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THE INTERNATIONAL SOLAR POLAR MISSION

M. Delahais, D. Eaton *

The International Solar Polar Mission is a two spacecraft project to be conducted jointly by NASA and ESA. The primary objectives are to investigate, as a function of heliospheric latitude magnetic fields, solar and non-solar cosmic rays and the interstellar/interplanetary neutral gas and dust. In order to perform these measurements, the two spacecraft will be injected into heliocentric orbits approximately at right angles to the ecliptic plane, by using the gravitational field of Jupiter.

Following launch using the Shuttle and the Inertial Upper Stage, the two spacecraft are injected into interplanetary trajectories and targeted towards Jupiter so as to pass slightly North and South of the Jovian equator. The gravitational field of the planet then causes them to go into heliocentric orbits of the desired inclination to the ecliptic, one spacecraft northwards and the other southwards. After passing over one pole of the sun, each spacecraft crosses the ecliptic plane and passes over the other pole. The complete mission time is approximately five years.

The paper to be presented introduces the mission and the experimental payload of the two spacecraft. However, the principal part of the presentation will be devoted to the management aspects of the project and the relationships between JPL (the NASA Project Manager), ESTEC (the ESA Project Manager) and JSC (the Shuttle Project Manager).

Comparisons are drawn between ISPM and the earlier ISEE cooperative two spacecraft mission launched by a Thor Delta in October 1977. Differences between a manned and unmanned launch vehicle will be explored and the resultant differences in safety approach, documentation etc. described.

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THE INTERNATIONAL SOLAR POLAR MISSION

I N T R O D U C T I O N

The International Solar Polar Mission (ISPM) is a two spacecraft ESA/NASA collaborative programme and will be the first project in which spacecraft are placed in heliocentric orbits almost at right angles to the ecliptic plane. In this way they can survey the sun at high solar latitudes. The desirability of such a mission has been stressed since the early days of satellites in the late nineteen fifties, but until the advent of the Space Transportation System the necessary propulsive force to launch a scientifically worth-while mission was not available.

The present paper will briefly describe the mission, the science, and the ESA spacecraft configuration, although the first two of these have been published in more detail elsewhere (1)(2)(3). However, the major part will be devoted to the management methods used for this collaboration and to the special features arising from the Shuttle-IUS launch vehicle. In particular, comparisons will be made with the International Sun-Earth Explorers (ISEE), launched just over two years ago, which was also a two-spacecraft, ESA/NASA collaborative programme but one which employed an expendable Thor-Delta launch vehicle.

THE SOLAR POLAR MISSION

Even with the injection capability of the Shuttle and three stage Inertial Upper Stage, there is grossly insufficient power to inject a spacecraft directly into a heliocentric orbit capable of surveying reasonably high solar latitudes. The strategy employed is therefore to utilise the gravitational field of Jupiter to provide the extra energy required.

The two spacecraft will be launched mated together with the Shuttle/IUS combination in the early days of February 1983 (Fig. 1).

