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STUDY OF AIRBORNE SCIENCE EXPERIMENT MANAGEMENT CONCEPTS FOR APPLICATION TO SPACE SHUTTLE

VOLUME II

Donald R. Mulholland, John O. Reller, Jr., Carr B. Neel, and Louis C. Haughney

Ames Research Center
Moffett Field, Calif. 94035

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PREFACE

The Airborne Science/Shuttle Experiments System Simulation (ASSESS) program was started in response to strong interest in the management of airborne research by the Airborne Science Office (ASO) at Ames Research Center, and in the similarities between the Airborne Science operation and that planned for carrying experimenters aloft on a regular schedule to conduct space research in the Shuttle Sortie Lab. The ASSESS program was instituted with the objective of conducting exhaustive studies of the established airborne science concept as it may apply to Shuttle planning. The program is in two phases: Phase A involves detailed observations and study of on-going missions managed by the Airborne Science Office, with the objective of translating this experience into the Sortie Lab program; and Phase B involves studies of airborne missions constrained to represent Sortie-mode missions with the purpose of providing additional information for Shuttle planning.

The tragic end to the many productive years of the CV-990 airplane, the "Galileo," in a midair crash on April 12, 1973, has caused an interruption in some of the studies of the ASSESS program. The program, nevertheless, is continuing with observations of on-going activities with the ASO Lear Jet and C-141 aircraft. When a replacement aircraft for the CV-990 is put into operation, observations of normal scientific missions will resume and the plans for Shuttle-simulation missions which were developed for the CV-990 will be implemented with the new aircraft.

This is the first in a series of reports covering the Phase A observations. It encompasses observations for the period April to November 1972 for the Lear Jet and CV-990 aircraft. The report has been written in three separate volumes. The first is an executive summary which provides a quick overview of the findings of the study. The main body of information is in this second volume. The third volume is a set of appendixes which give detailed information on the various missions studied.

A large amount of observational data has been obtained for this report; however, the activities and categories explored are so many and varied that in a number of cases the sample sizes are too small to determine more than a very tentative trend. As the ASSESS program continues, the enlarged fund of data will permit development of more representative trends to aid Shuttle planning.

Results from the ASSESS program are the product of the combined efforts of all who manage, support, and participate in the Airborne Science operation. Most of the data for this report were gathered under contract by a team of observers from Northrop Services Inc. The team included Bernard Shyffer, John F. Reeves, Gaylord M. Androes, and Norman J. Donnelly. The diligent efforts of these men are gratefully acknowledged.

This report is dedicated to the eleven men who were with the Galileo on her last flight. Their acceptance of the daily risks associated with scientific research was evidence of a quiet, steady courage that has characterized the pioneers in every human endeavor. Those we knew best by daily association were an unfailing source of energy and enthusiasm that imparted a spirit of adventure to CV-990 missions. Their contribution to the enlargement of man's knowledge is a living memorial to which we add a small part as we continue the work in which they were engaged.

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Section 1

AIRBORNE RESEARCH AND SHUTTLE SORTIE PLANNING

Airborne Research at Ames Research Center

A comprehensive program of airborne research has been operating at NASA's Ames Research Center for nearly ten years. Until April 1973, the primary aircraft was a CV-990; some five years ago a Lear Jet was added, and more recently a C-141 aircraft. Under the direction of the Airborne Science Office (ASO) at Ames, the CV-990 has flown a wide variety of scientific missions; the Lear Jet and the C-141, used primarily for research in infrared astronomy, are equipped with 30-cm and 91-cm IR telescopes, respectively.

The substantial experience in airborne research management gained in the Ames program is a reservoir of practical knowledge available to the planners of research operations for the Shuttle Sortie program as they formulate the experiments-management procedures and design the accommodations for the orbital research laboratory. The potential reductions in cost and time that might result for Shuttle from such a transfer of knowledge were first recognized and documented by Bader and Farlow in 1971 (ref. 1). A unique feature of the ASO operation is the active participation of experimenters in all aspects of the research program. The scientists not only have the responsibility to construct and test their equipment, but they also install it in the aircraft and participate in flights to obtain the scientific data. This one practice, more than any other, underlies the success of the Airborne Science approach. It has been enthusiastically accepted by the scientific community as productive of research results with a minimum of preparation time, with little formal documentation, and at a relatively low cost.

The ASSESS Program

In response to the interest of Shuttle Sortie planners in ASO management practices, a two-phase program (ASSESS) of study (Phase A) and simulation (Phase B) was undertaken to document the form and effectiveness of the Ames program in airborne sciences. The simulation phase of this evaluation includes several airborne missions constrained to simulate Shuttle Sortie scientific missions. The first of these missions is described in references 2 and 3.

Study Phase Airborne Missions

The initial study phase of the ASSESS program covered the eight-month period from April to November 1972, during which the flight activities of the Airborne Science Office were observed and documented to provide information on the management practices, the operating procedures, and the experiment performance for 17 Lear Jet and five CV-990 missions. The results of this initial study are summarized briefly in reference 4.

In relation to Shuttle-payload classifications, the Lear Jet is essentially a dedicated aircraft in the science of astronomy, while the CV-990 is more a multipurpose vehicle, which flies both dedicated and agglomerate types of missions. Figure 1-A illustrates typical mission timelines for the two aircraft. This figure indicates the relatively short period required in the Airborne Science program to achieve scientific data, from the proposal stage to the end of the flight mission. Only about nine months are required for a complete NASA-sponsored mission; one or two additional months might be needed for a mission sponsored outside NASA. Completion of a mission on the Lear Jet starting from the proposal submission takes somewhat less than a year for a new experiment. For a repeat experiment, this time is shortened to only two to four months. Lear and CV-990 mission activities are described in greater detail in the appendixes to this report, reference 5.

Lear Jet Missions

Table 1-A summarizes the 17 Lear Jet missions during the study period; a brief description of the experiments involved is given in table 1-B. Except for group 2 experiments, which measured concentrations of meteoric dust, the common objective was astronomical observations. Thus, 58 out of the 76 data flights were at night, with measurements in the visible to far infrared wavelength region, and used a variety of radiometers, spectrometers, and interferometers. Favorite sources were the galactic center, and various nebulae and planets. The ASSESS observations covered 17 experiments and 50 experimenters.

Certain physical arrangements were common to most of the Lear Jet missions. Experiment installation and checkout were usually one or two days; for new research teams, this was preceded by a laboratory setup time of about four calendar days. An average of five 2- to 3-hour flights was made during a mission, most often at the rate of one per night. In each case, there was only one experiment, although on many flights more than one astronomical source was observed. With two exceptions, there were always two experimenters on board the aircraft. The overall level of accomplishment was slightly better than one flight every two calendar days of residence.

CV-990 Missions

The CV-990 flight program during the observation period consisted of two Ames-based missions and three based at remote sites (expeditions); missions covered one to two months and involved an average of 15 experimenters (tables 1-C and 1-D). A total of 76 experimenters conducted 62 experiments in scientific disciplines as varied as oceanography, astronomy, and meteorology, using a wide variety of radiometric and photographic systems for remote sensing of earth surface and atmospheric phenomena, as well as sample-collecting devices for inflight or

