heat is so applied to this particular thruster the absorbed hydrazine suddenly decomposes, producing the observed impulse and corresponding depointing. The anomaly is still under investigation but, in consequence, all maneuvers now have to be carried out using the redundant thruster branch unless it is in an operation where heating of the suspect thruster can be avoided by on-board switching.

Finally, a phenomenon, which is not in fact anomalous but certainly causes problems, is the unexpectedly large pitch torque produced by thruster exhaust plume impinging on the solar arrays during north-south stationkeeping maneuvers. How this is dealt with is described more fully below.

East-West Stationkeeping

Strategy

The strategies developed to counteract the two significant perturbing effects for east-west stationkeeping of the Earth's triaxiality (J_{22} harmonic) and solar radiation are well known (e.g., see Ref. 2). A summary of the strategy applied for OTS follows. The objectives of the strategy are to minimize propellant consumption and frequency of maneuvers while maintaining the longitude within the required $10°E \pm 0.1$ deg deadband. The driving perturbation is the triaxiality effect and, at a longitude of 10°E, this requires a single prograde ΔV increment of about 0.07 m/s once every 3 weeks or so. To minimize the effects of solar radiation pressure which could result in a large eccentricity buildup if uncontrolled, the nominal strategy is to time the application of the velocity increments required for the triaxiality correction to maintain an eccentricity of about 0.00025 and the perigee of the orbit orientated toward the sun. With the effective area/mass ratio of OTS-2 (0.029 m^2/kg), the eccentricity then does not vary very much from the value of 0.00025 during the interval between maneuvers while the drift of the perigee away from the sun line is corrected by the maneuver. Control of both perturbing forces is therefore achieved with a single burn every 3 weeks or so, although occasionally a double-burn maneuver is required to restore the situation after it has been upset by some external disturbance (i.e., a north-south maneuver or excessive roll/yaw thruster pulses). The 0.00025 eccentricity results in a daily longitude oscillation of amplitude 0.03 deg.

This strategy works well with OTS; the achieved mean longitude history for the first year in orbit is shown in Fig. 6, with the arrows at the top of the figure denoting the occurrence of a maneuver and its direction. However, the achievement of a *regular* 3 week cycle has not proved to be practical due to normal mode thruster actuations which have a significant (10% of the J_{22} effect) but unpredictable effect on the east-west drift rate, and due to the periodic north-south maneuvers which have an in-plane effect two or three times that of an east-west maneuver, albeit mostly radial.

Early in the mission, the ± 0.1 deg longitude deadband was overrun on three separate occasions; on two of them 9.7°E longitude was reached before corrective action reversed the drift. The main reasons for these occurrences were the initial lack of appreciation of the effect that the normal mode thrusters had on the orbit during the tests, which required

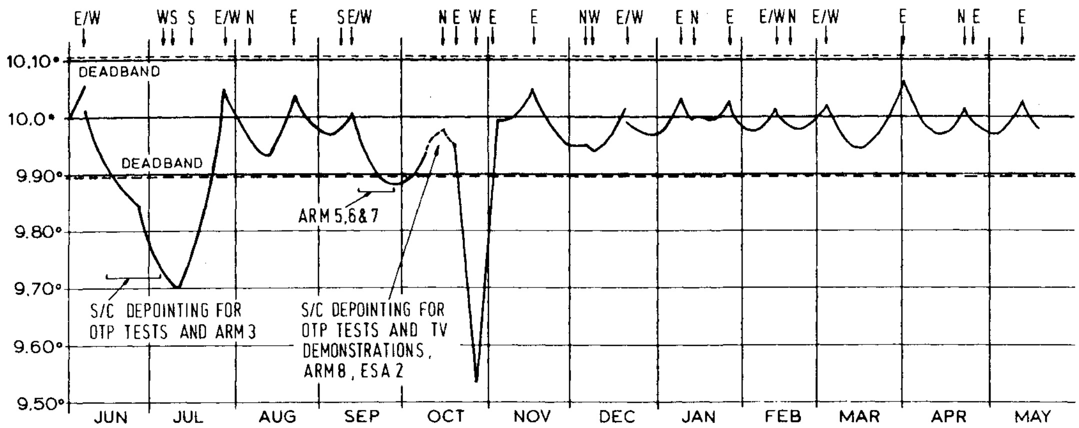

Fig. 6 OTS-2 history of mean longitude, first year (1978-1979).