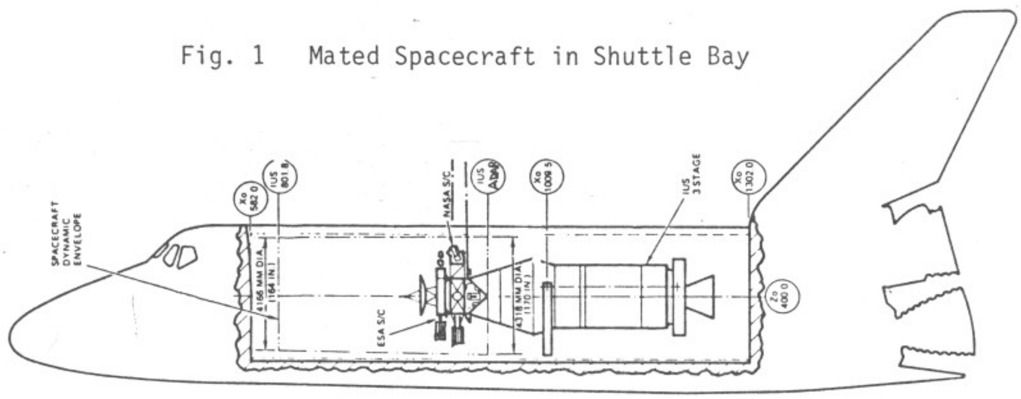
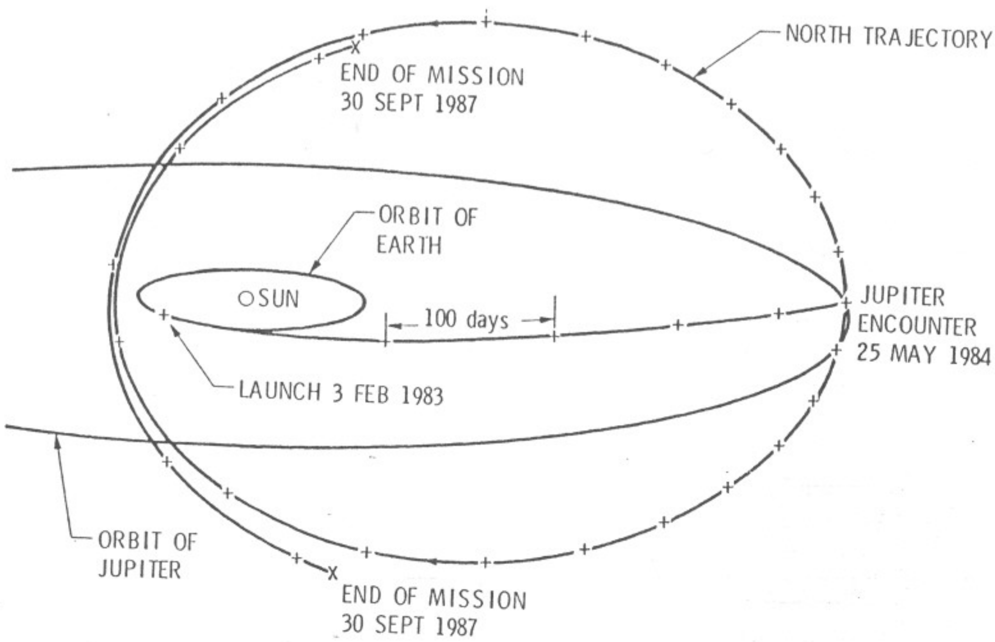


Fig. 1 Mated Spacecraft in Shuttle Bay

Once the Shuttle is in orbit the two spacecraft and the IUS will be separated from it and the IUS fired so as to put the spacecraft on an interplanetary trajectory towards Jupiter. Following burn out and separation of the IUS, the two spacecraft are separated, and they are targeted, by means of the on-board propulsion systems, to go slightly north and south of the Jovian equator.

Using the gravitational field of Jupiter the two spacecraft undergo a sling-shot effect and are thrown out of the ecliptic plane so as to go over the polar regions of the sun. After crossing the poles the two spacecraft re-cross the ecliptic plane and traverse the other polar region. The mission is terminated when the solar latitude of each spacecraft falls below 70° for the second time. The Jovian encounter will occur some 16 months after launch, in May/June 1984, the first polar crossing will be in late 1986 and, for financial reasons, the mission will be constrained to conclude not later than September 30th 1987. For convenience the two spacecraft are known as the north going and south going spacecraft, depending upon which solar polar area they first explore. Fig. 2 illustrates the mission profile.

Fig. 2 ISPM Mission Profile



In defining the mission, account has been taken of a number of limiting parameters and also for a range of STS performance and spacecraft weights.

For thermal reasons we do not wish to go closer to the sun than 1 AU (at perihelion) whilst the scientists do not wish to be further from the sun than 2 AU at maximum latitude. Obviously, there is a desire to carry out simultaneous observations from North and South and so the spacecraft solar orbits are approximately mirror image.
Table 1 gives some characteristics of the currently envisaged mission, but work on its optimisation continues and it will probably be some time before the final details are established . This optimisation study is being performed in close collaboration between analysts in JPL and ESTEC.

TABLE 1 Mission Summary

In Ecliptic

Launch Period	February 3-13, 1983
Launch Energy	114 - 120 km^2/sec^2
Jupiter Encounter Date	25 May 1984
Closest Approach to Jupiter	6.0 R_J

Ex-Ecliptic (Nominal Mission)

	South S/C	North S/C
Periphelion Date	9 March 1987	4 March 1987
Periphelion Distance	1.2 AU	1.2 AU
Maximum Solar Latitude	79^o	89.5^o
Total Time above 70^o Latitude(days)	188	237
Heliocentric Range at Maximum Latitude	1.8 - 2.0 AU	2.0 AU
Mission Termination	30 Sept.1987	30 Sept. 1987

THE SCIENTIFIC MISSION

In view of the number of spacecraft which have been launched in the last two decades, it is somewhat surprising to recall that, with one exception, all of them have been confined essentially to the ecliptic plane and that, therefore, observation of the sun has been limited to solar latitudes within $\pm 7^o$ of the solar equator, which is inclined at that angle to the ecliptic.