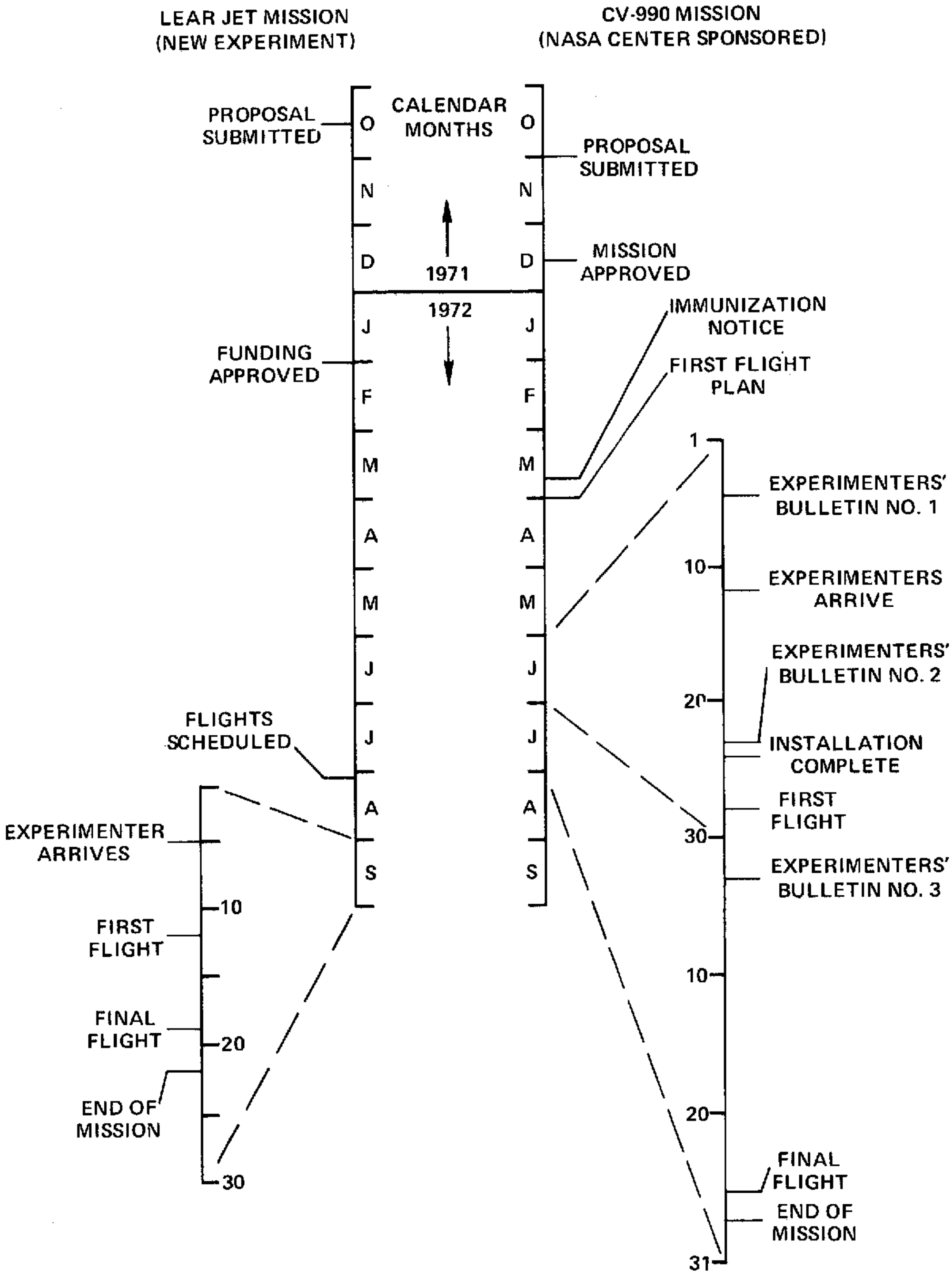

FIGURE 1-A. TYPICAL MISSION TIMELINES

TABLE 1-A. AIRBORNE MISSIONS; LEAR JET, APRIL TO NOVEMBER 1972

TYPE OF MISSION	FLIGHT PERIOD	DATA FLIGHTS	NUMBER IN			START INSTALL. TO FIRST DATA FLT., DAYS	TIME INTERVAL		LAB. SETUP, DAYS
			FLIGHT CREW	EXPMT. CREW	EXMT. TEAM		CALENDAR DAYS	DATES	
NEBULAE SPECTRA(1)*	4/4-4/13	6	2	1	3	1	11	4/3 TO 4/13	
METEORIC DUST(2)	4/17-4/21	3	2	2	2	3	8	4/14 TO 4/21	
ASTRONOMICAL, SPECTRA (3)	4/24-4/27	2	2	2	2	2	6	4/22 TO 4/27	
ASTRONOMICAL, SPECTRA (4)	5/10-5/11	2	2	2	4	1	3	5/9 TO 5/11	
ASTRONOMICAL, RADIOMETRY (5)	5/17-5/23	5	2	2	2	2	9	5/15 TO 5/23	
(4)	5/26-6/2	4	2	2	5	1	9	5/25 TO 6/2	
(1)	6/6-6/8	3	2	2	2	1	4	6/5 TO 6/8	
(3)	6/20-6/22	3	2	2	2	1	4	6/19 TO 6/22	
(4)	6/26-7/7	8	2	2	5	1	12	6/26 TO 7/7	
(2)	7/10-7/13	3	2	2	2	2	5	7/10 TO 7/14	
(4)	7/18-7/21	6	2	2	4	1	5	7/17 TO 7/21	
ASTRONOMICAL, INTERFEROMETRY (6)	8/2-8/7	4	2	2	2	4	22	7/17 TO 8/7	5
(2)	8/8-8/17	7	2	2 & 1	2	1	10	8/8 TO 8/17	
(4)	8/29-9/6	7	2	2	4	6	16	8/23 TO 9/7	
ASTRONOMICAL, SPECTRA (7)	9/12-9/19	3	2	2	3	1	18	9/5 TO 9/22	7
(3)	11/1-11/2	4	2	2	3	2	4	10/30 TO 11/2	
ASTRONOMICAL, SPECTRA (8)	11/8-11/16	6	2	2	3	3	12	11/6 TO 11/17	2
			END OF ASSESS OBSERVING PERIOD						

*IDENTIFYING NUMBER OF RESEARCH GROUP AND EXPERIMENT DESCRIBED IN TABLE 1-B

TABLE 1-B. DESCRIPTION OF EXPERIMENTS; LEAR JET, APRIL TO NOVEMBER, 1972

RESEARCH GROUP	INSTRUMENTATION	MEASUREMENT OBJECTIVE
1	ECHELLE – GRATING SPECTROGRAPH, IMAGE TUBE, f/16 TELESCOPE	SPECTRA OF NEBULAE IN VISIBLE REGION
2	PHOTOELECTRIC LASER, SIX-CHANNEL PARTICLE COUNTER	CONCENTRATION AND ACCRETION RATE OF SUBMICRON METEORIC DUST IN THE STRATOSPHERE
3	FABRY-PEROT INTERFEROMETER, LHe COOLED DETECTOR, 30-cm, f/5 OPEN-PORT TELESCOPE	ASTRONOMICAL SPECTRA IN FAR IR AND SUBMILLIMETER REGION; ISOTROPIC RADIATION, GALACTIC CENTER AND NEBULAE
4	MICHELSON INTERFEROMETER, LHe COOLED BOLOMETER, 30-cm, f/5 OPEN-PORT TELESCOPE	ASTRONOMICAL SPECTRA IN FAR IR; GALACTIC CENTER, NEBULAE, PLANETS
5	30-cm, OPEN PORT TELESCOPE, f/5; LHe COOLED BOLOMETERS, BAND PASS FILTERS	RADIOMETRY OF GALACTIC CENTER, NEBULAE, STARS AND PLANETS
6	INTERFEROMETER WITH DUAL LN_2 COOLED DETECTORS; GYROSTABILIZED MIRROR; 30-cm, f/5 OPEN-PORT TELESCOPE	NEAR IR INTERFEROMETRY OF PLANETS AND STARS
7	INFRARED SPECTROMETER; LHe COOLED DETECTOR; 30-cm, f/5 OPEN-PORT TELESCOPE	INFRARED SPECTRA OF NEBULAE, GALACTIC CENTER, PLANETS AT 16-23 μm, WAVELENGTHS
8	DUAL INFRARED SPECTROMETER; LHe COOLED DETECTORS; 16 TO 28 μm AND 20 TO 40 μm; 30-cm, f/5 OPEN-PORT TELESCOPE	SPECTRA OF JUPITER AND ORION NEBULA IN FAR INFRARED REGION

TABLE 1-C. AIRBORNE MISSIONS; CV-990, APRIL TO NOVEMBER 1972

NAME AND TYPE OF MISSION	FLIGHT PERIOD	BASE OF OPERATIONS	NUMBER IN FLIGHT CREW	NUMBER OF EXPMTRS.	NUMBER OF EXPERIMENTS	DATA FLIGHTS	PROJECT SCIENTIST	EXPERIMENT INSTALLATION, DAYS	FINAL PREPARA-TIONS, DAYS	EXPERIMENT REMOVAL	TIME INTERVAL	
											CALENDAR DAYS	DATES
AIDJEX EXPEDITION OCEANOGRAPHY	4/3/72 TO 4/21/72	EIELSON AFB AND FAIRBANKS, ALASKA	13	10	13	8	YES	18(3) 7	4(3) 4	3	35	3/21/72 TO 4/24/72
OCEAN COLOR EXPEDITION OCEANOGRAPHY	6/28/72 TO 7/24/72	MOFFETT, OTIS AFB, DAKAR, LAS PALMAS, ANDREWS AFB, MIAMI INTERNATIONAL	12	17	13	15	YES	13	2	2	44	6/13/72 TO 7/26/72
AUGUST 1972 MISSION METEOROLOGY AERONAUTICS (1)	8/9/72 TO 9/6/72	MOFFETT AND EDWARDS AFB	7 TO 10	15	7 1	9 7	NO	10	2	2	42	7/27/72 TO 9/7/72
METEOR SHOWER EXPEDITION ASTRONOMY AND GEOPHYSICS	10/2/72 TO 10/14/72	COLD BAY AND EIELSON AFB ALASKA	12	14	16	10	NO	16	3	2	37	9/11/72 TO 10/17/72
NOVEMBER 1972 MISSION METEOROLOGY AERONAUTICS (1)	10/24/72 TO 11/27/72	MOFFETT AND EDWARDS AFB	8 TO 13	20	13 1	5(2) 9	NO	4	3	2	44	10/17/72 TO 11/29/72

(1) THIS POSITION OF THE MISSION NOT OBSERVED BY ASSESS
(2) ONLY FIRST FLIGHT OF THIS SERIES WAS OBSERVED BY ASSESS
(3) PRIOR TO EARTH OBSERVATION FLIGHTS

TABLE 1-D. DESCRIPTION OF EXPERIMENTS; CV-990, APRIL TO NOVEMBER, 1972

MISSION	TEAM SIZE	EXPMT. NO.	INSTRUMENTATION	MEASUREMENT OBJECTIVE
AIDJEX	4	1+	IMAGING MICROWAVE RADIOMETER, 19.35 GHz	SEA, ICE, CLOUD BRIGHTNESS TEMPERATURE, SNOW AND SOIL MOISTURE
		2	MICROWAVE RADIOMETER, DUAL POLARIZED, 1.42 GHz	SAME AS ①
		3	MICROWAVE RADIOMETER, DUAL POLARIZED, 4.99 GHz	SEA, ICE, CLOUD B.T.,SEA SURFACE TEMPERATURE
		4	MICROWAVE RADIOMETER, DUAL POLARIZED, 37 GHz	SOIL, SEA, ICE, CLOUDS, BRIGHTNESS TEMPERATURE
		5	LASER GEODOLITE	SEA ICE ROUGHNESS, SEA WAVE STATE
	1	6	MICROWAVE RADIOMETER, DUAL POLARIZED, 10.69 GHz	SAME AS ④
		7+	5-CHANNEL MICROWAVE SPECTROMETER	RADIANCE OF H_2O VAPOR, TROPOPAUSE AND STRATOSPHERE SOUNDING
		8	MICROWAVE RADIOMETER 9.3 GHz	SKY RADIANCE FOR VARIOUS WEATHER CONDITIONS
		9	MICROWAVE RADIOMETER 31.4 GHz	SAME AS ⑧
	2	10	INFRARED IMAGER, 7.54 TO 14.0 μm	EARTH SURFACE RADIANCE FOR SURFACE TEMPERATURES
		11	INFRARED RADIOMETERS (3) 17-30, 15-15.2, 9.5-11.5 μm	RADIANCE OF EARTH SURFACE AND ATMOSPHERE, VARIOUS WEATHER; H_2O VAPOR, AIR, AND SURFACE TEMPERATURE
	1	12	ALUMINUM OXIDE HYGROMETER	ATMOSPHERE H_2O VAPOR, DEW AND FROST POINTS
	1	13	SOLAR PHOTOMETER	SOLAR BRIGHTNESS
OCEAN COLOR	3	1	SCANNING EBERT SPECTROMETER, 0.4 TO 0.8 μm	SPECTRAL REFLECTANCE OF OCEAN SURFACE
		2	INFRARED PHOTOMETER, 0.8 TO 1.1 μm	ATMOSPHERE BACKSCATTER OVER OCEAN
		3	EBERT SPECTROMETER, 0.4 TO 0.8 μm	INCIDENT SOLAR RADIATION (SPECTRAL)
	1	4	DIFFERENTIAL RADIOMETERS (3), 14 BANDS, 0.4 TO 0.8 μm	REFLECTANCE OF OCEAN SURFACE
	1	5	DIFFERENTIAL TV SYSTEM, 0.38 TO 0.70 μm	DIFFERENTIAL REFLECTANCE OF OCEAN SURFACE
	1	6	INFRARED IMAGER, 7.54 TO 14.0 μm	SEA SURFACE RADIANCE FOR SURFACE TEMPERATURE
		7	INFRARED RADIOMETERS (2); 9.5-11.0, 17-30 μm	RADIANCE OF SEA SURFACE AND ATMOSPHERE, TEMPERATURE AND H_2O VAPOR
	4	8+	MULTICHANNEL OCEAN COLOR SENSOR, 0.4 TO 0.7 μm	SPECTRAL REFLECTANCE OF OCEAN SURFACE
	2	9+	SURFACE COMPOSITION MAPPING RADIOMETER; 8.3 TO 9.3, 10.2 TO 11.2 μm	SEA SURFACE TEMPERATURE FROM SURFACE RADIANCE
	1	10	ALUMINUM OXIDE HYGROMETER	ATMOSPHERIC H_2O VAPOR, DEW AND FROST POINTS
	1	11*	ATMOSPHERIC GAS SAMPLING SYSTEM (ASP)	CONC. OZONE, CO_2, TOTAL OXIDANTS
	2	12*	GAS SAMPLING AND ANALYZING SYSTEM (SAS)	CONCEN. OZONE, H_2O, CO, CO_2, NO
	2	13*	CO_2 LASER SYSTEM	TRUE AIRSPEED BY DOPPLER BACKSCATTER

