SOHO's Recovery
– An Unprecedented Success Story

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Introduction

On 25 June 1998 (12 UT), the following e-mail was issued by the Operations Team at NASA/GSFC

 After the planned momentum management, while still in thruster mode, the Attitude and Orbital Control Subsystem (AOCS) switched into ESR (Emergency Sun Re-acquisition mode) on 2   June at 2   16, due to a procedure problem. On 25 June at   2   5 a second ESR occurred during standard ESR recovery, triggered by roll rate the reason is unclear. Some time later, at   8, a third ESR triggered by a fine Sun-pointing anomaly and all telemetry was lost. The Deep Space Network (DSN) used a   -m station (Madrid) to search for the downlink. Weak signal from the spacecraft is at the moment being received intermittently, but stable communication has not been established yet .

The SOHO mission is a major element of the joint ESA/NASA International Solar Terrestrial Programme (ISTP). ESA was responsible for the spacecraft's procurement, integration and testing. NASA provided the launcher, launch services and ground-segment system and is responsible for in-flight operations following the launch on 2 December 1995. The SOHO mission operations are therefore conducted under a NASA/Goddard Space Flight Center (GSFC) contract with Allied-Signal Technology Corporation (ATSC). Following the spacecraft's in-orbit checkout and the transit from low Earth orbit to its operational halo orbit around the Lagrangian point (L1) between the Earth and the Sun, the SOHO mission was declared fully operational in April 1996. SOHO then completed its two-year primary mission and entered an extended-mission phase in May 1998. On 25 June 1998, all contact with SOHO was lost.

The space scientist's and space engineer's worst nightmare was beginning to unfold – SOHO was lost in space

Within just a few hours of this e-mail message being received, an investigation team composed of ESA and Matra Marconi Space experts (MMS was the SOHO Prime Contractor) was in place at ESTEC in Noordwijk and at MMS in Toulouse. This team – in constant communication with NASA/GSFC in Greenbelt (USA) – studied the situation very carefully in order to propose measures for recovering spacecraft telemetry and attitude. The first recovery procedure was established in Europe, transmitted to GSFC and sent to SOHO on 25 June at 22   UT. It very soon became evident, after discussions with Jet Propulsion Laboratory (JPL) in Pasadena (USA), that the weak signals that were being observed at the DSN station in Madrid were only spurious, and that SOHO was not sending any live signals.

Due to the critical situation with the spacecraft and in order to centralise decision-making, it was decided to transfer the investigation team to GSFC. The first members left from ESTEC on 26 June, and the full ESA and MMS team was in place at GSFC by 28 June.

Milestones in the investigative process

The subsequent investigations showed that the loss of contact with SOHO had been preceded by a routine calibration of the spacecraft's three roll-control gyroscopes (gyros') and by a momentum-management manoeuvre. The spacecraft's roll axis should normally be pointed towards the Sun and the three gyros aligned to measure incremental changes in spacecraft roll attitude.

Calibrations are performed to determine the drift biases associated with each of the three roll-axis gyros when the spacecraft has no angular rotational motion about its roll axis when under star-tracker control. Once these bias values have been accurately determined, they are up-linked to the spacecraft's onboard computer to be subtracted from the gyro measurements when determining the actual motion of the spacecraft. The biases drift slowly over time and with temperature fluctuations, which means that gyro calibration must be repeated periodically.

The gyros are used primarily for Initial Sun Acquisition (ISA), for thruster-related activities such as momentum management and orbit station-keeping, and for Emergency Sun Reacquisition (ESR). Momentum management is accomplished using the spacecraft's Attitude Control Unit (ACU) computer, and is performed approximately every two months to maintain the reaction-wheel speeds within their operational limits. The reaction wheels provide the three-axis control torques needed to counteract internal and external disturbance torques imparted to the spacecraft, and thereby very precisely control its attitude, and also to slew the spacecraft for special roll off-pointing manoeuvres.

Momentum management is necessary because the reaction wheels increase in speed over time in order to maintain spacecraft attitude in the presence of the external disturbance torques. As the wheels accelerate to speeds that approach their operational limits, momentum management is performed to restore the reaction wheel speeds to adequate initial values.

In the momentum-management mode, the ACU computer commands the wheel speeds to new initial values and the spacecraft attitude disturbance that follows from the wheel deceleration/acceleration is counteracted by firing the thrusters.

Normally, the three roll gyros perform the following functions

– Gyro A is connected to the Failure-Detection Electronics (FDE) for roll-rate sensing for ESR to allow spacecraft roll-rate control using thrusters
– Gyro B is connected to the FDE for excessive roll-rate (anomaly) detection
– Gyro C is connected to the ACU for roll attitude sensing during computer-based control modes using thrusters.

The Emergency Sun Reacquisition (ESR) mode

ESR mode is a safe hold mode’ or a safety net’ configuration entered autonomously by the spacecraft in the event of anomalies. It is a hard-wired analogue control mode that is part of the Failure Detection Electronics (FDE). Unlike the other control modes, it is not under the control of the Attitude Control Unit (ACU) computer. Thrusters are used in ESR to control the spacecraft attitude.

