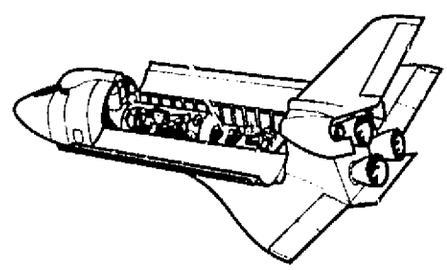
NASA TM X-62,457

ESA-SL-75-1

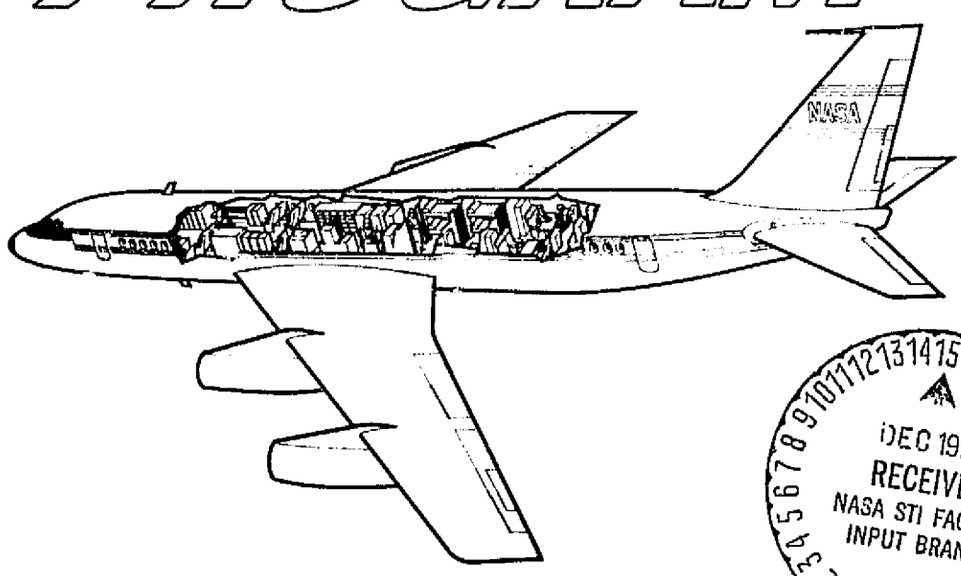
EXECUTIVE SUMMARY

NASA/ESA CV-990 SPACELAB SIMULATION

A JOINT ENDEAVOUR BY
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
AND EUROPEAN SPACE AGENCY



ASSESS PROGRAM



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16. Abstract

As a result of interest in the application of simplified techniques used to conduct airborne science missions at NASA's Ames Research Center, a joint NASA/ESA endeavor was established to conduct an extensive Spacelab simulation using the NASA CV-990 airborne laboratory. The scientific payload was selected to perform studies in upper atmospheric phy[illegible] and infrared astronomy with principal investigators from France, [illegible] Netherlands, England, and several groups from the United States. Two experiment operators from Europe and two from the U.S. were selected to live aboard the aircraft along with a mission manager for a six-day period and operate the experiments in behalf of the principal scientists. Communication links between the "Spacelab" and a ground-based mission operations center were limited consistent with Spacelab plans. The mission was successful and provided extensive data relevant to Spacelab objectives on overall management of a complex international payload; experiment preparation, testing, and integration; training for proxy operation in space; data handling; multiexperimenter use of common experimenter facilities (telescopes); multiexperiment operation by experiment operators; selection criteria for Spacelab experiment operators; and schedule requirements to prepare for such a Spacelab mission.

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NASA/ESA CV-990

SPACELAB SIMULATION

A Joint Endeavour by
National Aeronautics and Space Administration
and European Space Agency

Executive Summary

APPROVED: D. Lord, NASA

APPROVED: B. DeMoffre, ESA

July 1975

Although this simulation was jointly funded by NASA and ESA, the results obtained do not necessarily reflect the current policy of either agency with respect to Spacelab utilisation.

FOREWORD

This Executive Summary presents the principal highlights of, and the major lessons learned from, a joint NASA/ESA simulation of Spacelab operation using a CV-990 aircraft. The simulation is aptly referred to as the Joint ASSESS Mission, ASSESS standing for Airborne Science/Spacelab Experiments System Simulation. The ASSESS flights were carried out during the month of June 1975 from NASA's Ames Research Center under the auspices of the Airborne Science Office.