TABLE 1-D. DESCRIPTION OF EXPERIMENTS; CV-990, APRIL TO NOVEMBER, 1972 (CONTINUED)

MISSION	TEAM SIZE	EXPMT. NO.	INSTRUMENTATION	MEASUREMENT OBJECTIVE
AUGUST 1972	1	1*	STRATOSPHERE AIR SAMPLING SYSTEM (SAS)	CONCEN. O_3, H_2O, CO, CO_2, NO
	2	2*	ATMOSPHERIC GAS SAMPLING SYSTEM (ASP)	CONCEN. O_3, CO_2, SO_2, NO_x, CO
	6	3*	LASER OPTICAL RADAR	DETECTION OF CLEAR-AIR TURBULENCE
	2	4	FAR IR SPECTROMETER, 0.1 TO 2 mm	SPECTRA OF UPPER ATMOSPHERE GASES
	2	5^x	RAPID-SCAN EBERT SPECTRA-METER, 0.5 TO 0.9 μm	INCIDENT SOLAR RADIATION (SPECTRAL)
	1	6	INFRARED RADIOMETERS (2); 8 TO 30 μm, 15 μm	WATER VAPOR ABOVE AIR-CRAFT, STATIC AIR TEMPERATURE
	1	7	ALUMINUM OXIDE HYGROMETER	ATMOSPHERIC WATER VAPOR, DEW AND FROST POINTS
METEOR SHOWER AND UPPER ATMOSPHERE PHYSICS	2	1	MAKSUTOV SPECTROGRAPH SYSTEMS; 3000-3600 Å(2) VISIBLE WAVELENGTHS (4)	METEOR SPECTRA IN UV AND VISIBLE RANGE
		2	70 mm, f/1 CAMERA-SPECTRO-GRAPHS (4)	METEOR SPECTRA IN VISIBLE RANGE
		3	SCHMIDT SPECTROGRAPH SYSTEMS (3), VISIBLE WAVE-LENGTHS	METEOR SPECTRA IN VISIBLE RANGE
		4	INFRARED SPECTROGRAPH CAMERAS (2), >9000 Å	METEOR SPECTRA IN NEAR IR RANGE
		5	IMAGE INTENSIFIER CAMERA-SPECTROGRAPH, VISIBLE LIGHT	SPECTRA OF FAINT METEORS IN VISIBLE RANGE
		6A	TWO-CHANNEL PHOTOMETER 6000 TO 9500 Å	TIME VARIATION OF SHOWER INTENSITY
		6B	K-24 AERIAL CAMERA	STAR FIELD PHOTOGRAPHY
	2	7	F-24 CAMERA SPECTRO-GRAPHS (4) 1UV, 1 IR, 2 VISIBLE	METEOR SPECTRA AT WAVE-LENGTHS FROM UV TO NEAR IR
		8	JUMPING-FILM CAMERA, VISIBLE LIGHT	MULTIPLE-IMAGES OF METEOR TRACE
	1	9	TV VIDICON CAMERA SPECTROGRAPH (1), VISIBLE LIGHT	CONTINUOUS SPECTRAL RECORD OF METEOR SHOWER
		10	TV VIDICON CAMERA, VISIBLE LIGHT	PHOTO RECORD METEOR SHOWER AND UPPER ATMOSPHERIC WIND PROFILES
	2	11	IMAGE ORTHICON TV CAMERA-SPECTROGRAPH, VISIBLE LIGHT	CONTINUOUS SPECTRAL RECORD OF METEOR SHOWER
	3	12	WIDE-ANGLE CAMERAS (8), VISIBLE AND INFRARED WAVE-LENGTHS	UPPER ATMOSPHERIC WIND PROFILES, MAGNETIC FIELD LINE OBSERVATIONS
	2	13^x	ALL-SKY CAMERAS (2) 160° FIELD OF VIEW	MORPHOLOGY OF AURORAS
		14^x	BIREFRINGENT CRYSTAL PHOTOMETER	SPECTRAL PHOTOMETRY OF AURORAL EMISSIONS
	2	15	INFRARED RADIOMETERS (3), 8 TO 30 μm COVERAGE	EARTH SURFACE TEMPERATURE, STATIC AIR TEMPERATURE, H_2O ABOVE AIRCRAFT
	0	16	AEROSOL SAMPLE COLLECTION SYSTEM	CONCENTRATION OF AEROSOLS IN STRATOSPHERE

TABLE 1-D. DESCRIPTION OF EXPERIMENTS; CV-990, APRIL TO NOVEMBER, 1972 (CONCLUDED)

MISSION	TEAM SIZE	EXPMT. NO.	INSTRUMENTATION	MEASUREMENT OBJECTIVE
NOVEMBER 1972	1	1	AEROSOL SAMPLE COLLECTION SYSTEM	CONCENTRATION AEROSOLS IN STRATOSPHERE
	3	2*	STRATOSPHERE AIR SAMPLING SYSTEM (SAS)	CONCENTRAITON O_3, H_2O, CO, CO_2, NO
	3	3*	ATMOSPHERIC GAS SAMPLING SYSTEM (ASP)	CONCENTRATION O_3, CO_2, SO_2, NO_x, CO
	1	4	USED EQUIPMENT OF EXPERIMENT 2	CONCENTRATION JET ENGINE WAKE REACTANTS
	2	5	FAR IR SPECTROMETER, 0.1 TO 2MM	SPECTRA OF UPPER ATMOSPHERE GASES
	2	6	INFRARED RADIOMETERS (3), 8 TO 30 μm	EARTH SURFACE TEMPERATURE, H_2O ABOVE AIRCRAFT
	1	7	ALUMINUM OXIDE HYGROMETER	ATMOSPHERIC WATER VAPOR, DEW AND FROST POINTS
	3	8	AEROSOL SLIDE COLLECTOR SYSTEM	SHAPE, SIZE AND CONCENTRATION OF STRATOSPHERIC AEROSOLS
		9	AEROSOL FILTER COLLECTOR SYSTEM	ELEMENTAL COMPOSITION OF STRATOSPHERIC AEROSOLS
		10	LASER SCATTERING WITH PULSE HEIGHT ANALYZER	PARTICLE SIZE DISTRIBUTION OF STRATOSPHERIC AEROSOLS
		11	LASER SCATTERING NEPHELOMETER	INDEX OF REFRACTION OF STRATOSPHERIC AEROSOLS
	1	12	DIFFERENTIAL TV SYSTEM, 0.38 TO 0.70 μm	DIFFERENTIAL REFLECTANCE OF OCEAN SURFACE
	3	13	SKYLAB CAMERA, VISIBLE AND NEAR IR	EARTH TERRAIN FEATURES

* AIRCRAFT APPLICATION
\+ SATELLITE APPLICATION
x SATELLITE DATA CORRELATION

postflight identification of atmospheric trace constituents. Forty-nine of the 62 experiments had as the primary objective the collection of basic scientific information; eight experiments were engaged in the development of instrument packages for aircraft application, five of these for use on commercial aircraft and three for earth resources survey aircraft; and five experiments were engineering models of instruments that had been or were to be flown on satellites. In addition, three of the 49 basic-science experiments were used during satellite underflights to provide upward-looking information for correlation with satellite data. These 16 special-purpose experiments are identified in table 1-D.

An average of 12 experiments was flown on each CV-990 mission; the installation and check-out period was generally of the order of two weeks. Experiments on the CV-990 varied widely in complexity and amount of equipment; thus, the size of research teams varied from 1 to 6 people and the ratio of people to experiments varied from 1/4 to 6, usually between one and two. Thirty-seven of the 47 data flights occurred during the day; flights averaged about 4 to 5 hours in length. The overall level of accomplishment was one flight every 3-1/2 calendar days of residence.

Mission Experimenters

The experimenters in airborne missions during the ASSESS observing period represented primarily NASA centers and universities (table 1-E). NASA sponsored 58 percent of the experiments, with 24 percent from universities, 9 percent from other government agencies, and 8 percent from industry. One foreign research team was observed during this period. This mixture of experimenters is perhaps weighted in favor of NASA, since two of the major CV-990 missions were assembled by another NASA center.

Study Phase Documentation

This report covers the ongoing conventional airborne missions during the study period from April to November 1972, the ASO organization, and the experiment-management practices. Of particular interest are the procedures for selecting experiments, and the role of the scientists conducting them, for this element of the program bears the ultimate responsibility for the scientific results that determine overall mission success. ASO management practices and operational procedures are evaluated in terms of their potential application to the Shuttle Sortie program, and references to the airborne-orbital analogy are made in relation to specific points of interest. As the simulation phase of the ASSESS program continues, many of these comparisons will be investigated in greater depth to optimize the contributions of the ASO research management approach to the success of the Shuttle Sortie program.

TABLE 1-E. ASO AIRBORNE MISSION SPONSORS

ORGANIZATIONS REPRESENTED

MISSION	NASA	GOVT.	UNIVERSITY	INDUSTRY	FOREIGN
AIDJEX	2	1	1	0	0
OCEAN COLOR	3	1	0	1	0
AUGUST 1972	4	1	1	0	0
METEOR SHOWER	2	1	2	1	1
NOVEMBER 1972	4	1	1	1	0
LEAR PROGRAM	1	0	6	0	0
	16	5	11	3	1

NUMBER OF EXPERIMENTS

MISSION	NASA	GOVT.	UNIVERSITY	INDUSTRY	FOREIGN
AIDJEX	10	2	1	0	0
OCEAN COLOR	10	2	0	1	0
AUGUST 1972	5	1	1	0	0
METEOR SHOWER	9	1	3	1	2
NOVEMBER 1972	7	1	1	4	0
LEAR PROGRAM	5	0	12	0	0
	46 (58%)	7 (9%)	18 (23%)	6 (8%)	2 (2%)

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Section 2

BASIC CRITERIA AND PROCEDURES FOR THE FORMULATION AND APPROVAL OF AIRBORNE MISSIONS

Airborne science missions originate generally in two ways: as major missions generated by NASA or in response to unsolicited proposals from the scientific community. The general procedures and selection criteria involved are illustrated in figure 2-A.