Once the spacecraft has entered the ESR mode, a recovery sequence must be commanded and executed under ground operator control to proceed to the normal mode’ from which science observations are made. The first step in this recovery sequence involves the use of the ISA mode, in which the ACU computer takes over the commanding of the thrusters to point the spacecraft towards the Sun using the onboard Sun acquisition sensor SAS-1.

Conservative usage of SOHO's gyroscopes has always been implemented because gyros are recognised as being life-limited items. Problems encountered in other programmes using similar gyros led to the introduction of additional changes following launch to further preserve gyro lifetime. Consequently, Gyro A was deactivated (spun down) after every calibration manoeuvre to conserve its life. There is an automatic onboard function to reactivate Gyro A if the spacecraft autonomously enters its ESR mode. However, all gyros are intended to be fully active during momentum-management manoeuvres.

ESR-5 of 2 June 1998, 2 1 (UT)
The Failure-Detection Electronics of Gyro B was set to high gain’ for wheel management and was left on high’ instead of low’ after completion of the task. The reason was a recent change to the spacecraft command procedure, made in May. During standard momentum management, an ESR was triggered as a consequence of high gain, i.e. the roll-rate threshold was 2 times too low. In ESR-5, the spacecraft reconfigured to B-side (redundant/backup system used when there is a problem with the A-side/main system) and went into ESR Sun-pointing mode as expected. Gyro A, nominally available in ESR, was not spinning because the onboard software gyro-setting function was disabled from the ground. As roll control in ESR is based on the availability of a spinning gyro (A), this would subsequently lead to ESR-6.

ESR-6 of 25 June 1998, 2 5 (UT)
During the recovery from ESR-5 in initial Sun-acquisition mode, the spacecraft spun-up due to a non-zero Gyro-A drift-compensation value in the roll controller, while Gyro A was not spinning. The roll-rate anomaly was detected by Gyro B and the spacecraft was put into ESR-6. Subsequently, the spacecraft went back into B-side configuration. Sun-pointing was achieved by the Failure-Detection Electronics as expected.

ESR- of 25 June 1998, 8 (UT)
During the recovery from ESR-6, Gyro A output was read as zero by the ground operator (as expected in ESR), but in fact this value was caused by Gyro A not spinning. Gyro B's output was found to be non-zero and judged faulty. It was therefore switched off by

the ground, eventually causing ESR- . During the recovery from ESR-6, again via the Initial Sun-Acquisition mode, further uncontrolled spin-up of the spacecraft was due to

- Gyro A not spinning
- gyro drift compensation
- Gyro B being unavailable to stop the spin up.

Spin-up continued with increasing coning' motion, producing increasing pitch/yaw off-pointing (Fig. 1) until the fine Sun-pointing anomaly detector triggered at a spin rate estimated at about deg/s the spacecraft then fell into ESR- . The ESR- controller diverged at this spin rate, which greatly exceeded design values. This loss of attitude control ultimately resulted in loss of power, telemetry and thermal control.

Spacecraft status at loss of telemetry

Battery management

The battery-management status was not as it should have been. Two batteries were fully charged at the time of telemetry loss, but only one of them was connected to the main power bus, with the current limited to 1 .5 A. This was not enough to power the essential loads such as transponder, data-handling, etc., for which two batteries should normally be connected to the bus, giving a 5 A capability. In addition, the spurious switch-offs of three out of four battery-discharge regulators between January 199 and May 1998 had gone undetected.

Analysis of power-subsystem behaviour

Following ESR- , the power subsystem behaved as expected, until the loss of telemetry. A correlation of the diverging Sun-acquisition sensor angles (pitch and yaw), showed a good match with the solar-array regulation and battery-discharge/charge modes. Due to the limited current from the batteries (with only one of the four regulators active), a bus under-voltage occurred and triggered a random electrical load shedding, thereby reducing the bus load by around 1 A. When turning back towards the Sun, the automatic regulation system started to recharge the battery that had just been discharged, until the solar-array shadowing caused by spacecraft depointing again put it into battery discharge shortly before the loss of telemetry.

Analysis of RF subsystem behaviour

The RF subsystem reconfigured as expected during ESRs 5, 6 and . Telemetry is (by design) available on only one low gain antenna during an ESR. After ESR- , there was loss of telemetry at   (UT) and possibly the loss of carrier at   52 (UT).