The exception is Pioneer 11 which reached a solar latitude of 17^{0} before declining again towards the ecliptic plane. What has been studied to date is therefore an extremely small, and non-representative, portion of the solar environment.

Fig. 3 Idealised View of Sun (J.A.Simpson)

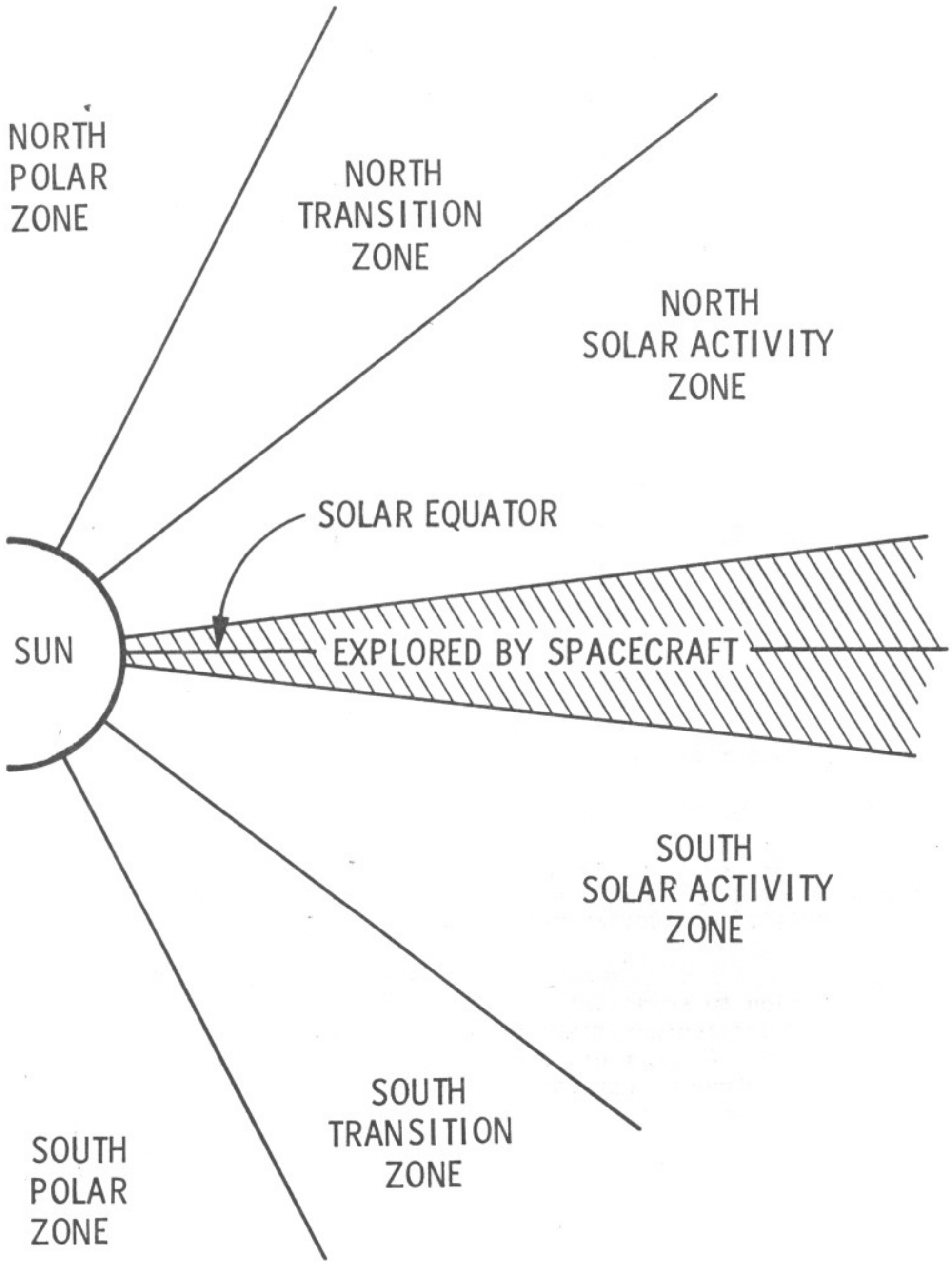


Fig. 3 illustrates the explored region of the solar environment compared to the various regions of solar latitude where differing coronal behaviour is to be expected.