Further details of the mission may be obtained from the final report, which will be supplemented by a series of appendixes on selected facets of the mission. These appendixes will be issued over the next few months.

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NASA/ESA CV-990 SPACELAB SIMULATION
EXECUTIVE SUMMARY

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National Aeronautics and Space Administration
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INTRODUCTION

Beginning in the 1980 time period, the advanced space transportation system will be used to conduct experiments in the space environment using a laboratory (Spacelab) carried into orbit by the reusable Space Shuttle. Spacelab is being developed and constructed in Europe under the direction of the European Space Agency (ESA). The Space Shuttle Orbiter is being built by the United States under the management of the National Aeronautics and Space Administration (NASA).

Spacelab is being designed to be a versatile laboratory capable of accommodating a variety of experiments. The pressurised Spacelab module provides a shirt-sleeve environment in which up to four payload specialists can operate experiments using the basic resources provided by the laboratory. Similarities between the method of experiment accommodation and operations planned for Spacelab and the methods used in conducting experimentation aboard aircraft by the Ames Airborne Science Office (ASO) led to the jointly planned ASSESS Mission using a CV-990 flying laboratory (Fig. 1). The mission was planned and carried out as an integral part of NASA's ongoing ASSESS Programme and included one week of simulated Spacelab operation.

Data for this summary were obtained from three main sources: the records of a team of observers, a general debriefing following the simulation period, and individual interviews with mission participants. The report was prepared jointly by NASA and ESA personnel associated with the mission.

MISSION OBJECTIVES

The overall objective of the Joint ASSESS Mission was to evaluate a simplified management and implementation concept for conducting Spacelab-like experiment operations. The following contributory objectives were addressed in conducting the mission:

- Experience involvement in international cooperative payload activities
- Evaluate experiment design approaches for Spacelab experiments
- Determine impact of operational requirements and procedures on Spacelab design
- Evaluate payload operations and ground integration of experiments

- Assess techniques for smooth integration of experiments and equipment
- Analyse factors affecting selection and training of payload specialists, particularly in proxy experiment operation

The Joint ASSESS Mission also served to encourage the development of a cadre of potential Spacelab experimenters. The mission did not address physiological or psychological factors.

MISSION GUIDELINES

The following Spacelab-compatible mission guidelines were established:

- Authentic science to be performed
- Six basic experiments to be operated (three European, three U.S.)
- Ames ASO practices to be used as starting point for mission planning and execution
- Participation of principal investigators (PIs) in overall mission to be maximised
- Four experiment operators (EOs, two European, two U.S.) to operate experiments in proxy role (i.e., on behalf of the PIs)
- Simulation period to cover 5 days with a data flight each 24-hr period (experiments operated by EOs), with EOs and a Mission Manager confined to vehicle and living quarters
- Unconstrained flights to be conducted for 2 weeks following the simulation period (experiments operated by PIs)
- All supporting equipment, tools, and spare parts to be carried on board
- Spacelab subsystems to be simulated where possible
- Use of experiment support equipment to be shared
- Communication to be limited to one video downlink, two 2-way voice links

MANAGEMENT

Policy Management

The mission was officially planned and guided by a Mission Planning Group (MPG) consisting of representatives from NASA and ESA Headquarters, Marshall Space Flight Center, Johnson Space Center, and Ames Research Center.

Implementation Management

Implementation of the mission was carried out by the organisation shown in Figure 2. The NASA/ESA panel consisted of one representative from each agency, who was available to make top-level policy decisions involving agency interests. The Mission Manager, provided by Ames, was the single point of contact for all negotiations, decisions, and assistance in carrying out the mission from inception to completion. He ensured that all ASSESS activities were carried out in accord with the policies established by the MPG.

A Mission Scientist was selected from the ASO to work with the PIs during the simulation period to help coordinate their overall requirements and reduce the number of interfaces with the Mission Manager.

The PIs were fully responsible for their own experiments throughout the mission, including design, testing, integration, and data taking. The EOs served as the PIs' representatives in operating the equipment to obtain meaningful data during the simulation period.

A ground-based Mission Operations Center, set up for the simulation period, housed the Mission Operations Manager, the PIs, the Mission Scientist, and the NASA/ESA panel. The center was directed by the Mission Operations Manager.