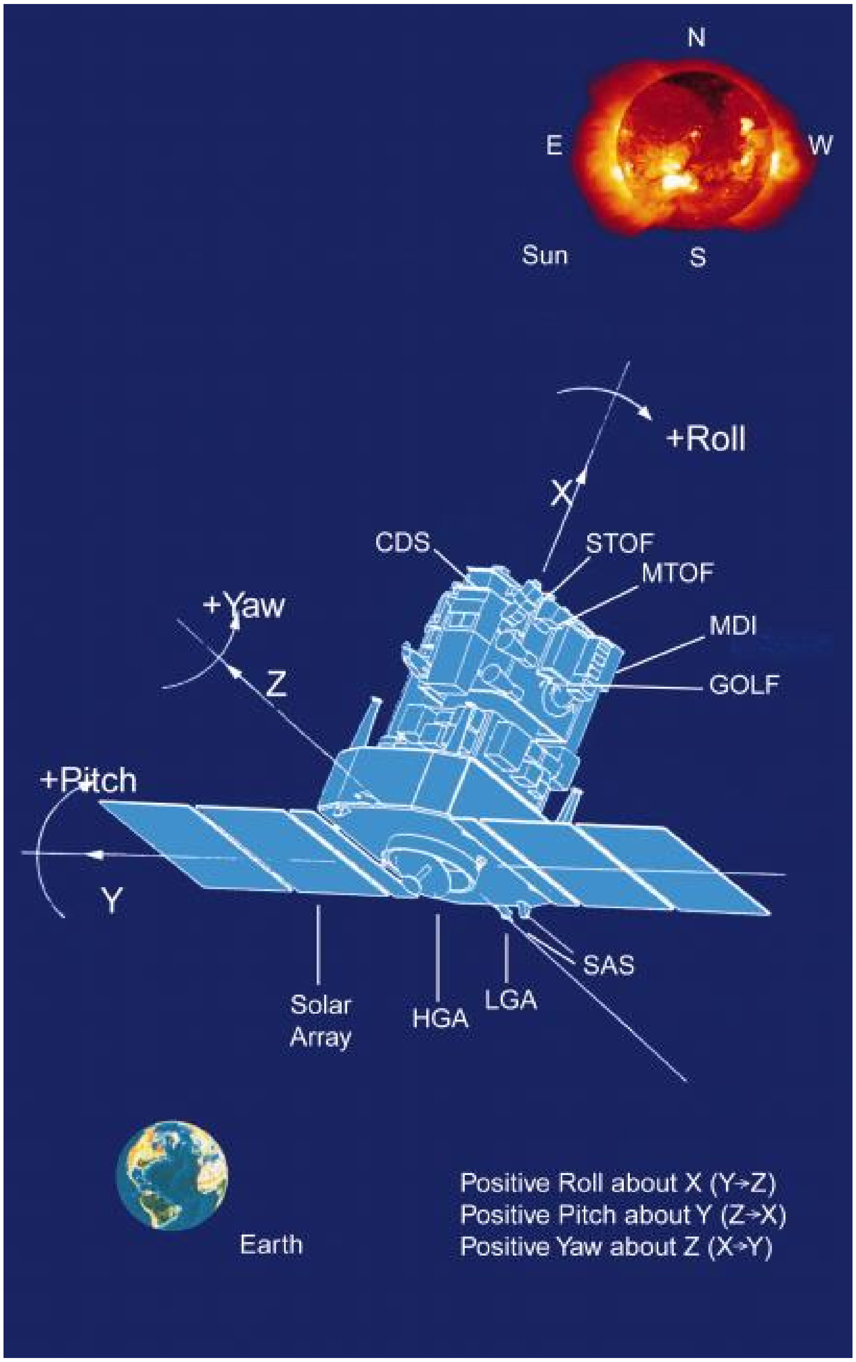

Figure 1. Rotational axes and sign conventions for SOHO manoeuvres

Analysis of data-handling subsystem behaviour

The data-handling subsystem reconfigured as expected during ESRs 5, 6 and .

Dynamic behaviour

Early in July, it was possible to run the dynamic mathematical model at MMS in Bristol (U) which concurred very well with the last few minutes of telemetry. SOHO was, based on spacecraft dynamic considerations, expected to transit from an -axis spin into a spin around its -axis, which would eventually be pointing coarsely towards the Sun. It was not known whether the   -axis would be pointing at the Sun. The predicted time for transition ranged from 1 day to several weeks, while the spin-rate prediction varied from   to 8 deg/s.