NASA-Originated Missions

CV-990 Expeditions

NASA originates CV-990 expeditions for the study of specific natural phenomena (e.g., solar eclipses) and for concerted studies in a single discipline field (e.g., aurora and airglow). Each expedition is first evaluated as an airborne science mission by the Airborne Research Steering Committee (ARSC) and, if feasible, assigned a tentative place in the CV-990 schedule.

If the proposed expedition might interest a large number of investigators (e.g., the aurora expeditions), a formal Announcement of Flight Opportunity (AFO) is distributed by NASA Headquarters to appropriate scientists and institutions throughout the world. When the mission would concern only a small group of scientists, the invitation to participate is made by letter or even by word of mouth, as in the case of the 1972 Giacobinid Meteor Shower Expedition.

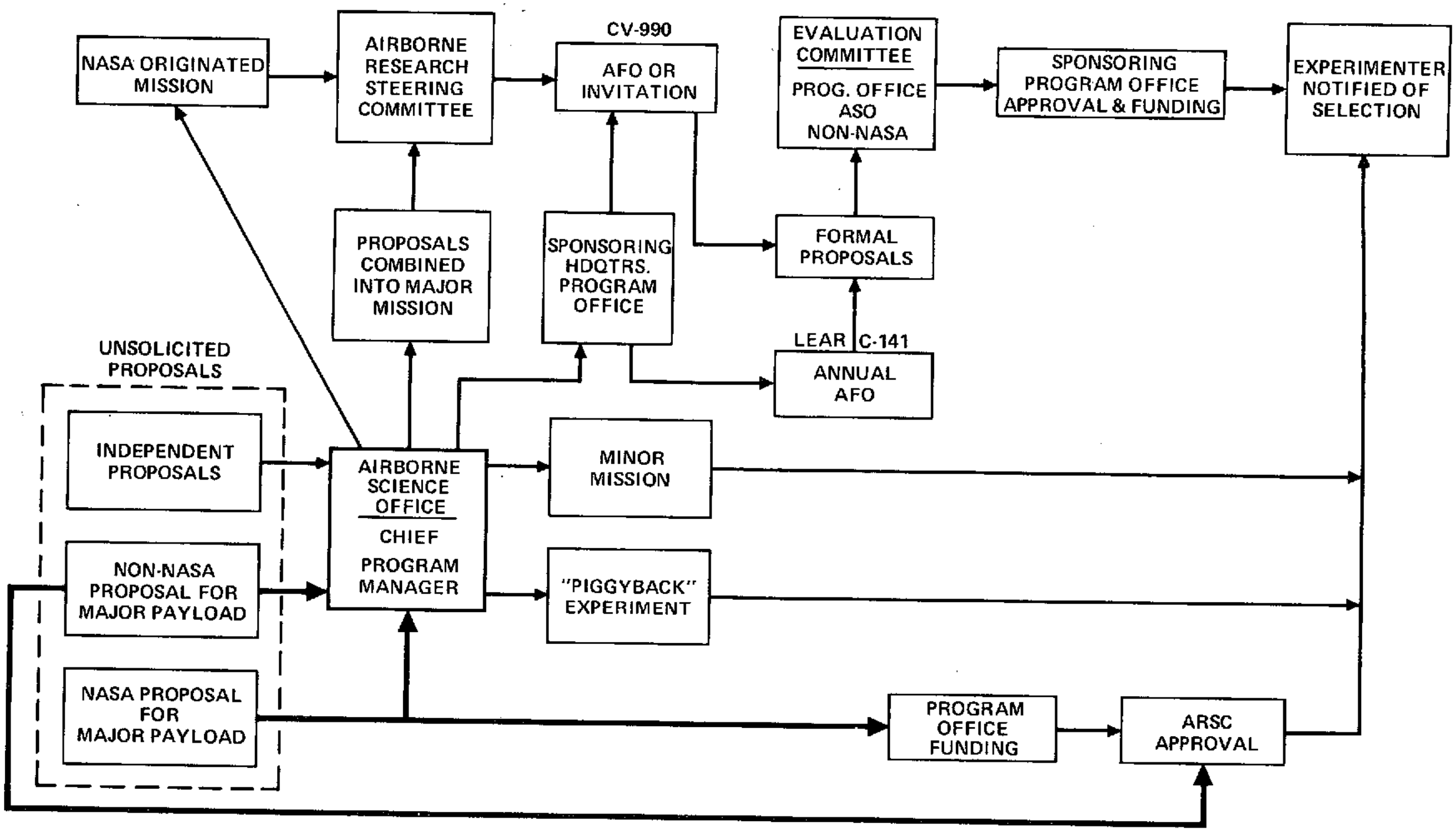
Lear Jet and C-141 Expeditions

Since the Lear Jet and the C-141 aircraft are dedicated almost exclusively to astronomical investigations, particularly in the infrared regions, their availability is publicized by yearly AFOs, which request proposals for use of the aircraft in the following year.

AFO Preparation and Proposal Evaluation

The AFO is prepared by the appropriate Airborne Science Office (ASO) program manager and issued over the signature of the associate administrator of the sponsoring program office at Headquarters (e.g., OSS, OA). By this action, the associate administrator gives only preliminary approval to the expedition. The AFOs provide background information on the proposed airborne investigations, the aircraft, and the procedure for submitting proposals, and refer the reader to the appropriate ASO program manager for further information.

FIGURE 2-A. PROCEDURES AND CRITERIA IN MISSION FORMULATION AND APPROVAL



SELECTION CRITERIA

- INTRINSIC SCIENTIFIC WORTH
- ADVANTAGES OF AIRBORNE OPERATION
- COMPATIBILITY WITH THE AIRCRAFT
- COMPATIBILITY WITH OTHER EXPERIMENTS IN PAYLOAD

Proposals received in response to AFOs are reviewed by an ad hoc evaluation committee composed of representatives from the appropriate program offices at NASA Headquarters and from the Airborne Science Office; the committee also usually includes a few senior, non-NASA scientists in the discipline concerned who have not submitted a proposal.

The ASO program manager reviews the proposals to determine whether the proposer's equipment can be installed and operated in the airplane and the airplane flown in such ways that the investigator will be able to obtain the data he wants. The committee's scientist members (both NASA and non-NASA) judge the scientific merit of each proposal and the advantages of doing the proposed research from the aircraft rather than from a ground observatory or a spacecraft. The committee then recommends a payload that permits a comprehensive, multifaceted investigation into the phenomenon being studied. (The evaluation committee may also recommend against an airborne expedition because of insufficient worthwhile proposals.)

Approval of the Recommended Payload

The director of the Headquarters program office (e.g., the director of the physics and astronomy programs) must then approve the recommended payload. His approval is the key to the mission because he thereby agrees to fund the entire expedition, including both the experimenters' grants and costs of operating the airplane. (Beginning in FY 74, the aircraft operating costs will be covered on an annual basis by the Institutional Management System (IMS), with the Headquarters program office covering only the experimenters' grants and extraordinary, nonroutine expedition costs.) The associate administrator over that program office next must ratify the plan for the expedition and its payload.

Once the cognizant officials over the Headquarters program office have sanctioned the expedition, the Airborne Research Steering Committee assigns a firm designation to the mission and resolves any conflicts in the aircraft schedule.

Expeditions Resulting from Unsolicited Proposals

Many CV-990 missions result from unsolicited proposals received by NASA Headquarters or by the Airborne Science Office. Such proposals are given a preliminary review by the program managers in the Airborne Science Office and the appropriate Headquarters program office. Depending on the nature and the complexity of the proposed research, the proposal may then take one of several routes.

Unsolicited Proposals Leading to an Open Major Mission

The proposed research may be in an area of such general interest that the ASO and the Headquarters program office will recommend that the mission be open to all interested scientists. In this case, the procedures followed are similar to those for a NASA-generated mission.

Proposal for a Major Payload

From a NASA center. The unsolicited proposal may cover several closely coordinated experiments constituting a major payload for the CV-990. The research program is arranged and the experiments in the payload are selected by one agency or group, usually from a NASA center, to fulfill some of their research and development objectives. Examples of these missions are the Goddard Space Flight Center (GSFC) Meteorology and Earth Observations Missions, the GSFC Solar Constant Expedition, and the Wallops/Langley Barium Ion Cloud Project. One person at the proposing center assumes the role of Project Scientist responsible for arranging the mission payload. Proposals containing a major payload must be approved by the Headquarters program office providing funds to the proposing center and the airborne expedition operational costs to ASO. (Beginning in FY 74, operational funds will be provided as noted for NASA- generated missions.) Once the funding for the complete mission is assured, the Airborne Research Steering Committee gives its final approval to the proposal.

From a non-NASA agency. An unsolicited proposal with a major experimental payload from a non-NASA organization requires only approval by ASO and the Airborne Research Steering Committee, which can designate the program as a firm one if they are satisfied that the proposal meets the criteria of an airborne science mission, that the proposing agency can fund the expedition, and that the mission can be accommodated in the CV-990 schedule.

Consolidation of Independent Unsolicited Proposals into a Payload

Occasionally, the unsolicited proposal pertains to a worthwhile experiment that by itself does not justify the use of the CV-990 aircraft or for which sufficient funding is not available. In this case, the ASO consolidates such proposals into a payload that would justify a mission. In such payloads most experiments can obtain data on most flights, and each experimenter has one or more flights for which he is the prime investigator – that is, flights for which he can determine the route and time. Such a consolidated payload also permits the inclusion of experiments that can provide mutually supporting data, although each experiment is independent of the others.

The ASO arranges these consolidated payloads with the help and the informal approval of any Headquarters program office that may be involved in funding any of the proposals. The payload and mission are then recommended to the Airborne Research Steering Committee, which applies its usual criteria in deciding whether or not to approve the mission for the CV-990.

Funding Negotiations

For CV-990 expeditions resulting from unsolicited proposals, the program office's approval and, where necessary, guarantee of funding for the operation are developed in two ways: by direct negotiation between the ASO and the program office and by the presence on the Airborne Research Steering Committee of a permanent member from the NASA organizations that use the CV-990 for their programs (i.e., OA, OSS, OAST, and OMSF).

When a non-NASA agency asks to use the aircraft, the negotiations take place directly between that agency and the ASO.

Unsolicited Proposals for the Lear Jet and the C-141 Aircraft

Since the AFOs for the Lear Jet and the C-141 aircraft are open-ended and renewed yearly, any unsolicited proposals for their use are merely kept on file for presentation to the next meeting of the evaluation committee.

"Piggyback" Experiments

"Piggyback" experiments fly on a space-available, noninterference basis. They are generally small ones and have very broad flight requirements that can be satisfied by many types of missions. These "piggyback" experiments usually require, at most, nominal funding to cover experimenter travel expenses. Moreover, they often are ready to be flown with only short notice, a few weeks or so. These experiments come from the unsolicited proposals to ASO and from experiments that have already flown on the CV-990.

When space is avilable on an upcoming mission, the ASO program manager will choose "piggyback" experiments to fill the space; he looks first for those that can contribute supporting data to the primary experiments.