DOCUMENTATION

Documentation used for the Joint ASSESS Mission was held to a minimum and consisted of:

1. Control documents
   - CV-990 Experimenters' Handbook
   - Mission Operating Plan

2. Implementation documents
   - Two Experimenters' Bulletins
   - Experiment procedures and checklists
   - Approvals by Airworthiness and Flight Safety Review Board
   - Flight plans
   - Various Ames internal documents, such as shop orders, safety inspection records, and installation drawings

EXPERIMENT SELECTION AND DEVELOPMENT

A nucleus of three European experiments was chosen on the grounds of scientific desirability and Spacelab compatibility. This payload nucleus was complemented by the choice of three compatible U.S. experiments. Overall experimental objectives required that data flights be made at night. The experiments and their sources are summarised in Figure 3. The sharing of basic experiment hardware created complex requirements for programmed interchange of sensors on a priority basis by the EOs during the flight period, just as may be expected on Spacelab.

The PIs developed their experiments at their home bases using the standard racks provided by the ASO and in accordance with guidelines furnished in the ASO CV-990 Experimenters' Handbook. A readiness review was held at each experimenter location approximately 2 months before the flight phase of the mission.

EXPERIMENT OPERATOR SELECTION AND TRAINING

The EOs, two Europeans and two Americans, were selected for their appropriate scientific backgrounds in astronomy and atmospheric physics, and represented a wide range of experience – from graduate science student to scientist/astronaut. Each PI worked directly with the EOs to familiarise them with the equipment and operation of his experiment. For each experiment, one EO was assigned primary responsibility, and one or more EOs were assigned secondary responsibility. Primary responsibility included both proficient experiment operation under nominal conditions, and ability to perform significant trouble shooting and repair. Secondary responsibility was limited to proficient operation under nominal conditions. Final training of the EOs at payload level took place during the experiment integration phase at Ames and involved ground activities and one aircraft flight. Total training time for the individual EOs varied from 21 to 67 days.

GROUND AND FLIGHT OPERATIONS

Integration of each experiment in itself was accomplished at the experimenters' home bases. Upon arrival at Ames, each experiment was subjected to incoming inspection for safety and airworthiness, after which it was integrated into the aircraft as a part of the total payload (Fig. 4). Several times during the mission (except during the simulation period), special electromagnetic interference (EMI) tests and measurements were made to help in developing a shielding, isolation, and grounding philosophy for Spacelab equipment. Three presimulation mission flights were conducted for equipment checkout, since no ground support equipment (GSE) was provided for this purpose.

The constrained period simulating Spacelab flight began on Monday, June 2nd, at 13.00 hours and ended Saturday, June 7th, at 23.30 hours. During this period, the Mission Manager and EOs flew each flight and remained confined to the aircraft and living quarters. The Wednesday flight was cancelled due to aircraft problems, and it was decided to extend the simulation period by one additional day to achieve the fifth planned flight. Following the constrained period, two additional weeks were devoted to unconstrained flights with experiment operation by the PIs themselves to complement the data obtained by the EOs and to permit comparison of EO and PI performance.

During the simulation period, ground and flight operations were coordinated from the Mission Operations Center. One formal briefing and one formal debriefing were held daily via the audio and video links. These briefings were supplemented by informal PI/EO discussions using the same links.

ASSESS-SPACELAB SIMILARITIES

Installation and operation of a complex set of experiments aboard an aircraft cannot totally simulate such a payload aboard Spacelab. However, there are many similarities that permit many lessons to be learned relevant to Spacelab experiment planning and operation. These are summarised below:

Spacelab Mission	ASSESS Mission
Significant experiments to be conducted from Spacelab	Authentic science conducted from aircraft
Fixed countdown to liftoff	Rigid schedule to takeoff
Orbiter and Spacelab operations to be separated	Aircraft and experiment operations separated
Essential services (power, environment, etc.) and standard equipment fittings (racks, windows) to be provided	Power and shirt-sleeve atmosphere provided; standard racks and modified windows available
Control and data management system (CDMS) to be provided	Airborne digital data acquisition system (ADDAS) provided
Large weight and volume capability to be provided	Ample weight and volume provided for Spacelab simulation
Payload specialists to perform experiments; mission specialist to control resources	Experiment operators performed experiments; Mission Manager controlled resources
Relatively benign environment to permit use of laboratory-type equipment	Only slightly modified laboratory equipment used