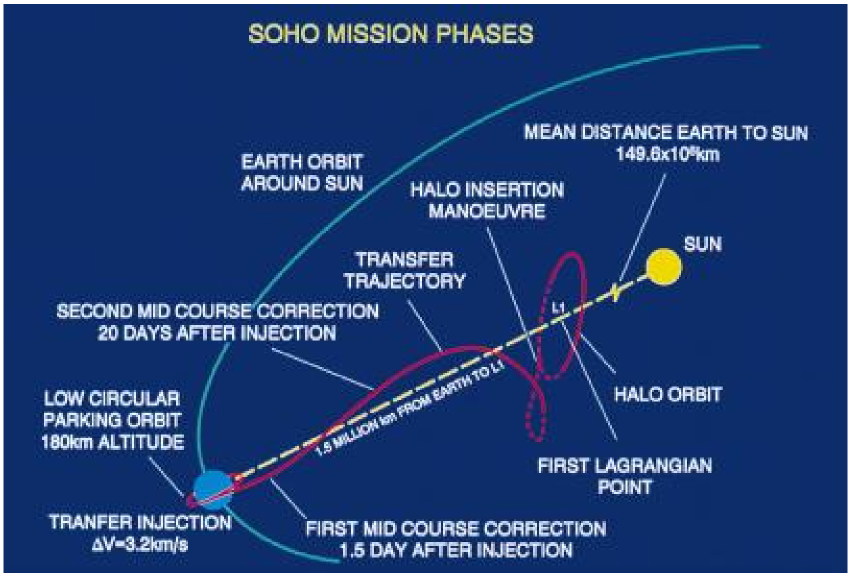

Figure 2. SOHO transfer trajectory and L1 halo orbit

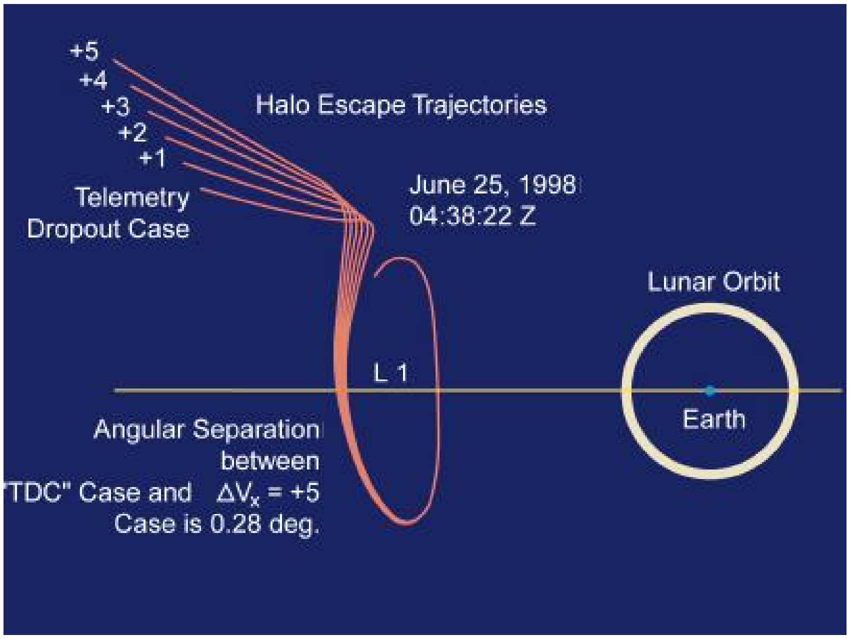

Figure . Computed potential halo escape trajectories, for delta-V's of 1 to 5 cm/sec

The Investigation Board

The SOHO Mission Interruption Joint ESA/NASA Investigation Board was established by the ESA Director of Scientific Programmes and the NASA Associate Administrator of the Office of Space Science to gather information and determine the facts, as well as to identify the actual or probable cause(s) of the SOHO mission interruption.

The primary purpose of this Board's investigation and subsequent management action was to identify and effect necessary changes and pursue corrective actions to prevent the recurrence of similar problems in the future and thereby improve the effectiveness of ESA/NASA operations.

The Board met at GSFC in early July 1998 and published its preliminary report on 1 July. The final report was published on 1 August. Recommendations were reviewed on 2 and December 1998 during the Re-certification Review.

Thermal predictions

Thermal simulations were run at MMS in Toulouse (F) and spacecraft temperature predictions were established for the and - - axes being pointed towards the Sun, and for intermediate cases with angles of 5 to the Sun. These thermal predictions showed that certain equipment items and instruments on the side of the spacecraft in shadow would be experiencing extremely cold temperatures, e.g. -62 C for the high-power amplifiers. The thermal model was subsequently also installed at GSFC for the on-going analyses.

The orbit predictions

SOHO's nominal trajectory is a halo orbit around the L1 Lagrangian point (Fig. 2), approximately 1.5 million kilometres from Earth. Halo orbits around L1 are inherently unstable and station-keeping (propulsive) manoeuvres must occasionally be used to stabilise them. If this reference trajectory is propagated from the point where SOHO's telemetry was lost and no additional delta-V is applied, it diverges only very slowly, retaining orbital halo characteristics up to mid-November 1998. Thereafter, the divergence would accelerate and eventually result in the spacecraft's escape into a solar orbit.

Several hypothetical trajectories based on post-loss delta-Vs were studied for delta-V's ranging from 1 to 5 cm/s (Fig.). The inertial orientation of the -axis would be moving by about 1deg/day due to the global orbital motion of the spacecraft around the Sun near the L1 point. This implied that after roughly 9 days, the -axis would be perpendicular to the Sun, such that the solar arrays would face the Sun for half of the spin period. This meant that if SOHO was to be recovered, it had to be achieved when the -axis would be coarsely perpendicular to the Sun and before the end of November. Fortunately, the two conditions were compatible.

Spacecraft recovery (Table 1, Fig.)

On 2 July, based on a proposition from researchers at the US National Astronomy and Ionosphere Center (NAIC), the 5-m diameter dish of the Arecibo radio telescope in Puerto Rico (Fig. 5) was used to transmit an S-band signal (at 2. 8 GH and with a power of about 58 kW) towards SOHO whilst using the -m dish of NASA's Deep Space Network in Goldstone (USA) as a receiver, thereby locating the spacecraft's echo and tracking it for more than one hour. The radar echoes from SOHO confirmed its predicted location, and a spin rate of 1 rpm.