The addition of "piggyback" experiments to a mission's payload is totally within the discretion of the ASO program manager and allows the most efficient and productive use of the airplane. In some cases, "piggyback" experiments have paid their way, in effect, by obtaining useful data when the primary experiments, for one reason or another, did not obtain the data for which they were intended.

Applications to the Shuttle Sortie Program

The selection of experiments for major missions with specific purposes follows generally the pattern established for spacecraft programs in the 1960s. A major difference, however, is the much shorter time between experiment selection and flight in the airborne program as compared with the spacecraft program. Airborne experiments are selected 6 to 12 months before flight; even less lead time is needed for individual unrelated experiments that are consolidated into one payload; and "piggyback" experiments often are approved only a few weeks before flight. Rarely is an experiment scheduled more than a year in advance. Such short lead times enhance the timeliness of experiments and reduce overall experiment preparation costs.

The handling of unsolicted individual experiments and "piggyback" experiments to fill any excess space on airborne science missions is particularly relevant to the Shuttle Sortie program. A file of such experiments is maintained for reference as the need arises.

An important impact of ASO management participation in this area is the role of the appropriate ASO program manager. By virtue of his scientific background and intimate knowledge of the aircraft through his function as mission manager, the program manager is able to evaluate proposals for their scientific value as well as their compatibility with the aircraft environment.

Section 3

ASO MANAGEMENT STRUCTURE AND PROCEDURES

Airborne Science Office (ASO) direction of inflight research over several years has fostered the development and refinement of management techniques which maximize opportunities to achieve scientific objectives and which emphasize simplicity and informality of operation and reporting.

These techniques are largely the result of the circumstances under which ASO conducted its first mission in 1965. At that time, the nucleus of the present ASO consisted of the expedition manager, an assistant expedition manager for experiments, a technician, and a secretary. (The latter two were detailed only for the duration of the first mission.) Manpower was provided, as needed, by other Ames Research Center organizations, principally the Flight Systems Research Division (one pilot and a USAF navigator temporarily on duty at Ames), the Technical Services Division (aircraft maintenance, inspection, and experiment installation), and the Research Facilities Division (mechanical engineering). The participating scientist had to be wholely responsible for assembling and operating his experiment and for ensuring it would work. The management staff, because of its small size, was forced to operate informally and flexibly with a minimum of formal documentation. As the airborne science method proved to offer unique advantages for conducting research, particularly observations of natural phenomena, more missions were conducted, more aircraft were used, and additional personnel were added. Yet the basic procedures remained the same.

ASO Management Structure

The chief of ASO is responsible for overall planning and administration of ASO programs and operations. His immediate staff consists of a technical assistant, an administrative assistant, and two secretaries. Airborne science missions have fallen into three broad scientific categories: (1) astronomy, (2) meteorology and earth observations, and (3) geophysics and space sciences. For each one of these three discipline areas, the ASO has a program manager who is a scientist with experience in that discipline and who is responsible for the airborne missions in that area. Two of these program areas have full-time assistant program managers, one for the (Lear Jet) astronomy program and one for meteorology and earth observations. When a particular airborne science mission is developed, one of these five persons is assigned as mission manager, with complete responsibility for that specific mission. For large missions, an assistant mission manager is also appointed; on occasion, other members of the ASO staff assist the program managers in this capacity.

A permanent CV-990 facilities manager is responsible for the experimental support systems on board the CV-990. He is assisted by a mathematician who programs and operates the data acquisition system (ADDAS) and by two contract electronics technicians. A similar group supports the C-141 aircraft.

Two flight planners/navigators support operations on all the ASO aircraft and are closely involved in mission planning from its inception. A mechanical technician manages the laboratory provided for experimenters by ASO.

Functional support of ASO activities is provided by cognizant groups within Ames on a regular basis as requested, or occasionally to meet special needs (fig. 3-A). ASO does not duplicate with its own resources any services that can be provided by other Ames groups. Contractor support is used for some routine functions such as aircraft maintenance. Table 3-A summarizes flight personnel requirements for missions during the ASSESS study period, in terms of man-flights in direct support of research activities (including the flight crew) and for transporting aircraft maintenance crews (via the CV-990) to remote bases.

Key Elements of the ASO Management Approach

The ASO management approach centers on the intimate involvement of the experimenters in all aspects of the airborne science mission. They design and assemble the experiment, subject only to the general constraints of flight safety, available electrical power, and the aircraft environment. They test and maintain the experiment to their own standards of performance and reliability, and they operate it in flight.

Success in obtaining scientific data is always the primary purpose of the flights. Thus, ASO concentrates on maintaining an atmosphere conducive to research, conducting each mission as though it were a field expedition. ASO provides the airborne platform and the necessary support for the experimenter's work. The ASO program/mission managers are experienced research scientists, and thus they can communicate and work easily with the experimenters.

Continuity of management throughout the project is another important element of the ASO approach. The experimenters always have the same point of contact, the ASO mission manager or members of his small staff. A mission manager is assigned at the inception of each CV-990 mission, often when it is first tentatively proposed. He follows all details through the final flight and post-flight data analyses, and he actively participates in all CV-990 flights. For the Lear Jet program, the manager provides a similar continuity for a series of missions (only one experiment at a time can be flown). He is the single point of contact for experimenters and follows each mission from inception to completion. Usually there will be several missions in various stages of development concurrently in progress.

The effectiveness of ASO programs is greatly enhanced by the physical proximity of most of the Ames support groups and the ASO within the Ames hangar building (fig. 3-A). Communication and coordination among these groups are thus facilitated and usually consist of face-to-face discussions rather than memos or even telephone calls.

While sharing the fundamental concepts of the ASO approach to airborne science research, the CV-990 and the Lear Jet operations have unique experiment-management features of value to the Space Shuttle program. As noted, a CV-990 mission usually involves a coordinated grouping of experiments, while a Lear Jet flight series centers on a single experiment. The management of CV-990 missions will be discussed in some detail. The same functions are performed for Lear Jet experiments, but usually as combined rather than individual assignments. Thus, elements of the Lear Jet program are discussed only where they differ from those of the CV-990.

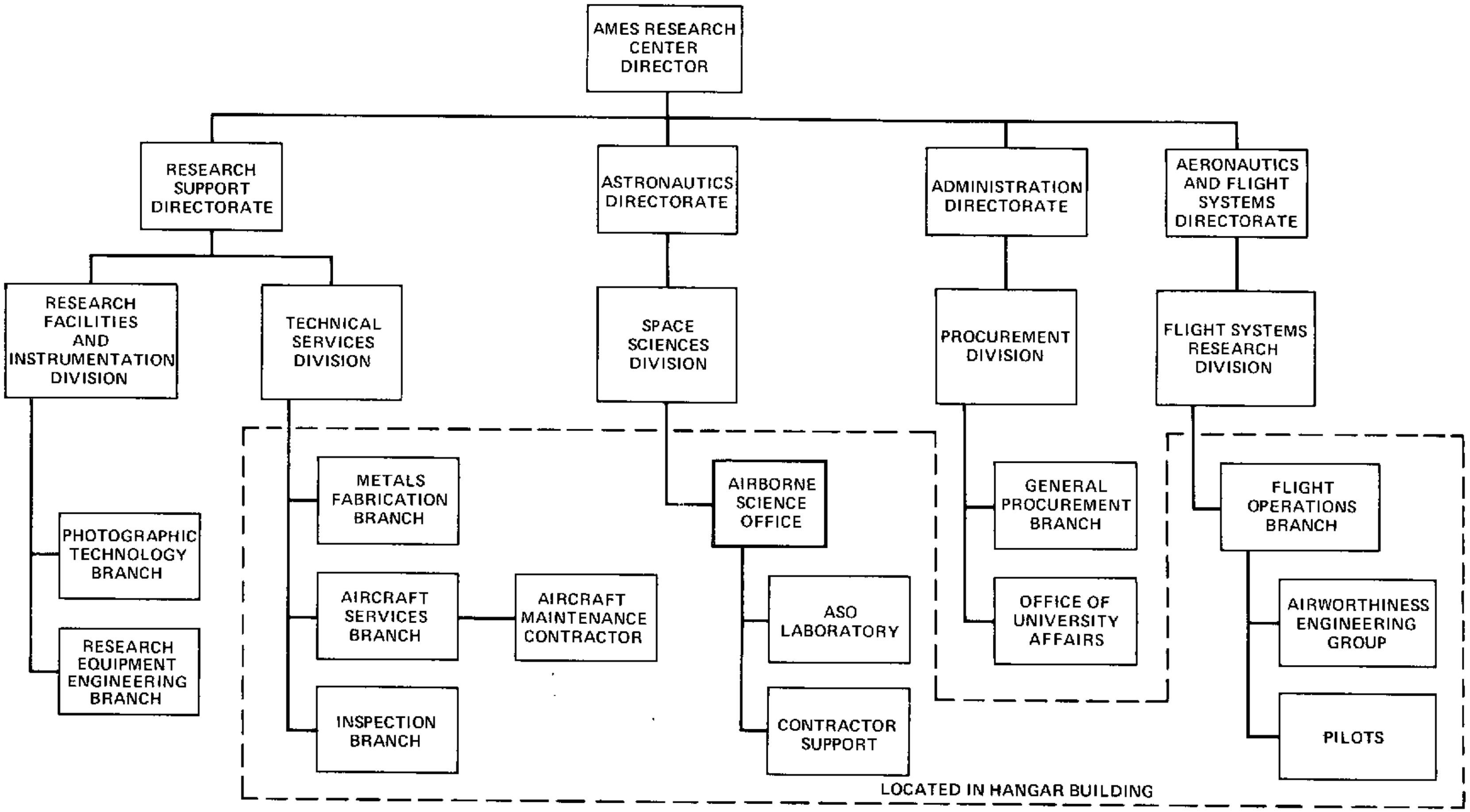


FIGURE 3-A. RELATION OF AIRBORNE SCIENCE OFFICE TO ARC SUPPORT GROUPS

TABLE 3-A. FLIGHT PERSONNEL SUMMARY

AIRCRAFT	MISSION	MAN-FLIGHTS			SUPPORT MANPOWER RATIO*		
		EXPERI-MENTERS	RESEARCH SUPPORT PERSONNEL	AIRCRAFT MAINTENANCE PERSONNEL	DATA FLIGHT	GROUND OPERATIONS (REMOTE BASE)	MISSION OVERALL
LEAR JET	ALL	139	152	0	1.09	0	1.09
CV-990	AIDJEX	66	104	14	1.58	0.21	1.79
	OCEAN COLOR	206	183	42	0.89	0.20	1.09
	AUGUST 1972	91	65	0	0.71	0	0.71
	METEOR SHOWER	107	128	21	1.20	0.20	1.39
	NOVEMBER 1972	84	57	0	0.68	0	0.68
	ALL	554	537	77	0.97	0.14	1.11

* DATA FLIGHT S.M.R. = RESEARCH SUPPORT PERSONNEL FLIGHTS/EXPERIMENTER FLIGHTS
GROUND OPERATIONS S.M.R. = AIRCRAFT MAINT. PERSONNEL FLIGHTS/EXPERIMENTER FLIGHTS

CV-990 Missions

The airborne mission and its experiment payload normally are managed from the ASO by the mission manager. On occasion, an experiment payload for the CV-990 may be managed primarily by another NASA center or other government agency, although final approval and mission responsibility remains with the ASO manager. Goddard Space Flight Center, for example, sometimes assembles the principal experiments, designates the project scientist, prepares the aircraft layout, and outlines the mission objectives. In such a case, the ASO mission manager works closely with representatives of the sponsoring center to coordinate mission preparations, and he still retains direct control over experiments not part of the primary group. On all CV-990 missions, he coordinates research activities during the flight period.