According to J.A. Simpson (University of Chicago), the regions close to the solar equator and the solar poles are expected to exhibit quite different phenomena to the zone from 10° to 40° latitude (the so-called "Solar Activity Zones") where much more violent particle phenomena are likely to be observed. Furthermore, due to the solar rotation period of approximately 27 days, any long term phenomena on the solar surface are obscured from view for 50 % of the time.

It is the objective of the ISPM to explore the heliosphere and view the sun over the full range of heliographic latitudes. This mission will therefore replace our current parochial view with a more accurate assessment of the total solar environment.

It is not within the scope of this paper to deal at any length with the various scientific objectives of ISPM. However, the following list of principal study areas, whilst not exhaustive, gives some feeling for the problems to be attacked by ISPM.

- the solar corona
- the solar wind
- structure of the sun-wind interface
- heliospheric magnetic field
- solar and non-solar cosmic rays
- interstellar and interplanetary neutral gas and dust

It is also envisaged to make use of the spacecraft telemetry system to make radio science observations.

Among the secondary objectives of the mission one might mention interplanetary physics observations for the initial Earth-Jupiter phase, when the separation between the two spacecraft will be accurately known, and of the order of 0.01 AU, and measurements of the Jovian magnetosphere during the fly-by phase.

The Invitation to scientists in USA and Europe to participate in the ISPM mission was made in April 1977 and created considerable interest. A total of 85 experiment proposals were received, both for experimental hardware and for theoretical studies, and these were screened and analysed by a joint ESA/NASA board.

Finally, the hardware investigations shown in Table 2 were selected for the mission. The names listed show, however, only the tip of the iceberg. All of the principal investigators listed have co-investigators from other institutes and frequently from other countries, so that the total number of scientists listed as PI or CoI is in excess of 200 from a total of 65 universities and research institutes in 13 different countries.

TABLE 2 Selected Payloads

OBJECTIVE	NASA SPACECRAFT	ESA SPACECRAFT
Magnetic field	ACUNA (GSFC)	HEDGECOCK (London)
Solar Wind Plasma	ROSENBAUER (Lindau)	BAME (Los Alamos)
Solar Wind Composition	---	GLOECKLER/GEISS (Maryland/Bern)
Low Energy Ions	---	KEPPLER (Lindau)
Low Energy Electrons/ Protons	STONE (Caltech)	LANZEROTTI (Bell Labs)
Particles/ Cosmic Rays	---	SIMPSON (Chicago)
Plasma Waves/ Radio Observation	STONE (GSFC)	STONE (GSFC)
Solar X-Rays/ γ-bursts	CLINE (GSFC)	HURLEY/SOMMER (CESR/ Garching)
Corona and XUV Solar Disc	MACQUEEN (Boulder)	---
Cosmic Dust	---	GRUEN (Heidelberg)
Zodiacal Light	GIESE (Bochum)	---
Interstellar Gas	ROSENBAUER (Lindau)	---

Also included: Radio Science Investigations
Interdisciplinary Investigations

Special mention should be made of a number of selected radio science and inter-disciplinary investigations, which do not furnish hardware to the spacecraft. The former utilises the uplink and downlink RF system of the spacecraft to conduct their experiments, particularly near solar conjunctions, whilst the latter make, as the name suggests, correlative investigations using the data acquired by the various hardware experiments.

PROJECT STATUS

Although discussion of out of ecliptic plane missions took place as early as 1959, it was only in the early years of this decade that active work started on both sides of the Atlantic, at first independently and later as a joint mission. This gradually took shape in 1976 as the "Out of Ecliptic Mission" and a year later its title was changed to the current one. It was decided that each Agency would be wholly responsible for one spacecraft, and that NASA would accept responsibility for the launch and for data acquisition and distribution. A joint control centre was to be established at JPL, which was given the responsibility for the NASA portion of ISPM, although ESA would continue to be responsible for controlling its spacecraft throughout the mission.

For the NASA spacecraft, JPL placed competitive design phase contracts and are presently engaged in negotiating the development and manufacturing phase contract with TRW. ESA, who use somewhat different procurement techniques to NASA, first carried out feasibility studies in-house and in industry. This was followed by a competitive system design phase in the first half of this year and, after further submissions Dornier System (Germany) leading a multinational European consortium was selected at the end of September, to be responsible to ESA for detail design, manufacture and test of the European spacecraft. Since, in the ESA system, it is possible to start work whilst negotiations continue, the Kick-Off meetings were held earlier this month and work is now well under way.