Table 1. Main Events in the Recovery Activities

Day	Date	Time	Days from ESR	Event(s)
1 6		8	-	Emergency Sun Reacquisition (ESR-)
1 6	25 June		-	Interruption of mission
2	2 July	1	28	Confirmation of orbital position and spacecraft spin rate by Arecibo and DSN radar
215	Aug.	22 51	9	Reception of spacecraft carrier signal by DSN
22	8 Aug.	2 1		Reception of spacecraft telemetry
22	12 Aug.	2 9	8	Begin thawing of hydrazine tank
2	28 Aug.	2 2	6	End thawing of hydrazine tank
2 2	Aug.		66	Begin thawing of hydrazine lines
259	16 Sept.	5 5	8	Start of attitude recovery
259	16 Sept.	18 29	8	ESR-8
259	16 Sept.	18	8	SOHO lock to Sun
266	21 Sept.	16 58	9	SOHO in RMW
268	25 Sept.	1	92	Orbit correction (first segment)
268	25 Sept.	19 52	92	SOHO in Normal Mode
2 8	5 Oct.	18 21	1 2	Start of instrument recommissioning
	5 Nov.		1	Completion of instrument recommissioning

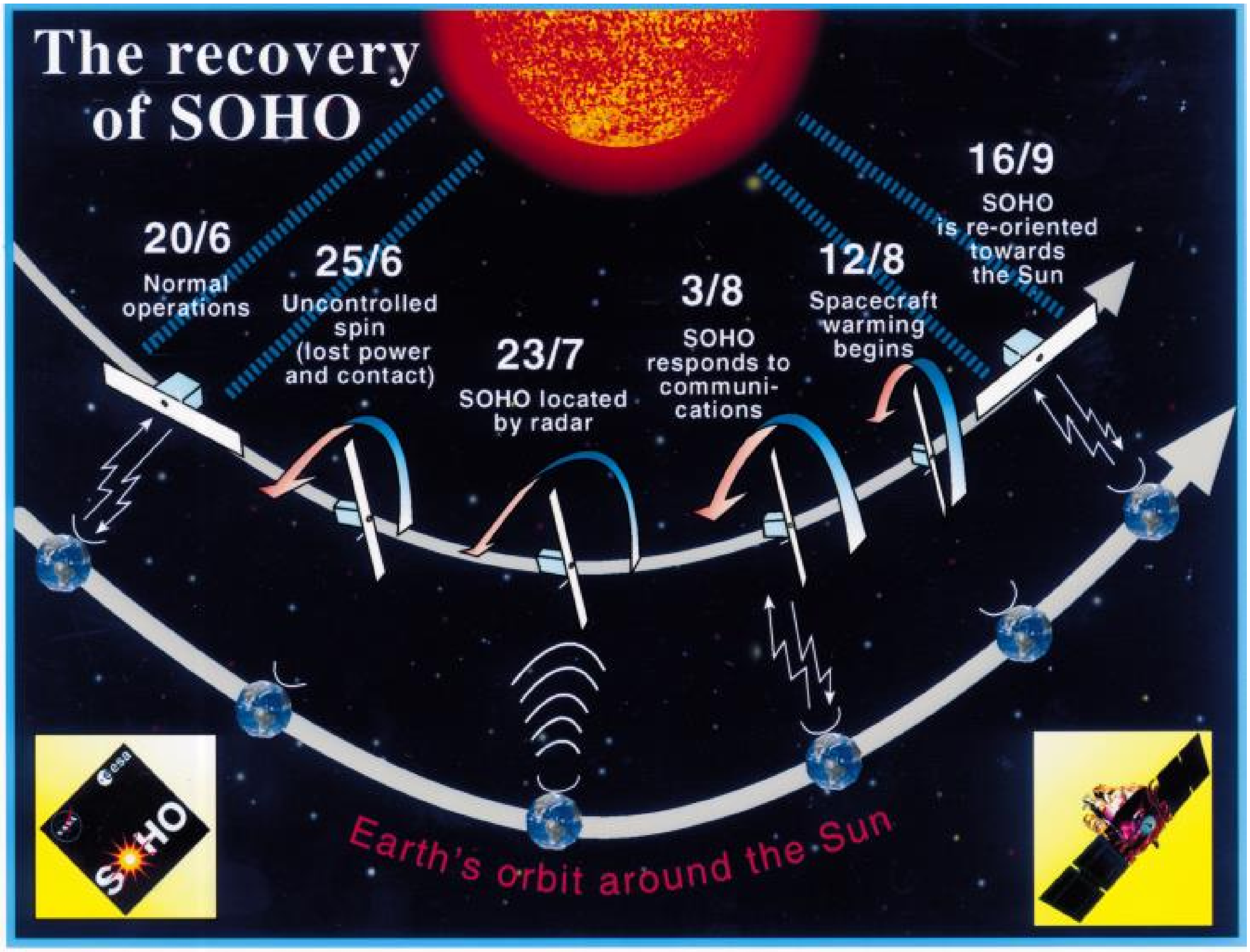

Figure . Some of the key events in SOHO's recovery

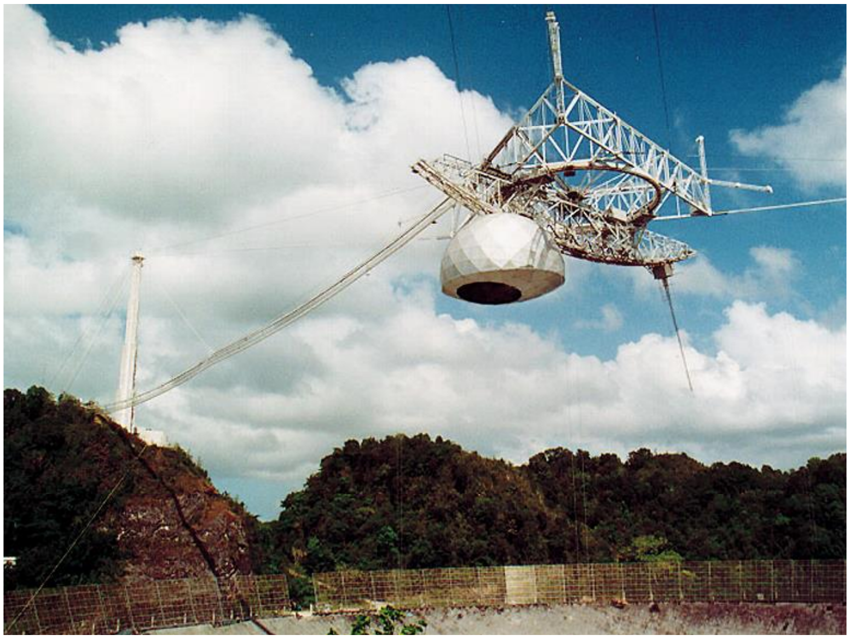

Figure 5. The Arecibo radio telescope in Puerto Rico

Carrier recovery

From the moment that contact with the spacecraft was lost, the Flight Operations Team at GSFC continued up-linking commands, via the DSN, for at least 12 hours per day (normal pass) plus all available supplementary time. The ESA ground stations in Perth (Australia), Vilspa (Spain) and Redu (Belgium) supported the search for a down-link signal. Special equipment was set up at the ground stations to search for spikes in the down-link spectrum and view it in real time at the SOHO operations facilities.

On August, contact was re-established with SOHO after six weeks of silence. Spikes in the down-link were detected by the spectrum analyser installed at Goldstone and by ESA s Perth station, at 22 .9 5 MH and with a ground Automatic Gain Control (AGC) of –1 5 dBm. The spikes were lasting between 2 to 1 s as expected. A commanding sequence was successfully executed through receiver-2, which was connected to the – facing low-gain antenna. Attempts during the following days to command the spacecraft via its facing low-gain antenna were unsuccessful, indicating that it was SOHO’s – -axis that was pointed towards Earth. Analysis of the frequency of the spikes being detected allowed SOHO’s rotation period to be more accurately established it was 52.8 sec.

From carrier detection to telemetry reception

The next objective, after contact had been re-established on August, was to acquire and decode the telemetry. Unfortunately, despite taking special measures at the ground stations in order to be able to receive bursts of telemetry, it proved impossible to decode any such telemetry, which would have told us the status of the spacecraft. It was decided to use the on-board batteries, by first recharging them for several hours and then switching on the telemetry using that stored energy.