Functions outlined in this section are common to all missions, whether performed by the ASO manager and staff or not. For simplification, the usual case where both the payload and overall mission operations are managed from the ASO is used to illustrate mission management practices.

CV-990 Mission Origins

CV-990 missions are of two general types. A mission may be for a single purpose, as in the 1972 AIDJEX mission for the study of ice movement in the Arctic Ocean (appendix A). Or it may comprise two or more groups of independent experiments having some common parameters in terms of flight time, profile, and routes, the geographical location, or the operational techniques and instrumentation. The 1972 Meteor Shower Expedition, for example, was designed primarily for observation of the Giacobinid shower, but it later was extended to include observations of auroras and of rocket launches for meteorologic and geomagnetic studies (appendix D). The November 1972 mission was planned for measurements of clear-air turbulence, two separate groups of studies on atmospheric sampling, and an experiment on stratospheric jet wakes; though independently proposed, the experiments were to some extent complementary.

The concept of an airborne mission and the early considerations of its feasibility often are the result of informal discussions between members of the scientific community, with perhaps some general guidance from an ASO program manager who is knowledgeable in the research area. By one of several paths, unsolicited proposals with recommendations will reach the ASO, to be evaluated by the cognizant manager. If in his opinion, most likely augmented by informal discussions with other scientists in the field (perhaps potential participants themselves), the proposals have scientific merit and promise of support, arrangements may be made to issue a formal Announcement of Flight Opportunity (AFO). For a more complete discussion of the AFO, the evaluation of proposals, and alternate procedures for mission formulation, see section 2. (Examples of the interesting and varied ways a mission may originate are given in appendixes B and D.)

By this time, the ASO manager will have invested considerable effort in evaluating the scientific validity of the experiments and in outlining a tentative flight program to meet the stated objectives. He also will become well acquainted with many, if not all, the participating scientists and experiments by the time mission approval has been obtained and he becomes manager of that particular mission.

In special cases, and by common agreement, a project scientist is designated by the organization sponsoring the mission; this may be an NASA center or another government agency such as the National Science Foundation. He may or may not have an experiment of his own onboard. His role will vary from one of strong direction to that of a scientific advisor, with primary concern for the experiment payload, and an obligation to work closely with the ASO mission manager at all times to achieve integration of the many diverse mission elements.

CV-990 Mission Development

Experimenter relations. Soon after mission approval, the manager issues the first Experimenters' Bulletin, which gives a summary of mission objectives, a tentative schedule, and a listing of experiments and experimenters. Successive bulletins provide updated information and additional detail.

The mission manager, in consultation with the aircraft facilities manager, plans the layout of the aircraft interior on the basis of information from the experimenters on the physical parameters of the proposed experiment packages. This process is purposely kept open and flexible to allow the addition or deletion of experiments and give the experimenter the option of modifying his equipment. Within reason, changes may be made up to the close of the development period so long as they do not affect other experiments or the overall schedule.

The CV-990 Experimenters' Handbook introduces each new experimenter to the special environment of the aircraft, special aircraft facilities, methods of experiment installation, and available support services. He is expected to use the data in the handbook as a guide in the design of his equipment; he must conform to the loading and stress limits that are dictated by safety and airworthiness requirements. The principal events in the development of an experiment are shown in the upper part of figure 3-B.

During the entire period between mission approval and the experimenter's arrival at Ames, the mission manager is in frequent contact with the experimenter, usually by phone; formal written communications are seldom necessary. If possible, the experimenter visits Ames to see the aircraft and meet the support personnel involved. He is introduced to those with specific responsibilities for portions of the mission and is encouraged to take questions directly to these other staff members when appropriate, with the provision that the mission manager be kept informed of all developments.

Equipment drawings and an appropriate stress analysis submitted to the mission manager by the experimenter are reviewed by the Airworthiness Engineering Group (Ames Flight Operations Branch), which is responsible for the safety aspects of the experiment installation. With rare exception, the engineering evaluation (while binding) is transmitted informally, through the mission manager, back to the experimenter.

During the preparatory period, the mission manager is assisted by a number of other personnel (fig. 3-B). The facilities manager is responsible for arranging for the experimenter's use of standard facilities available on the CV-990. These include electric power, cabling, timing signals, photographic coverage, intercom, and the ADDAS system. The data systems manager handles (and programs) experimenter requests for the recording of data in the ADDAS or use of

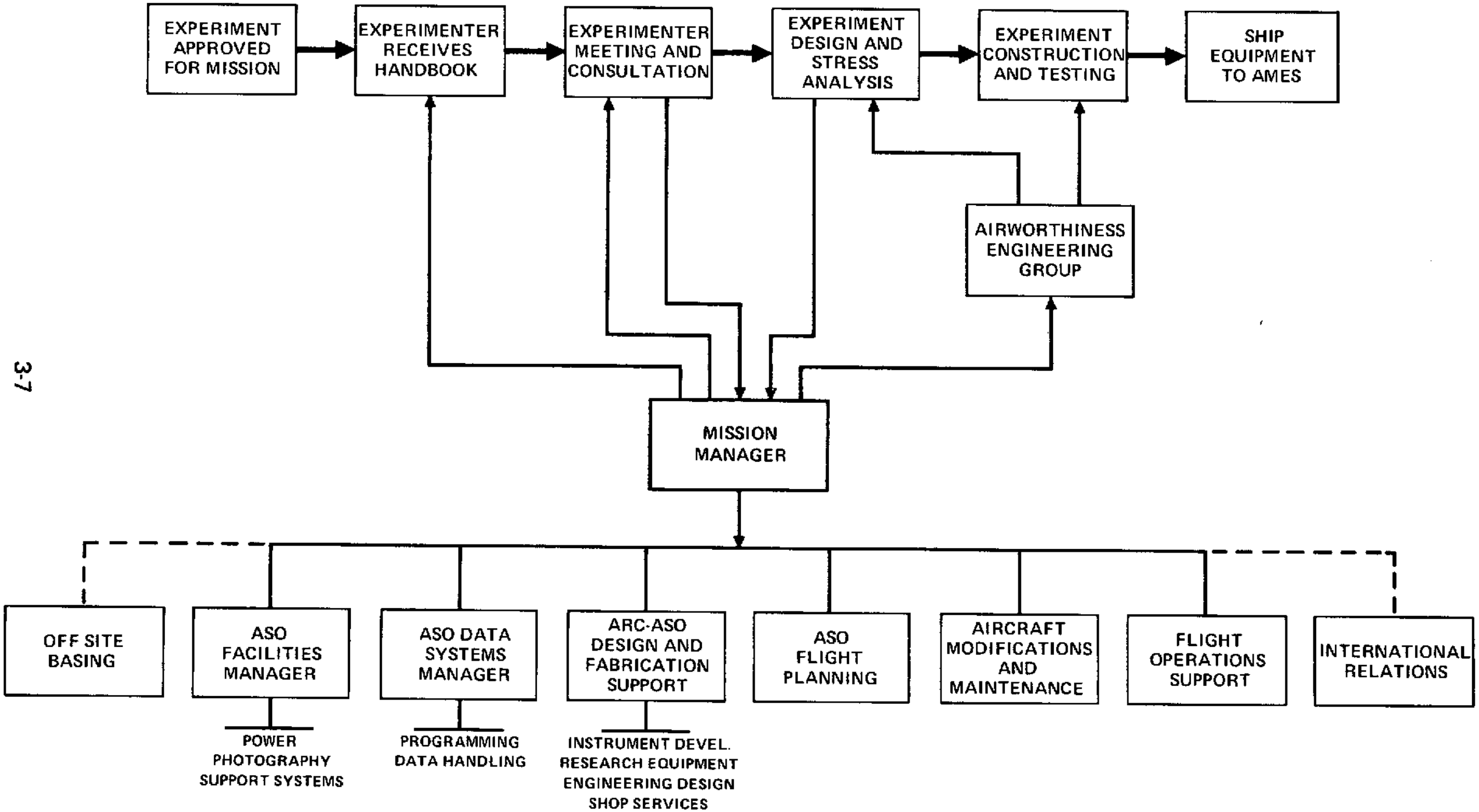


FIGURE 3-B. MISSION PREPARATION PROCEDURES

the system for real-time computation while experiments are in progress. The ADDAS is available for calculations using experimental data, provided the programmer is furnished all pertinent information well in advance of the mission. The mission manager arranges for the design and fabrication at Ames of any special openings or housings external to the fuselage required to accommodate experimenter equipment. The cognizant design engineer deals directly with the experimenter; for complex experiments, he may travel to the experimenter's laboratory to coordinate the design (fig. 3-C).

The experimenter is expected to make his own support devices to match aircraft tie-points in conformance with aircraft specifications for construction (section 6). In special cases, design services for brackets and mounts may be provided by an ASO or other Ames designer. The experimenter is expected to work directly with that person.

Planning and logistics. The ASO mission manager has overall responsibility for all flight planning, aircraft modifications, flight research support services, and mission logistics. To accomplish these tasks, he must request support from ASO staff members, ASO contract services, and appropriate Ames specialty groups. Details of the procedures involved are given in section 10 and appendixes A through D.

The mission manager coordinates the diverse flight plans desired by various experimenters with a flight planner/navigator in the ASO and informally consults with the aircraft command pilot of the Flight Operations Branch on various aspects of the developing flight schedule. Flight planning is relatively simple for a one-time astronomical phenomenon that occurs at a fixed time and place; typically, however, several differing flight plans must be prepared to meet contingencies, and planning for a multipurpose mission may involve several widely divergent flight plans, each for the special benefit of a particular experiment.

For a mission based away from Ames, arrangements must be made for use of the remote base and the ferry flights to it. The navigator collects information pertinent to remote bases and suitable alternate fields within mission range. Arrangements for the use of an Air Force Base are initiated by the mission manager through the resident Air Force Liaison Officer; in the case of a commercial field, the ASO contract support manager makes the arrangements under the direction of the mission manager. When the mission schedule is firm, the manager initiates a formal flight request for flight operations and aircraft maintenance support on the part of Ames and contract personnel.