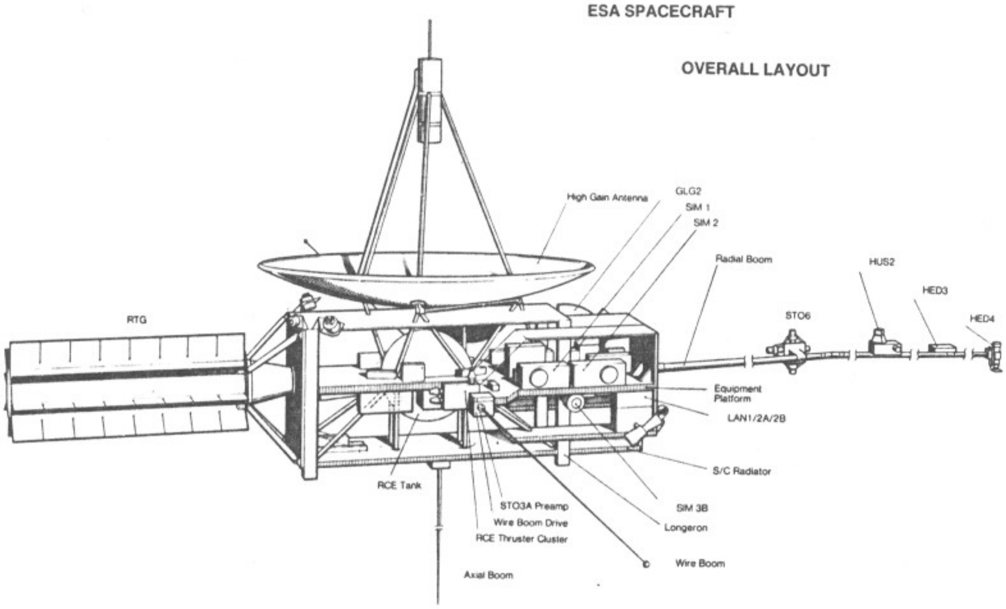
SPACECRAFT DESIGN

It is not the purpose of the present paper to discuss the spacecraft designs, but a few words on special features may be of interest.

Due to the need to travel to Jupiter distances from the earth the most dominant external feature of each spacecraft is the 1.65 metre dish antenna which is fed by a 20 watt X band transmitter to pass telemetry to the ground network. To ensure continuity of data when the spacecraft are not being tracked by the ground network each spacecraft has a data store incorporated. Power for the spacecraft is provided via radioisotope thermal generators (RTG) which are provided by NASA. In addition to the major targetting manoeuvre to ensure correct fly by of Jupiter (and therefore a correct heliocentric orbit), there is a need for almost daily attitude manoeuvres to keep the antenna pointing towards the earth, and both NASA and ESA have selected a hydrazine reaction control system to provide this.

A special feature of the NASA spacecraft is the despun platform which carries the coronagraph/X Ray XUV telescope. This three axis stabilised section will track the sun with an accuracy of 3 arc seconds. The rest of the NASA spacecraft and the whole ESA spacecraft will spin at approximately 5 rpm during the operational part of the mission. However, the spacecraft designs will have to cope with a 70 rpm spin during the IUS powered flight.
In order to give some feeling for the complexity and size of the two spacecraft, which each have main bodies about 8 feet by 5 feet, Fig. 4 shows an artist's impression of the ESA spacecraft, and Figs. 5 and 6 plan views of the platform layout.

Fig. 4 ESA Spacecraft Configuration



ESA-NASA COLLABORATION

It would be useless to pretend that there are no problems in designing, planning, building and testing two spacecraft as far apart as Los Angeles and West Germany. However, by careful planning and utilisation of goodwill, the task is not as difficult as it might seem.