Spacelab Mission (cont.)	ASSESS Mission (cont.)
Short development times planned for Spacelab	Less than 1 year scheduled for ASSESS experiment development and flight
Payload specialists and mission specialist to be confined to Orbiter/Spacelab for 7 days	Experiment operators and Mission Manager confined for 5 days
Simplified ground operations planned	Very simple acceptance and experiment integration procedures used
Common test equipment and tools to be available	Common test equipment and tools used
Communication to be provided between payload specialist and PIs on the ground through TV downlink and bidirectional voice link	TV downlink and bidirectional voice link operational during the periods the aircraft was on ground
Experiment facilities to be used by more than one group of investigators	Detectors changed at focal plane of common telescopes

MISSION RESULTS

The Joint ASSESS Mission provided valuable scientific and engineering data that will not only enhance scientific knowledge but will also provide sound guidelines for the design and operation of future Spacelab experiments. The mission also provided an opportunity for participants to experience an environment similar to that which will exist prior to and during an actual Spacelab flight.

PIs and EOs alike voiced strong satisfaction with their mission experience and education. Their comments are reflected in the following evaluation of the mission.

Scientific Data

Scientific results of the mission will be reported by the PIs in the relevant scientific literature. All PIs reported obtaining good data, particularly on the following topics:

- the IR source around the star ρ Ophiuchi
- the IR and the near-UV spectra of Venus
- the near-UV spectra of blue-type stars in Scorpius
- the near-UV and IR spectra of the earth's upper atmosphere
  - both twilight and nighttime airglow

-selected features of atmospheric constituents
  ozone absorptions
  Herzberg bands of O_2
  NO concentration
  OH cloud structure
-both broad survey spectra and high-resolution scans in limited regions

The sun, the moon, and the diffuse nebula M-17 were used as calibration objects.

Management

As in previous missions conducted by the ASO, this mission was directed successfully by the Mission Manager acting as the single point of contact for the activities of the PIs and EOs throughout the entire period from experiment preparation through science flights. Although the workload created by the unusual aspects of the simulation mission at times was taxing, the Mission Manager and his assistant nevertheless effectively provided the direct communications necessary for a streamlined operation so that only minimum documentation was required.

Experiment and Related Equipment Performance

Some initial problems were encountered, but in all cases good experiment performance was achieved before the end of the mission. Some of these problems were related to the aircraft (e.g., aerodynamic buffeting of open-port telescope) and would not occur in Spacelab. Spacelab-related problems were typically:

- Electromagnetic interference (EMI) affected the performance of some experiments; however, problems of this kind gradually were solved during the mission.

- Hand guidance of a 20-cm telescope proved not feasible; the problem was solved after the simulation period through utilisation of a gyrostabilised mirror system.

- Internal misalignment of optics was observed on one of the experiments; a time-consuming realignment was required.

- The centralised data management system interface posed some problems initially because debugging of the total system could not start until the full payload had been integrated (no data system simulator was available).

- Some experiment mounts were disqualified by the ASO airworthiness personnel, and had to be re-engineered and rebuilt at Ames. The problem resulted partly from incomplete information in the CV-990 Handbook and partly from the fact that on-site safety reviews could not be held earlier in the programme due to budget constraints.

Experiment design and arrangement within the aircraft did not permit optimum simultaneous operation.

Experiment Operator Performance

In principle, the concept of proxy experiment operation was successful. However, it was noticed that the time required to adapt to the aircraft environment (noise, lighting, habitability) was directly related to the experience of the EOs. Shortcomings in the training programme were recognised by most of the EOs and the PIs. These shortcomings did curtail EO efficiency, particularly during the early part of the mission, and a distinct learning curve was noted.

The onboard activities were, in fact, quite complex and demanding, and resulted in a very high workload for the operators. For this reason, the PIs significantly reduced the number of experimental parameters in some cases to allow the EOs to accomplish a reasonable degree of success. During the unconstrained period, the PIs, with their instrument familiarity and greater manpower support, were able to accomplish the full scientific objectives.

A striking aspect of the mission was that EOs were able to successfully perform maintenance and repair tasks and contributed significantly to the good working order of the equipment. Guidance from the PIs, during the conference periods, was particularly helpful in this respect.

The EOs agreed that, in flight, the Mission Manager provided a valuable link with the aircraft subsystem support, and it was apparent that he played an important resource management role in addition to his other tasks.