Several attempts to charge even one of the batteries and connect it to the power bus were unsuccessful. Investigations by battery experts in Europe showed that below 2 V there would not be enough power to maintain the Battery Charge Regulator (BCR) in an on’ position. Therefore, to charge just one battery it was necessary to keep sending the BCR on’ command repeatedly. On 8 August, after 1 h of in-loop commanding, telemetry was successfully switched on and battery-2 was connected to the bus. Seven frames of telemetry were then received at the GSFC Control Room via the normal network. To avoid discharging the battery, the Battery Discharge Regulator (BDR) was opened at the end of the test, switching off the power and hence the transmitter.

At this time, it was established that the following items of equipment were working correctly the Central Data Management Unit (CDMU), including the decoder, transponder-2, High Power Amplifier-2 (HPA-2), the Service Module Remote terminal Unit-2 (SRTU-2), and the AOCS Remote Terminal Unit (ARTU).

Now the main challenge was to keep the 28 V bus alive by ensuring that the battery remained charged. The next day, 9 August, the telemetry was switched on again and a command issued to also switch on the Payload Remote Terminal Unit (PRTU). This enabled temperature readings to be acquired for each instrument.

Battery charging

A new power budget was established based on the power consumptions of the onboard equipment needed for the recovery operations being planned, as well as the charge/discharge ratio of the batteries. Since the solar arrays were only illuminated for part of the time (the angle to the Sun at this time was approximately 5), the batteries were being charged for only 5 of the time. The newly established power budget showed that the batteries would charge over several cycles if the total power consumption remained below 6 W. However, telemetry required 1 5 W for a minimum configuration, and would therefore quickly drain the batteries. Recovery of the spacecraft would therefore require periods of battery charging alternated with other activities. After lively debate among the recovery-team members, the end’ of battery charging was first set at between 5 and 6.5 V and was later readjusted to between and 1 V.

Attitude determination

During the same period, the telemetry data on the Sun Acquisition Sensors (SAS) had been collected. The availability of this data confirmed that the Failure Detection Electronics (FDE) were working fine as far as SAS data processing was concerned. The analysis of the SAS data confirmed a spin period for SOHO of 52.6 s, that the spacecraft's -axis was facing the Sun and that the angle between the spacecraft rotation axis and the Sun was about 6. .