Fig. 5 Lower Platform Layout

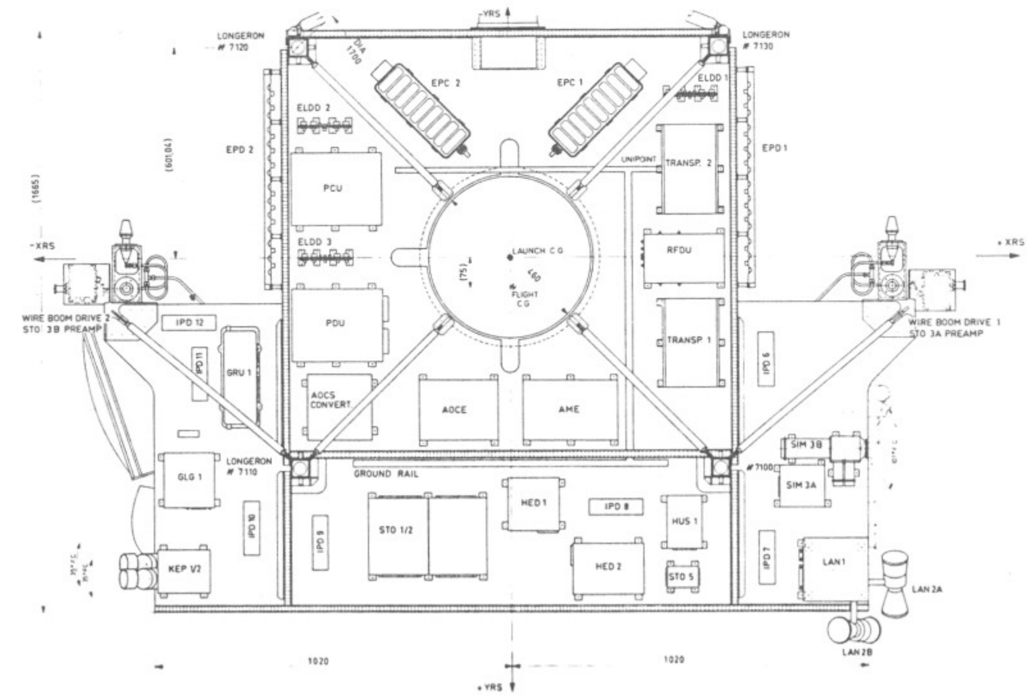
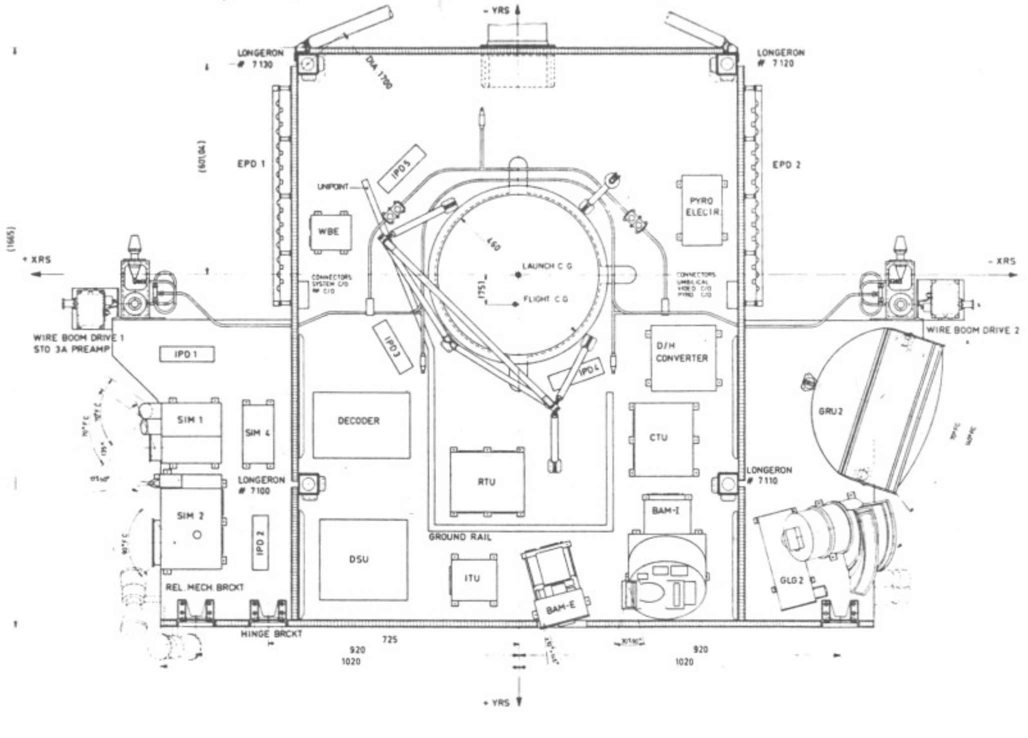