LESSONS LEARNED FOR SPACELAB

The Joint ASSESS Mission illustrated that a low-cost programme with a low level of preparatory requirements, testing, and documentation can operate successfully under the proper management approach. Appropriate and timely information on constraints and capabilities, as well as guidelines for hardware development, do enhance the chances for success. It can be concluded that low-cost programmes such as those envisaged for Spacelab can be successfully implemented, under the right conditions.

It was evident from the ASSESS mission that an aircraft can serve as an excellent platform for optimising the methodology, design, and operations aspects of experiments conceived for Spacelab. This observation is particularly relevant when these experiments are still in an embryonic stage and before large amounts of development time and money have been expended.

Lessons learned for Spacelab in specific areas are outlined below. Some underline experience that is familiar to participants from the NASA manned space programme but may be new to the Europeans.

Management

Simplified management techniques can be effectively applied to experiment development, integration, and operations with a low level of imposed specifications and testing, resulting in relatively low cost, if the participants are competent and are strongly motivated.

A small planning group with representation from each appropriate participating organisation is effective in establishing policy and guidelines for mission implementation.

A Mission Manager with adequate authority can effectively execute the policies of the planning group and act as the single point of contact for the management of all mission integration activities. Such a manager must have the appropriate background to understand experiment objectives and instrumentation, and interexperiment and carrier interfaces. He should have a small but competent staff to which he can delegate responsibility for details. To ensure effective coordination through all phases of the mission, the Mission Manager should not normally fly on Spacelab.

The application of ASO practices to the Joint ASSESS Mission was generally successful, and these techniques should form a basis for the planning of Spacelab payloads and operations. As expected, however, the added complexity of Spacelab-type operations does call for somewhat more rigid and formal arrangements than those normally associated with airborne payloads. In particular, a comprehensive implementation plan that details day-to-day activities is essential.

Reliance on the PI for the development of his own experiment provides a high degree of motivation to ensure successful delivery and operation of the hardware. Free contact between the PI and other mission participants (via the Mission Manager) encourages the successful conclusion of these activities. Some limited formal review of experiment progress is needed, however.

Relatively small amounts of control and interface documents and procedures suffice to ensure a successful low-cost mission, as long as the requirements are clearly specified. To be effective, this simplified documentation approach requires clear delegation of responsibilities to participants and quick and efficient communication among team members.

Experiment Equipment

Early in the development of experiment equipment, the design of individual components must be guided by the fact that each experiment will be operated as an integral part of the total payload.

Payload specialists can make significant contributions to experiment design, particularly in the area of equipment operation, if they become involved sufficiently early in the design process.

Electromagnetic compatibility (EMC) engineering should be considered as a basic requirement throughout the Spacelab payload design process.

Although the use of off-the-shelf equipment is encouraged, some minimal standard of performance should be established to avoid the low reliability that was noticed in some minor items, such as strip chart recorders.

With no limitations imposed on power, volume, and weight, the demands of available equipment can be quite high. For example, on the ASSESS flights the values of these quantities were as follows:

Volume: 10 m^3

Weight: 1700 kg

Power: 3 watts/kg

Although these values could be reduced by state-of-the-art advances, off-the-shelf equipment used on Spacelab may still require modification to satisfy payload constraints.

Minor (but time-consuming) activities, such as switching, should be automated to permit full concentration on the real experiment operation.

All experiments should include displays that indicate proper operation.

Cryogenic support for experiments should be included in any general provisioning support system developed for Spacelab. On ASSESS, significant problems were encountered with experimenter-provided cryogenic equipment.

Subsystems

Four minicomputers were provided as part of the experiment equipment, despite the availability of the ADDAS on the CV-990. This suggests that the Spacelab CDMS capabilities for interfacing with minicomputers have to be investigated further. The tendency of experimenters to provide their own minicomputers suggests that the need for CDMS for basic recording and computation may not be as great as originally anticipated. At the same time, ASSESS emphasised the very real need for centralised handling of houskeeping data.

Integration of experiments with the CV-990 data management system and its associated software presented problems on ASSESS. This area can be expected to be problematic with Spacelab as well, and will require special and timely attention.

Ground-based processing of scientific data contributes significantly to successful proxy operation of experiments when large amounts of data have to be evaluated.

During tracking and pointing operations, a dedicated keyboard and display is required. It is questionable whether time sharing of a single keyboard and display by several users can provide satisfactory results.