Table 1 Orbit determination accuracy

a) Measurement accuracy

Station	Measurement	Improved calibration, 1σ	Noise, 1σ
Fucino	Azimuth, deg	0.028	0.002
	Elevation, deg	0.027	0.006
	Range, m	25	4
Villafranca	Range, m	1500	10

b) Orbit accuracy

Measurement	Accuracy, 1σ
Perigee, apogee height, m	210
Semimajor axis, m	50
Inclination, deg	0.0028
Position, km	2.5
Velocity, cm/s	19

The position accuracy has components of about 1.8 km for both longitude and latitude, i.e., 0.0025 deg.

depointing of the spacecraft, and the failure to allow sufficient time for orbit determination following either such maneuvers or the occurrence of other events (ARM, ESA) involving thruster actuation. Since that time, a daily check of longitude is made via antenna azimuth and elevation measurements independently of the weekly orbit determination, and possible effects on the orbit of any tests involving thruster actuation are considered carefully before the tests are implemented, with the result that the deadband has not again been overrun.

In recent times with the accumulated experience of many maneuvers and confidence in the accuracy obtainable from the orbit determination, it has been possible to demonstrate the feasibility of reducing the stationkeeping deadbands from the initial ±0.1 deg, first to ±0.05 deg and then to ±0.035 deg in both latitude and longitude. The penalty for these reductions is an increased frequency of maneuvers and an increase in propellant consumption. To achieve ±0.05 deg, east-west maneuvers are required every 14 days and north-south maneuvers every 28 days. To achieve ±0.035 deg, weekly maneuvers are necessary with an east-west eccentricity and longitude drift correction alternating with a combined inclination and drift correction. The increase in propellant consumption arises from the need to maintain eccentricity less than 0.0001 and therefore to compensate for the solar radiation pressure effects directly. The increase is small, on the order of 2 m/s per year, i.e., 4% of the total annual propellant budget.

Table 2 East-west thruster performance

Thruster	Branch	No. of maneuvers	Total burn time, s	Mean error, %
East	Prime	6	181	−2
West	Prime	5	51	No data
East	Redundant	12	344	−1
West	Redundant	4	158	No data

Orbit Determination

Orbit determination calculations are made weekly using measurements from Fucino, Italy (longitude 13.6°E, latitude 41.98°N) and from Villafranca, Spain (longitude 3.95° W, latitude 40.44°N). Whereas Fucino provides measurements of azimuth, elevation, and range, Villafranca provides the range component only. Measurement frequency is broadly every 2 h for the 2 days following a stationkeeping maneuver and every 4 h at other times.

Because of the unfavorable geometry, additional tracking support (further ground stations plus further tracking facilities) were brought in initially in order to calibrate the above-mentioned ground stations. The results of these tracking exercises are summarized in Table 1a. Comparing the overlapping periods of consecutive orbit determinations, an estimate for the orbit accuracy is obtained. Neglecting the periods including maneuvers, the orbit accuracy (consistency) figures shown in Table 1b were obtained.

Thruster Performance

Up to July 1979, 27 maneuvers had been performed. Most of these maneuvers used the east thruster on the redundant branch of thrusters. In general, performance of these two north thrusters is predictable and close to prelaunch predictions. Table 2 summarizes the burns and relative performance.

Implementation

The implementation of the east-west maneuvers has developed through several stages. Prelaunch predictions of thruster misalignment torques required a cautious approach at first. To be sure of maintaining roll and yaw control, maneuvers were implemented with the stationkeeping control loops on-line and burns were limited to a duty cycle of 1 s every 30 s to avoid large pitch overshoots. However, it became apparent that the thruster misalignments were, in fact, very small and following some checks it was found feasible to dispense with the stationkeeping loops and implement the maneuvers in normal mode. Burn sizes of about 10 s cause a small increase in nutation, which is quickly damped out, and a

Table 3 North-south maneuver performance

Year/day	Direction	Corrected burn time, s	ΔZ, m/s	Error, %	In-plane components	
					Radial, m/s	Tangential, m/s
78/198	S	2000	4.35	−28	−0.200	−0.035
78/229	N	1267	3.17	−12	−0.150	−0.018
78/252	S	816	2.04	−10	−0.076	−0.018
78/290	N	1878	4.83	−6	No data	
78/341	N	2535	6.44	−7	−0.274	0.035
79/015	N	1688	4.08	−11	−0.249	−0.011
79/050	N	1428	3.49	−8	−0.205	0.002
79/113	N	2105	4.94	−12	−0.193	0.043
79/153	N	2406	5.80	−8	−0.193	0.048
79/190	N	1745	4.13	−9	−0.118	−0.001