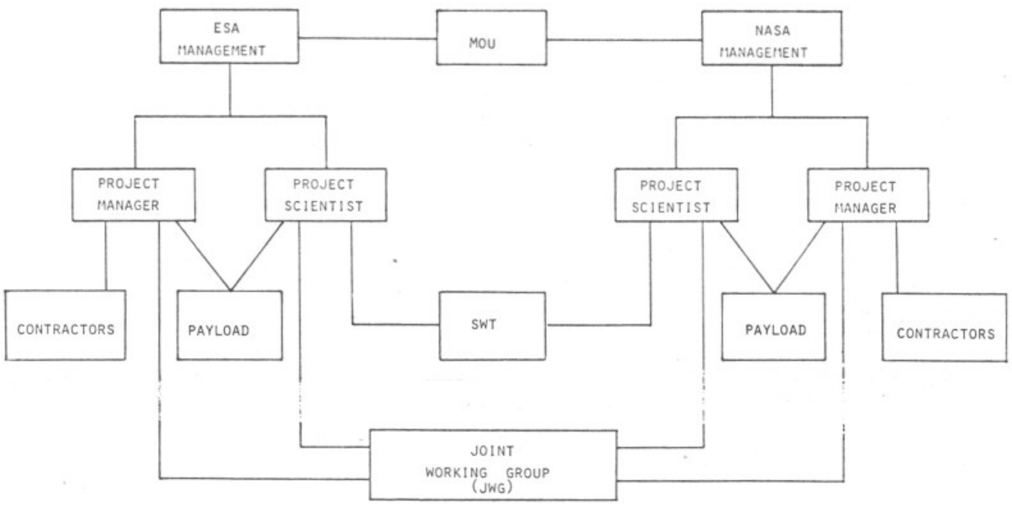
Fig. 6 Upper Platform Layout



The most important point to appreciate in the NASA-ESA relationship is that it is one of friendly collaboration between independent agencies. It is not a customer-contractor relationship nor is one Agency a sub-contractor to the other. In place, therefore, of a contract as the document governing the relationship, the Administrator of NASA and the Director-General of ESA signed on March 29th 1979 a Memorandum of Understanding (MOU) between the two Agencies. In this the responsibilities of each are identified in general terms, to be carried out on a best endeavour basis, and in accordance with the normal procedures employed in Europe and in the USA. By this means the greatest possible independence of action is maintained for each Agency.

The cooperative spirit envisaged in the MOU is continued at the next level down where the two Agency project managers and the two project scientists are formed into a Joint Working Group (JWG) which has control of the running of the joint project.
This meets about four times a year throughout the project life until launch. However, each Agency is completely responsible for his own spacecraft and contractors although some joint interface meetings at working level are held. Contact with the very large scientific community associated with ISPM is maintained via Science Working Team (SWT) which is co-chaired by the two Project Scientists and which meets twice a year at present. The SWT, of course, continues to exist after launch throughout the mission lifetime. The inter-relationship of the various bodies is shown in Fig. 7.

Fig. 7 ESA/NASA Working Relationships



Joint technical management methods are based very much on those used successfully by the International Sun-Earth Explorers (ISEE) collaborative project which was launched two years ago. Essentially they consist of reducing to an absolute minimum the number of interfaces, defining these accurately and early, before spacecraft design is too far advanced, and then sticking to them fairly rigorously. Obviously some give-and-take is necessary but it is amazing how many design engineers, faced with a rigid interface enforced by an equally rigid project manager, can find acceptable and economic solutions without infringing it.

Just as the interfaces are reduced to a minimum, so is the documentation which needs to be jointly signed off. It is extremely important, that only those elements which are necessarily part of the joint documentation are included to avoid annoying and sometimes costly delays whilst approval on both sides of the Atlantic is being obtained.

Also, since NASA and ESA documentation systems have little commonality, both sides have to be prepared to make concessions on the structure, content and sometimes even the existence of some mutual documents.

If the above sounds extremely cumbersome it is worth noting that in ISEE, after some early difficulties, we were able to complete the project with less than 6 slim mutual documents and to reduce the technical interface to a purely mechanical one. The only area where we ran into trouble was with the coupled structural analysis where the initial incompatibility of the mathematical models produced for the two spacecraft caused some problems and wasted time. For ISPM we have held early discussions on this subject prior to selecting contractors so that, hopefully, the problem will not recur. On the other hand, there is no doubt that our ISPM interfaces will be more complex, involving mechanical, electrical and radio-frequency, and that a good deal more mutually signed off documentation will be needed. Despite this, JPL and ESA intend to adhere to the philosophy used on ISEE whereby the two spacecraft, the two RTG and the launcher come together for the first time at ETR at the start of the launch campaign.

ISPM AND THE SPACE TRANSPORTATION SYSTEM

It is very important to appreciate that without the STS it is doubtful whether any meaningful ex-ecliptic exploratory mission could be achieved, and certainly not the ambitious two-spacecraft solar polar mission described above.

On the other hand, compared to expendable launch vehicles, its utilisation introduces complications, some of them costly, which need to be taken account of in budgeting and scheduling. These may be loosely grouped under the headings of management, technical/environmental and safety.