Suppression of Spacelab-generated EMI is an important design consideration. In this context, the CDMS is a major potential contributor because of its intimate interfaces with experiments. The single-point grounding philosophy represents a good approach for Spacelab (and experiment) design.

Payload Planning, Integration, and Operations

Time line compatibility and observation compatibility for experiment operation are important factors in the choice of Spacelab payloads.

Common usage of equipment calls for careful planning, including the provision of backup items in the event of malfunctions.

Involvement of the experimenter in the integration procedure contributes to the efficiency of the process.

Firm management of equipment/stowage is necessary to ensure that all essential items are brought on board, non-essential items are excluded, and stowage is arranged to facilitate equipment usage in flight.

Good metal workshop and electronic laboratory facilities should be provided for support of level II and level III integration.

Pre-integration of experiments (level IV and some level III) in Europe is technically feasible.

Proxy operation of experiments is a workable concept, providing that the appropriate operators are chosen and adequate training is provided.

A downlink TV capability will be important for occasional repair tasks, but probably will not be required frequently for normal Spacelab experiment operation.

Experiment setup times and procedures can represent a major part of experiment operation and must be considered in developing the mission time lines.

Nominal experiment operations should not require real-time communications with ground-based PIs. However, PI/payload specialist conferences should be scheduled on a regular basis, and planning should be sufficiently flexible to allow for additional conferences to cover any unforeseen problems that may arise.

Payload specialists should not be normally responsible for subsystem operation and maintenance, but should concentrate fully on payload operation.

EO Selection and Training

Selection and training of payload specialists for Spacelab missions will be critical elements in the overall success of the mission. From the unique

EO/PI relationship evaluated during the joint ASSESS mission, it is apparent that:

- The Spacelab payload crew should be specialists who can interpret the data and can develop an intuitive feeling for the measurements. They should understand the experiment and its objectives and should have sufficiently detailed knowledge of electro-mechanical aspects of experiment hardware to permit trouble shooting and correction as warranted.

- Some payload specialist participation in experiment development, integration, and payload checkout phases of his primary experiment(s) is required. Therefore, payload specialists should be selected at the appropriate time to enable them to participate during these phases with their primary experiments.

- Payload specialist training should be well planned and organised as an integral part of the total mission, and should include substantial training at payload level for which adequate equipment is required to fully exercise the man-machine interface.

- Limited pre-mission flights of the ASSESS EOs and payload was an important factor in their training, adjustment to environment, and overcoming latent snags. This experience suggests that Spacelab payload specialists will benefit from aircraft flights with their equipment or some equivalent form of integrated mission simulation.

- The development of a payload specialist/PI team relationship is essential to successful proxy experiment operation.

- Mission simulations should include practice in payload specialist/PI communication under realistic conditions.

- A marked improvement in EO performance was noted as the simulation period advanced, implying that both training (learning and practice) and extended flight duration are important aspects of Spacelab operation. In addition, at least one payload crewman should be well trained in maintaining facility equipment.

FINAL REMARKS

The objectives of the Joint ASSESS Mission were purposely limited to obtain the most meaningful results. It should be noted that guidelines for this mission were selected before the capabilities of Spacelab and its resources were finalised. In addition, the mission was designed for compatibility with the limiting conditions provided by the CV-990 aircraft and its support equipment. Consequently, in planning any future Spacelab simulation mission, modification of the mission objectives and guidelines will have to be considered to meet new conditions.

Figure 1.- CV-990 flying laboratory.