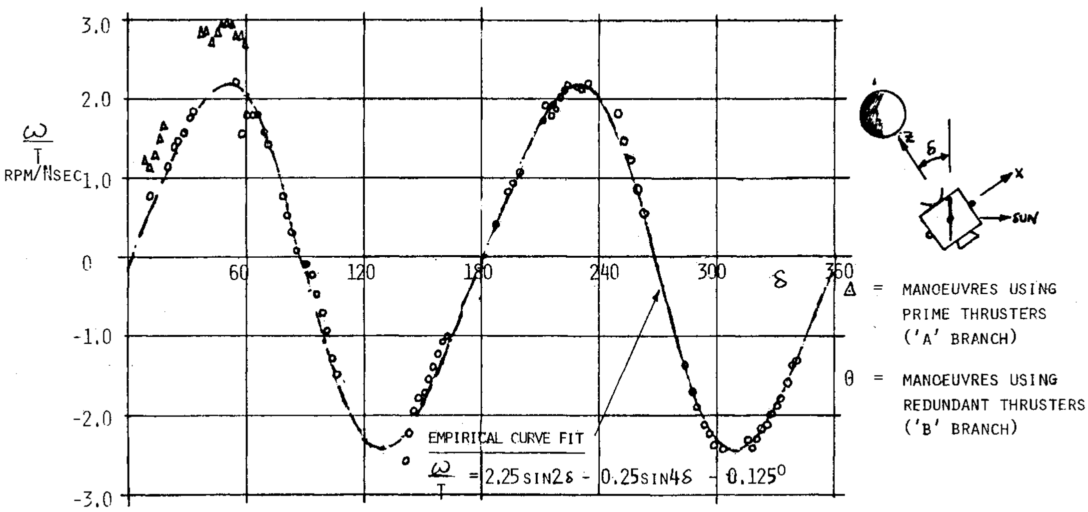

Fig. 7 Variation of FMW speed per Newton-second of impulse with solar array orientation.

virtually indistinguishable pitch transient. Thus, east-west maneuvers are now extremely straightforward. In addition, it has recently been possible to use the prime branch thrusters for east maneuvers as the yaw thruster on this branch, suspected of spurious operation, is not used and, furthermore, need not be heated (see above).

North-South Stationkeeping

Strategy

The strategy adopted to counteract luni-solar perturbations and maintain a ± 0.1 deg latitude deadband (i.e., inclination less than 0.1 deg) is to correct only for secular effects and to ignore cyclic effects. This strategy requires burns in a north (or south) direction at a satellite right ascension with respect to the first point of Aries of between 270 and 279 deg, depending on the year (90-99 deg for south burns).

The problem with the yaw thruster on the prime thruster branch has meant that these maneuvers are constrained to using the redundant thruster branch. The thrusters on this branch are north pointing, producing a velocity increment in a northerly direction. Because of this and because the maneuvers have developed into a very complex operation, they are performed only once every 6 weeks or so and are timed to occur some 4-5 days before the next east-west maneuver becomes necessary. This timing allows any in-plane cross coupling of the impulse to be corrected by the east-west maneuver.

The strategy enables the inclination to be maintained at less than 0.07 deg throughout the year and for one-third of the year it is, in fact, kept less than 0.05 deg. If the requirement existed, the orbit determination accuracy is good enough to permit maintenance of inclination at less than 0.05 deg throughout the year.

The north-south deadband of ± 0.1 deg latitude has not been transgressed throughout the mission.

Thruster Performance

Accuracy assessment of the thruster performance is complicated by the fact that the two yaw thrusters used to implement the burn are naturally also used for yaw control. Prior to a burn, they are pulsed to maintain the limit cycling between the ± 0.1 deg yaw thresholds set in the stationkeeping control loops. These pulses should therefore be added to the programmed impulse of the burn itself. During a burn, yaw pointing is maintained by interrupting the continuous operation of one of the two thrusters. These "off-modulation" pulses are therefore lost pulses which need to be subtracted from the programmed burn. Thus, the number of pulses used for yaw control has to be known in order to estimate the actual performance.

In general, the resolution of the RIG telemetry is sufficient to do this and the results obtained are certainly within the accuracy obtained for the estimation of the achieved impulse from orbit determination. Table 3 summarizes these results and shows that the achieved thrust levels were approximately 10% below prelaunch predictions. This deficiency is currently unexplained.

Implementation

The implementation of the north-south maneuvers is achieved as for east-west maneuvers, with the stationkeeping control loops enabled to provide thruster control of the roll and yaw axes and the FMW providing pitch control via the normal mode control loop. The required north-south impulse is achieved by firing the two yaw control thrusters simultaneously.