Operations in a foreign country require advance permission from the nations involved to overfly their territory and/or to base in their country. The ASO mission manager initiates such requests to the Office of International Affairs at NASA Headquarters, which, in turn, asks the U. S. Department of State to make the formal request. Those actions must be initiated three to six months prior to the operation.

CV-990 Mission Integration

Installation of experimental equipment follows the procedures shown in figure 3-D. Equipment assembly and initial checkout are performed in the Airborne Science laboratory. The

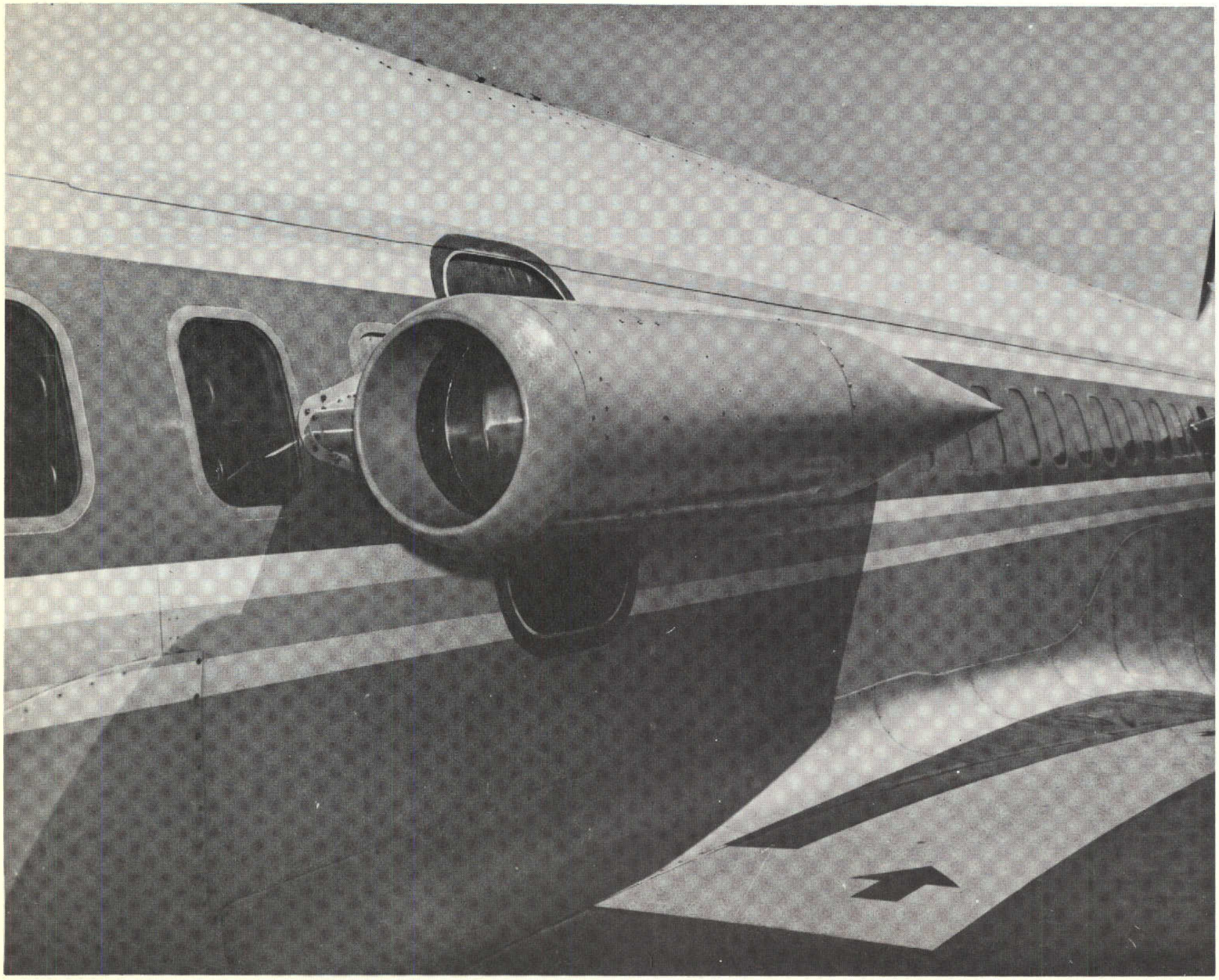


Figure 3-C. External housing for clear air turbulence experiment, August 1972 mission.

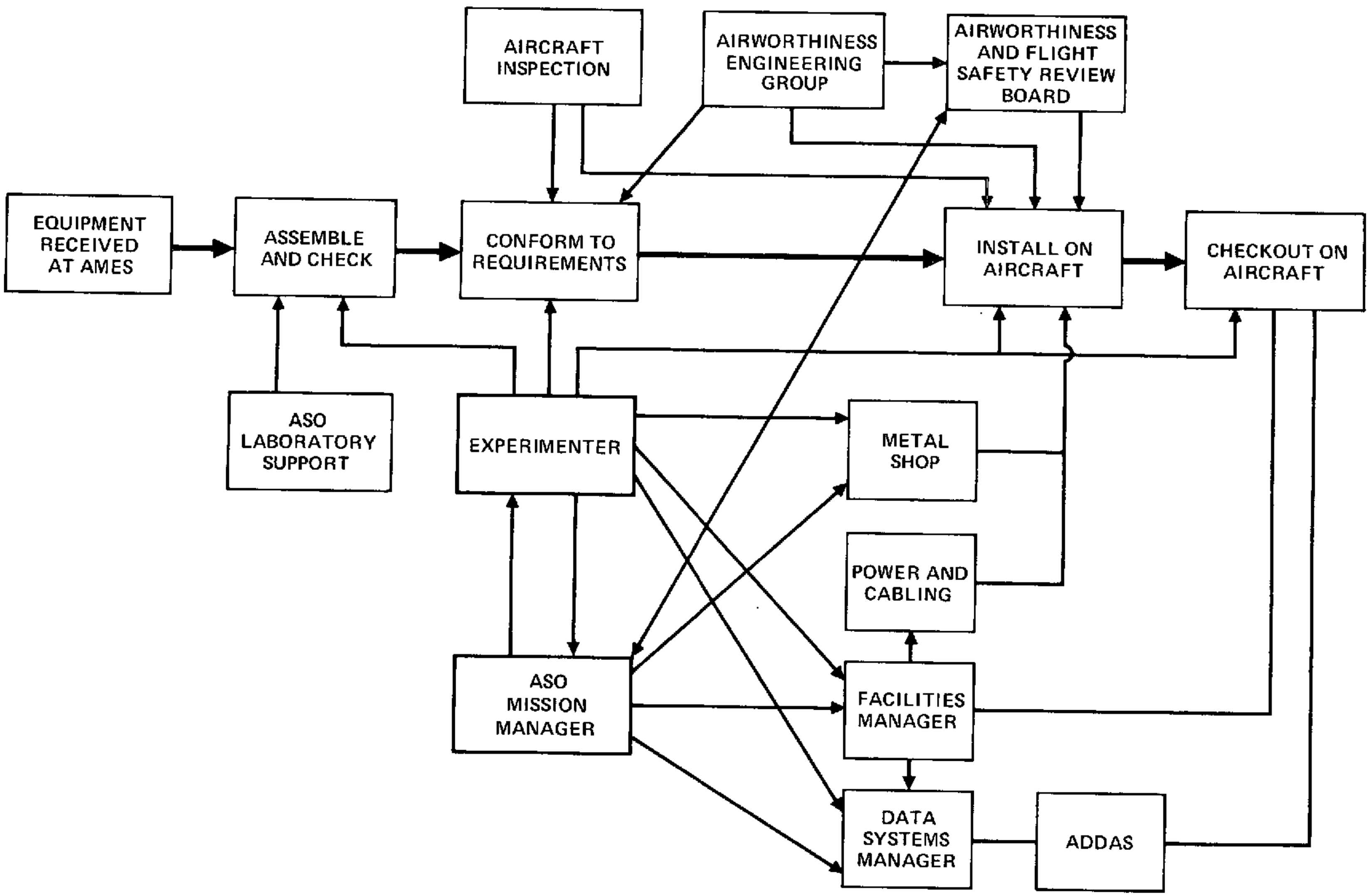


FIGURE 3-D. EXPERIMENTAL EQUIPMENT INSTALLATION PROCEDURE

experimenter is provided with bench space and tools, if needed. Vacuum pumps and cryogenics are available, approved aircraft fasteners are on hand for assembly, and basic equipment is available for simple machine work.

The assembly period in the ASO laboratory may be the first opportunity for experimenters to meet one another, and it often leads to fruitful discussions of mutual problems. The mission manager monitors the progress of each experimenter and arranges for special support needs.

An aircraft inspector and a member of the Airworthiness Engineering Group make a first check of the equipment for conformance to aircraft standards and indicate any necessary modifications. When the standard racks are used, there generally are few problems except the improper use of hardware. Special mounts occasionally necessitate additional bracing.

Following inspection, the equipment is loaded onto the aircraft. The physical handling of equipment is done by technicians from the Metals Fabrication Branch (fig. 3-E). Under the direction of the aircraft facilities manager, ASO support technicians connect the necessary cables between power outlets and equipment racks and between experiments and the ADDAS. The experimenter monitors and assists in the installation. After completion of the aircraft installation, the experimenter verifies the operation of his equipment, now powered through the aircraft systems, in the presence of other functioning experiments, and tied to the onboard computer systems.

A final preflight inspection is always made of each experimental installation in the aircraft. It may be decided at this time that additional bracing is required for equipment mounted on top of racks. The aircraft inspector also checks to ensure that each rack is separately grounded and that each separate piece of equipment is electrically bonded to a rack or other suitable ground. No mission can pass this point without the written approval of the Airworthiness Engineering Group and the aircraft inspector for each experiment installation.

Before any CV-990 mission can be undertaken, the Airworthiness and Flight Safety Review Board meets with the mission manager, pilots, and in special cases, experimenters for a review of all experiment designs, operational and contingency plans, and any other factors related to the safety of the mission and its equipment. All experimenters are required to attend a briefing concerning safety procedures for the aircraft; if pertinent, special survival equipment for overwater and arctic flight is discussed. Finally, there is a general experimenters' meeting with the mission manager to discuss the installation, any remaining problems, and the flight plans.

CV-990 Mission Operations

Each mission begins with a pilot check flight, which serves as a check on aircraft maintenance and allows the flight crew to evaluate any new installations pertinent to aircraft operations. During these flights, each experimental installation is carefully inspected for evidence of excessive vibration in response to normal aircraft operations.

The second flight, normally a local flight, provides an initial operational shakedown of the various experiments and an opportunity for new experimenters to become accustomed to the aircraft environment.

Figure 3-E. Equipment rack lifted into CV-990 cabin.