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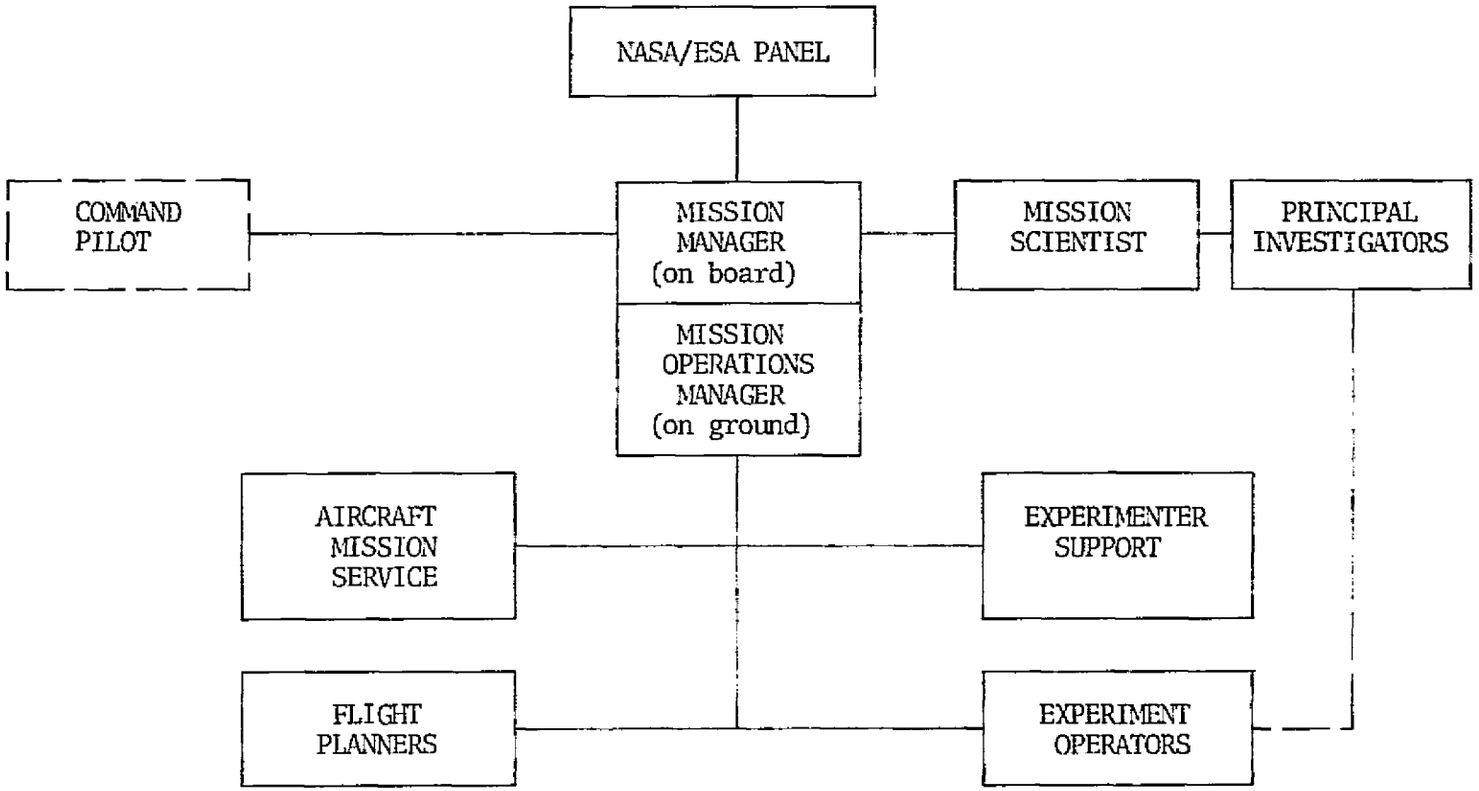

Figure 2.- Joint ASSESS mission implementation organisation.

ORGANISATION	INSTRUMENTATION	MEASUREMENT
Observatoire de Meudon CNRS-Verrières University of Groningen	30-cm Cassegrain telescope with filter wheel IR photometer Cooled Ge bolometer	High-resolution mapping of dark clouds and HII regions
Queen Mary College	Polarising interferometer Cooled Ge bolometer	IR emission spectrum of upper atmosphere
University of Southampton	Imaging Isocon TV camera IR photometer All-sky camera	Observation of OH airglow clouds
NASA/AMES Research Center	30-cm Cassegrain telescope (Meudon) with variable filter-wedge spectrometer Cooled In Sb detector	Near IR spectra of Venus and Late type stars
NASA/Jet Propulsion Laboratory	Tunable acousto-optical filter spectrometers (2) with telescopes	UV and visible measurements of atmospheric transparency, solar flux, planetary atmospheres, and interstellar molecules
University of Alaska	1-m Ebert-Fastie spectrometer-telescope and stabilised mirror	
University of Colorado	12.5-cm Ebert-Fastie UV spectrometer	
University of New Mexico	35-mm camera with IR image intensifier 16-mm camera with image intensifier for time-lapse photography IR photometer	IR photography of OH airglow clouds

Figure 3.- Experiments for CV-990 NASA/ESA ASSESS mission.

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Figure 4. Integrated experiment payload in CV-990 aircraft.