It was envisaged that burns of up to 2000 s would be required and these would be executed as a single continuous firing. However, on the first attempt at such a maneuver, a dramatic increase in FMW speed occurred with the upper tolerance limit for the FMW being reached after less than 60 s into the firing, and the maneuver was terminated. Initially, it was suspected that this was the result of a pitch torque induced by badly misaligned thrusters. However, subsequent maneuvers demonstrated that it was due to "plume impingement," i.e., the thruster exhaust plume hitting the solar array panels and producing a pitch torque. This had not been considered during planning of these operations as it was thought to be negligible. The magnitude of the plume impingement torque is proportional to the orientation of the solar array panels relative to the thruster plumes and varies sinusoidally as illustrated in Fig. 7.

The operational procedures have therefore been changed to accommodate these plume impingement torques. In the first place the planned firing has to be split into several shorter burns so that the FMW speed change is kept within the $\pm 10\%$ operating limits. Second, a momentum off-loading maneuver has to be introduced after each burn to return the speed to a suitable starting value for the following burn and so on. At the times of year where the plume impingement torque is maximum, as many as 10 shorter burns have to be implemented. In addition, the timing of each burn has to be very carefully planned so that the centroid of the separate burns is the same as the centroid of the continuous firing in order to achieve the required effect on the orbit plane.

These maneuvers are further complicated by the problem of "missing pulses" in the attitude control thrusters, particularly the roll axis control thrusters, in conjunction with the seasonal offset apparent on the Sodern sensor roll output. As mentioned above, this offset is corrected in normal mode control by injecting a seasonally varying bias voltage into the control loop. Unfortunately, this bias is not also fed to the stationkeeping control loops, with the result that when these loops are switched on, they immediately see a large roll error (maximum 0.2 deg) and thrusters are pulsed to reduce this to within the $+0.05$ deg threshold. The resulting overshoots in the situation where a thruster fails to respond, i.e., only gas is expelled, could be large and have, on one occasion, come very close to the ARM threshold of 0.4 deg.

The solution to this problem has been to prime the thrusters some time before the maneuver (i.e., pulse them until a repeatable impulse is obtained), and to remove the roll error by open-loop pulsing of the yaw thrusters before enabling the control loop. Thus the roll rate at first crossing of the threshold is low and the resulting limit cycling is relatively gentle. The pitch thrusters which are to be used for momentum off-loading during the maneuver are also primed in the same way.

The maneuvers are currently implemented as described without difficulties. However it can be seen that the whole operation is a great deal more complex than originally envisaged. It is also time-consuming both in preparation and execution.

In-Plane Coupling of Impulse

The north-south maneuvers are executed a few days before a necessary east-west maneuver, so that any cross coupling of the north-south maneuver impulse into the east-west direction can be determined and then allowed for in planning the east-west maneuver.

In-plane coupling has several sources, all connected with the firing of the thrusters: 1) misalignment of the north-south facing thrusters, 2) spacecraft attitude errors relative to the orbit plane, 3) roll thruster actuations for attitude control during the maneuvers, and 4) pitch thruster actuations necessary for momentum offloading to balance plume impingement torques. Of these sources, the contribution from the roll and pitch thrusters have proved to be most significant. The roll thrusters produce a thruster component directed radially inward toward the Earth. The magnitude of the resulting velocity increment is typically 0.1 m/s for 1000 s of burn, which is larger than a normal velocity increment for an east-west maneuver but, being radial, affects only the orbit eccentricity and argument of perigee. The pitch thrusters produce a radial and an along-track velocity increment, respectively, about 0.02 and ± 0.01 m/s per 1000 s of burn at the time of maximum plume impingement torque. The along-track component can be significant in its effect on the longitude drift rate. Table 3 includes the observed radial and along-track components for each maneuver. The resulting effect on longitude drift rate has been counteracted without problem at the execution of the east-west maneuvers. It has, however, meant that a two-burn maneuver is required occasionally and there can be some disruption of the east-west strategy.

Conclusions

The Orbital Test Satellite (OTS) has made a convincing demonstration of fulfilling all of its mission objectives and is continuing to do so. In particular, the integrity of the design concept has been clearly proven with respect to the spacecraft's availability for communications traffic; this is apparent when it is noted that in over 18 months of routine operation the total outage of the spacecraft has been 6 h, an availability of 99.96%.

Experience with OTS has shown a few areas where small improvements in design to upgrade unit performance or to permit operational simplification could be considered for incorporation on the future operational ECS spacecraft. The OTS mission continues to provide a platform for advanced communication experiments. The remaining consumables are such as to allow full mission capability until at least mid-1984, three years more than the originally planned mission duration.

Acknowledgments

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