For ISEE, which was launched on a Thor-Delta 2914 the ESA interface was almost entirely with Goddard Space Flight Center, who were responsible for the NASA spacecraft with only one meeting with the NASA Thor-Delta personnel and two visits, each of about three or four people to Kennedy Space Center to set up the launch campaign. There was a minimum of paperwork and the whole organisation was well established and functioning smoothly. No such simplified structure yet exists for the STS, although the SPIDO team in Johnson Space Center are making substantial progress and consequently there is a need for many meetings, not only at JPL for spacecraft matters, but also at JSC for STS, GSFC for TDRSS and at KSC for launch matters. For instance, it has been necessary to set up six STS interface working groups at JSC plus a ground operations group at KSC, each of which will have to meet on several occasions before launch. Although thanks to excellent cooperation from JSC and JPL, ESA do not attend all meetings, the ESTEC project team has already, three years before launch, made more man-visits to the USA on these problems than we did in the whole of the ISEE project. So far, we have succeeded in reaching agreement and signing of the master Payload Integration Plan, but discussion on its many annexes and appendices has not yet started.

The technical interface with the Thor-Delta launcher was simple and well-known. As a result it was possible to design the spacecraft from the start of the project against a fixed environment, and a minimal number of analyses were needed to confirm the mutual compatibility. The STS, on the other hand, has much more complex interfaces and, since neither the Shuttle nor the IUS have yet flown, they are in process of evolution and therefore liable to change. In the absence of hard facts, considerable numbers of relatively complex analyses need to be performed to ensure that the resultant combination will be acceptable and workable.
In the case of ISPM, whose two RTG's (one on each spacecraft), dissipate approximately 9000 watts of heat, considerable additional problems exist, particularly to ensure that no damage can ensue if it is necessary to abort the mission after the cooling water pipes have been disconnected. The necessitiy for much of this additional effort is clear, but some analyses might be considerably cheapened if common sense was sometimes accepted as an alternative to rigorous mathematical proof.

The third high cost difference between STS and expendable vehicles lies in the area of safety. For ISEE essentially our only safety concern as a spacecraft was to ensure that we could not produce conditions on the launch pad and during early flight which could endanger the launch vehicle or ETR. Our safety obligations for ISPM last throughout the launch and attached in-orbit phase until deployment from the Shuttle and, even more importantly, are man-rated.

Moreover, new cases are still being formulated. A recent, and still unresolved problem, can be used to illustrate this point. Our spacecraft, like the NASA spacecraft, has a hydrazine gas propulsion system on board. We had been led to believe that, provided a triple interlock was used to protect against accidental discharge of the hydrazine into the cargo bay, no caution and warning system was necessary. Very recently the overall Shuttle Safety Requirements Document was issued which stipulates that any hydrazine system capable of discharging via the thrusters in the cargo bay is a catastrophic hazard for which triple electrical and triple mechanical interlocking is required, with the electrical interlocks monitored on the crew deck and with the possibility of crew intervention. The actual interlocking requirement gives us no major problem, but the need for monitoring is very severe since we planned to launch with an essentially dead spacecraft and, at the present time, we have absolutely no knowledge of how to introduce crew intervention in a meaningful way. We are of course in discussion with JSC on this point but, if we were forced to meet these changed requirements they would represent a huge cost, not only in the spacecraft design but also by introducing us to completely new interfaces, such as flight deck displays, crew training and additional shuttle connections. All of these were unforeseen and therefore, of course, unbudgeted.

Another example of the impact of the very essential emphasis on safety is the number of safety reviews deemed necessary.

For ISEE our safety submission was a single documentation dump whereas, for ISPM, a total of four (including level 0) operational safety and three ground safety reviews are proposed. Assuming an attendance of three ESA personnel at each, this represents a cost in excess of 30,000 dollars for travel and subsistence alone.

The preceeding paragraphs should not be interpreted as meaning that the ESA ISPM team is somewhat opposed to the STS and critical of the management methods and individuals encountered. This is very far from the truth. We are full of admiration for the magnitutde of the task being undertaken and for the skill and helpfulness of our friends in JPL, JSC and KSC who have shown themselves very ready to adapt themselves and their methods to meet the wishes of "those crazy Europeans", as one JSC engineer called us. We are at the beginning of a new era, the management techniques as much as the Shuttle itself are in development and it is certain that in a relatively short time most of the problems quoted above will be resolved. In the meantime, however, it is essential that we international payload managers realise that transitional problems do exist and that we make due allowance for it in our planning, our manpower and, above all, in our budgets.

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