Thawing of the hydrazine tank

Another challenge was the thawing of the onboard hydrazine tank and the associated pipes and thrusters. From the first temperature readings from the telemetry and the thermal analyses performed, it was estimated that at least 8 kg of the estimated 2 kg of hydrazine in the tank was frozen. Thrusters 1, , , and 8 and their associated pipes were also frozen, due to temperatures colder than –21 C (minimum thermistor reading obtained). These elements are on the – -axis of the spacecraft and therefore not illuminated by the Sun. The -facing side of the spacecraft showed more favourable temperatures, around C.

The tank thawing operation was started on 12 August, after a cycle of battery charging, but the first signs of a temperature increase were not observed until 25 August. The tank heating was performed with the two batteries on the bus and, after telemetry switch-off, by providing power only to the tank heaters (all other equipment was switched off except for short temperature and battery-voltage telemetry checks every h). The tank thawing process had to be interrupted three times to recharge the batteries. The total power consumption during the heating operation was about 8 W (with telemetry off).

Thawing of the tank was completed on August, after 2 5 h of heating (more than 11 days, without taking into account the battery charging periods). This was longer than the expected days owing to higher than estimated heat losses during the interruptions to charge the batteries, and probably also the larger mass of frozen hydrazine. A very careful balance between the time devoted to battery charging and the power available for thawing the complete propulsion subsystem had to be maintained.

Thawing of the hydrazine lines

Once the tank had been thawed, the thawing of the pipes and thrusters was started on September. Following a long discharge cycle, it was not possible to recharge the batteries whilst simultaneously maintaining the temperature of the propulsion subsystem – the latter was becoming colder and the batteries were discharging. Priority had to be given to recharging the batteries as well as the maintenance of the 28 V bus, which was crucial for communication with the spacecraft. It therefore became evident that the complete thawing of the propulsion subsystem was a major challenge.

Fortunately, it was possible to patch the onboard data-handling software in order to use the available solar-array power more efficiently, switching the heaters on only when power was available from the solar arrays. Also, by fine-tuning the battery-charging/thawing cycle, an optimum duty cycle of 2 h of charging and 5 h of heating was established.

Thawing of the propulsion subsystem was believed to be not yet complete when spacecraft attitude recovery activities were started on 16 September – thrusters B and 8B, and their associated pipes, were still frozen. This had prompted the investigation of alternative attitude-recovery strategies without these thrusters.

Possible recovery scenarios

Four possible alternatives were identified

1. Full ESR recovery – a two-step approach based on the assumption that the full B-side of the propulsion system would be available for recovery. The first step would be stepwise spin-down of the existing -axis rotation to about 1deg/s. Full recovery would then be initiated once the Sun was close to the centre of SAS-1's field of view. During this ESR recovery, all eight branch-B thrusters would be used with SAS-1 for pitch and yaw control, and with one of the gyros for roll control.

2. ESR without roll control – this approach took into account the possibility that there might be insufficient power for the above scenario ESR recovery without roll control would be pursued, using the -axis de-spin, four thrusters of branch-B only, and SAS-1.

. Dual-spin recovery – this scenario, proposed by NASA, was based on the idea of stabilising a spinning spacecraft around its axis of minimum moment of inertia. However, this posed nutation problems, and would not achieve a closed-loop coarse Sun-pointing attitude like in ESR.

. ISA recovery – similar in concept to ESR recovery, this approach uses the A-side with ISA mode, in case the B-side (ESR mode) would not be available. An important difference is that the ISA mode makes use of the SAS-1 sensor only, leading to less than hemispheric coverage (ESR uses three SASs, and thus has omni-directional coverage), this would make the timing of the ISA triggering more critical.

The final choice was alternative 2 — ESR without roll control.

Attitude recovery

After a three-week-long period of meticulous preparation and an aborted attempt on 9 September, attitude recovery was established on 16 September as follows

- After a full battery charge, the propulsion subsystem received a 6 h heating boost in order to test the thrusters needed for recovery. (It was established that all 8 branch-B thrusters were available.)
- A design calibration was carried out, followed by a 2. deg/s de-spin (in three steps). In less than an hour, data evaluation confirmed that the thrusters were working as expected and that the target spacecraft spin rate had been achieved.
- A second three-step de-spin manoeuvre brought the spacecraft rotation rate down to .86 deg/s. After a careful check on the success of the manoeuvre and a go' for all subsystems, ESR-8 was triggered to point the spacecraft towards the Sun without roll control. The roll rate was then corrected using thrusters 5 and 6 in open-loop from the ground.

On 22 September, there was an attempt to make the transition from ESR to ISA (Initial Sun Acquisition), then to FSA (Fine Sun Acquisition) and on to RMW (Roll Mode with Wheels). However, this was not successful for several reasons and ESR-9 was triggered. Later the same day, while recovering from ESR-9, a command timing problem triggered a reconfiguration of the data-handling system and a spacecraft emergency was declared on 2 September, lasting until normal-mode recovery.

After a busy week of recommissioning activities for the various spacecraft subsystems and an orbit-correction manoeuvre, SOHO was finally brought back to normal operating mode on 25 September, at 19 52 58 UT. Remarkably, the only equipment failures at spacecraft level were in two of the three gyros. All other subsystems were working as well as they had before contact was lost.

Instrument re-commissioning

From thermal models, confirmed by housekeeping data received on 9 August, it was established that the instruments had been through an ordeal of extreme temperatures, from approximately 1 C to less than –12 C. Understandably, the twelve instrument teams were anxiously awaiting the moment when they could switch on and check out their instruments.

Instrument re-commissioning started on 5 October with the SUMER instrument, followed by VIRGO on 6 October, GOLF on October, COSTEP and ERNE on 9 October, UVCS on 1 October, MDI on 12 October, LASCO and EIT on 1 October, CDS on 1 October, SWAN on 18 October, and CELIAS on 2 October. The re-commissioning exercise proceeded very smoothly proving that, even after more than three months of forced inactivity, the experiment operations teams were collaborating and working as effectively as they had before the SOHO mishap. All twelve instruments also performed as well as they had before the unfortunate loss of contact, and

Figure 6. Some of the members of the SOHO Recovery Team, at NASA/GSFC on 1 September 1998

some even better, despite the extremes of heat and cold to which they had been subjected.

Epilogue

As luck would have it, SOHO's tribulations for 1998 were not yet over. On 21 December, the last onboard gyro failed during the preparation of a routine orbit-correction and wheel-management manoeuvre. The spacecraft was again put into ESR mode, using two-axis attitude control for pitch and yaw and controlling the roll axis in open-loop from the ground. By early in January 1999, it was possible to control the yaw manually from the ground. The use of thrusters to maintain SOHO's attitude had a significant impact in that a weekly orbit correction was now needed, consuming an average of   kg of hydrazine.

Following SOHO's initial recovery with only one gyro operational, a gyroless mode of operation was already being contemplated. In early January, therefore, it was decided to accelerate the development of gyroless operation. This called for modification of the onboard Attitude and Orbit Control Subsystem (AOCS) software and, in particular, the controller that had used the gyro. A software patch was prepared and tested in Europe before being delivered to GSFC for uploading on 29 January. Recovery from ESR was started on   January and wheel-management and orbit-correction capabilities were achieved on 1 February, making SOHO the first three-axis-stabilised ESA spacecraft to be operated without a gyro.

Acknowledgement

The more than 16 members of the SOHO Investigation/Recovery Team (Fig. 6) – drawn from the ESA, Matra Marconi Space, NASA and AlliedSignal Flight Operations Team – are to be congratulated for a job well done. They had achieved their mandate – to re-establish communications with SOHO and to return it, as far as possible, to full routine operation – under very demanding technical and schedule constraints. r

WWW

The SOHO Web page with daily images, operation plans, targets, and image gallery is available at
sohowww.estec.esa.nl (European site) and
sohowww.nascom.nasa.gov (US site)
The latest EIT images can also be found on the Web at
unbra. nascom.nasa.gov/eit/eit full res.html

The Re-certification Review

The SOHO Mission Interruption Joint ESA/NASA Investigation Board strongly recommended that the two Agencies immediately proceed with a comprehensive review of SOHO operations, addressing issues in the ground procedures, procedure implementation, management structure and process, and ground systems. This review process should be completed and process improvements initiated prior to the resumption of SOHO normal operations.

The Re-certification Review took place at GSFC on 2/ December 1998. The conclusions and recommendations of the Review were as follows

- The Board acknowledges the outstanding achievements of the SOHO Recovery Team
- The spacecraft is operating in a Sun-pointing mode with all instruments on and collecting high-quality science data
- Roll gyro redundancy has been lost, which increases the risk associated with recovery from future spacecraft anomalies
- The Board endorses the implementation of several measures to increase ground-system effectiveness in order to reduce risk to operations
- Recommendations include a strengthened management structure and processes with increased staffing and includes a phased approach to transition to normal operations
- Implementation of the response to these recommendations will contribute significantly to the mitigation of risk in future operations and ensure the obligations of both Agencies.

SOHO Mission Interruption Joint ESA/NASA Investigation Board – Extract from Final Report

Contact with the Solar Heliospheric Observatory (SOHO) spacecraft was lost in the early morning hours of 25 June 1998 (EDT), during a planned period of calibrations, manoeuvres, and spacecraft reconfigurations. Prior to this, the SOHO Operations Team had concluded two years of extremely successful science operations. A joint European Space Agency (ESA)/National Aero-nautics and Space Administration (NASA) engineering team has been planning and executing recovery efforts since loss of contact, with some success to date.

ESA and NASA management established the SOHO Mission Interruption Joint Investigation Board to determine the actual or probable cause(s) of the SOHO spacecraft mishap.

The Board has concluded that there were no anomalies on board the SOHO spacecraft, but that a number of ground errors led to the major loss of attitude experienced by the spacecraft.

The Board finds that the loss of the SOHO spacecraft was a direct result of operational errors, a failure to adequately monitor spacecraft status, and an erroneous decision which disabled part of the onboard autonomous failure detection. Further, following the occurrence of the emergency situation, the Board finds that insufficient time was taken by the Operations Team to fully assess the spacecraft status prior to initiating recovery operations. The Board discovered that a number of factors contributed to the circumstances that allowed the direct causes to occur.

The Board strongly recommends that the two Agencies proceed immediately with a comprehensive review of SOHO operations addressing issues in the ground procedures, procedure implementation, management structure and process, and ground systems. This review process should be completed and process improvements initiated prior to the resumption of SOHO normal operations.