Subsequent flights are the data flights to meet mission objectives. The mission manager coordinates activities and provides information to the experimenters, but avoids interfering with their work. Experimenters may request changes in the flight plan during a flight, and if the navigator and the pilots agree, such changes can be and frequently are made. This degree of flexibility in flight planning is an important ingredient in the success of a mission.

A mission may run on a fixed schedule of flights, or it may have a variable schedule subject to weather or other parameters. When decisions on flight scheduling are required, the mission manager, the navigator, the pilots, and any concerned experimenters confer as to the desirability of a flight on a given day.

The mission manager has the prime responsibility for the entire mission and is coordinator of all research activities. He is the vital interface between experimenters and flight crew, between mission and base support personnel, between airborne experiments and participating ground stations. To assure mission success, he works closely with the command pilot, who has direct responsibility for aircraft operations, to reprogram for unforeseen delays. He is also the senior Ames representative for matters of policy and procedure in contacts with outside organizations.

In the field, the mission manager adapts his plan and procedures to suit the climate of the mission. It is normal to have a daily experimenters' meeting, attended by representatives of the flight and ground crews, to review the previous flight, dispose of problems, and discuss future plans. The mission manager also has frequent meetings directly with the flight and the ground crews to keep informed of the aircraft status and to confer with them on scheduling. In these and many other ways, the mission manager provides the focus and impetus to make the mission go.

Lear Jet Missions

Lear Jet Mission Development

Experiments utilizing the Lear Jet follow the same general steps as those on the CV-990, except that only one experiment and a maximum of two inflight experimenters are involved at one time (see appendix E). There can be no mission manager or other support personnel aboard; the command pilot coordinates inflight operations and research activities. Thus, the Lear Jet operation is somewhat simpler than that of the CV-990.

The experimenter is provided a Lear Jet Experimenters' Handbook, similar to that for the CV-990. Again, the necessity to conform to aircraft practice in construction is emphasized by the mission manager. Standard fixtures are used to adapt electronic equipment to aircraft racks. The experimenter, particularly if new to airborne research, visits Ames as early as possible to become familiar with the aircraft environment and meet the support personnel with whom he will work.

Other activities during this period include frequent contacts between the manager and the experimenter, evaluation of proposed experimental equipment, and the development of preliminary flight plans on the basis of experiment requirements. Before shipping his equipment, the experimenter is expected to send drawings and a stress analysis of his experiment. In addition, Lear Jet experimenters are required to attend a high-altitude indoctrination course, arranged by the ASO manager (see Section 9). Experimenters' Bulletins are unnecessary because of the very small number of people involved.

The scheduling of experiments on the Lear Jet is much more flexible than on the CV-990. Lead times are shorter and experiment development schedules often slip, requiring rescheduling of one or more experiments.

Approximately two weeks before his arrival at Ames, the experimenter confirms with the mission manager any special equipment (e.g., special brackets, cryogenics, a vacuum pump, or heliostat, etc.), experiment weight, electrical power requirements, and flight schedule. Finally, the manager issues a work order requesting the necessary installation services for the particular experiment.

Lear Jet Mission Operations

A first-time experimenter is usually assigned a two-week period on the Lear. Much of the first week is taken with assembly and inspection of his equipment, as well as any modifications indicated by the aircraft inspection and airworthiness engineering representatives. There also may be aircraft interface problems to be solved. By the end of the first week, a typical experiment is aboard the Lear and ready to fly.

Practice flights for familiarization and experiment shakedown are encouraged, but not always performed. Operation of a Lear Jet flight is much more informal than that of a CV-990. Flight plans are prepared in advance, for the aircraft does not carry a navigator, and when changes are indicated the experimenters interact directly with the pilots via the aircraft intercom system. Lear Jet flights are a maximum of three hours, with no more than two hours observing time. Experiment weight and cabin space are far more restricted than on the CV-990, and perhaps below those proposed for an experiment station in the Shuttle Sortie laboratory. Further details of this operation are given in appendix E and reference 1.

The ASO Management Approach and Shuttle Sortie Planning

The ASO management approach outlined here can serve as a basis, both in concept and in practice, for a new experiments management plan tailored to the Shuttle Sortie research environment. The unique features of the ASO approach may be summarized as follows:

1. Complete involvement and participation of the experimenters in the entire project.
2. The experimenter acceptance of total responsibility for the successful operation of his experiment.
3. Use of scientists as program managers.

4. Maintenance of a research environment at all times.

5. Minimum ASO interference in the experimenter's work.

6. Continuity and centralization of management in the same small staff (2 to 6 people), resulting in a single point of contact between experimenter and management throughout the entire mission.

7. Minimum documentation.

8. Participation of the program manager in the CV-990 flights as mission manager.

9. Physical proximity of the ASO, the experiment installation, and the flight operations facilities.

This management approach has been demonstrated to be productive of high-quality research at relatively low cost, for a wide spectrum of experiments and experimenters, in two widely different modes of operation, over a period of nine years. The motivated scientist, it has been shown, is capable of moving into the flight environment, with full responsibility for his experiment, to accomplish his research objectives on his first airborne mission.

References

1. Mulholland, Donald R.; Reller, John O., Jr.; Neel, Carr B., Jr.; and Mason, Robert H.: Shuttle Sortie Simulation using a Lear Jet Aircraft, Mission No. 1, NASA TMX-62,283, December 1972.

Section 4

THE EXPERIMENTER AND ASO MISSION MANAGEMENT

The primary advantage of direct and full involvement of the research scientist is that the experiment is at all times under his direct control; the authority and responsibility rest with one person who is willing to stake his professional reputation on the outcome, and is motivated accordingly. When maximum experimenter involvement is combined with a streamlined, informal operations plan – conducive to implementation by small research groups in a time span of a few months – the base is laid for a highly flexible program that can be adapted to experiments from many different scientific disciplines, with a minimum of formal reviews, coordination, and documentation to prepare for a mission.

The conduct of an experiment in the airborne laboratory is analogous to ground laboratory research: similar advantages accrue when the originating scientist is in direct command. His background of experience and know-how are immediately available to optimize operation for local conditions, to analyze anomalous results, to isolate a defective component, to modify the research plans, and to decide on improvements for subsequent operation. His presence makes the experiment self-contained, in effect, since real-time or immediate postflight data evaluation ensures the continuity of valid scientific results. All these factors combine to achieve maximum scientific productivity with a relatively modest investment in manpower and considerable economy of design.

This section explores the experimenter's role in the Airborne Science Office (ASO) research program and his relationship with ASO management staff and policies. It is this area of ASO experience in flight research management that has the most direct application to the Shuttle Sortie planning process. Thus, the emphasis in this section is on that critical relationship between scientist and manager, and the respective responsibilities of each at the various stages of an airborne mission. The technical details of each stage are left to other sections as referenced herein.

The Airborne Platform as a Research Tool

An airborne experiment begins when an established scientist in some relevant field of research decides that an airborne platform either will enhance his present results or is the only reasonable vehicle for performing a new experiment. The reasons for using an airborne experiment platform are varied. Infrared astronomy research in the longer wavelengths cannot be performed on the surface of the earth because of atmospheric absorption of the incoming signals. An airborne platform may be needed to survey the surface of the earth, as in the development of an instrument for satellite use, or for rapid measurements of soil moisture and ocean chlorophyll, or even for visual observations of whale migrations. It can be used to make wide-ranging studies of dust particles and trace-gas contaminants in the upper atmosphere, or as a camera platform for observing astronomical phenomena not visible from easily accessible land areas. Whatever the reason in a particular case, the potential experimenter must weigh the possible gain against the effort required; in this decision, two favorable factors are the relative simplicity of ASO procedures and the prior in-the-field experience (as opposed to in-the-laboratory) of the scientist. If he has field research experience, the experimenter is better able to plan and carry out the preparations for an ASO mission since he is aware of the kinds of operational and maintenance problems to be encountered.

Mission Proposals and Planning

As discussed in sections 2 and 3, an experimenter can contact the ASO, informally, for information relative to his experiment plan, its suitability for airborne research, and the schedule of research flights in future months. He might join a mission now in the early planning stage, or his interest may initiate consideration of an entirely new flight series. As it turns out, most of the experimenters in the Lear Jet program are university scientists operating under NASA grants, while the CV-990 aircraft has been used in recent years by scientists more from NASA and other government agencies than from universities. Foreign scientists are encouraged to take part in these programs.

In his formal proposal, the experimenter (principal investigator) outlines his research objectives, the measurement techniques, the required flight parameters and logistics, the anticipated environmental constraints, and the physical parameters of his test equipment. In the general case, several of these become the subjects of negotiation with the ASO mission manager early in the mission planning stage. For example, flight planning for the CV-990 requires coordinating several flight requests into a single program, which may not exactly suit any one experimenter; in the Lear Jet program, the proposed volume or power of an experiment may exceed practical limits. The compromises necessary in a particular case will be determined, in part, by the priority assigned to the experiment. In most cases, the ASO manager is able to accommodate surprisingly diverse objectives within a single mission; only rarely must a secondary experiment be eliminated. By frequent, informal contacts with the mission manager, the experimenter keeps abreast of mission planning activities.

Experiment Development

The experimenter has the entire responsibility in the design, fabrication, and prooftesting of the airborne experiment. A brief summary of the experimenter/ASO relationship in this area is given here; more technical details of experiment design and construction are given in section 5.

To meet aircraft safety limits, the experimenter must conform to the requirements given in the Experimenters' Handbook, as well as practical limits on experiment size and weight imposed by aircraft parameters. Certain arrangements, such as position relative to viewing ports and power requirements, are negotiated with the program manager. Otherwise, the individual is free to select his equipment from whatever source, to do whatever testing he thinks appropriate, and to arrange his schedule in whatever way suits his in-house support, within the established time frame for submission of design information to the ASO and the arrival of the equipment at Ames.

The wise experimenter will consult at frequent intervals with the ASO manager not only to clarify areas of uncertainty but also to make use of services the manager has at his disposal. These services include consulting and design input on mechanical, optical, electronic, and data systems from specialists within the ASO or on the center staff. Much of this consultation is done informally by telephone contact with the specialist involved. On occasion, special arrangements can be made to fabricate complex equipment supports at Ames.

When the experiment design has been fixed, the experimenter submits the appropriate information for a safety review by ASO and others in sufficient time for return recommendations to be implemented before shipment to Ames. In this one area, flight safety, he must accede to ASO management.

The experimenter is not obliged to document or report the results of his proof testing, although he is at liberty to consult with the ASO manager or directly with support specialists on matters of concern to him. Other than the aircraft and its environment, ASO does not normally provide test facilities in support of an experimenter's test program.

In the simplest case, the experimenter, as the principal investigator, will perform the entire job himself. If one or more assistants are needed as alternates or as specialists in a given area, they must be selected and trained by the experimenter during the development period. (ASO normally does not furnish personnel to operate experiments in flight.) The ASO staff involved in the preparatory period includes the mission manager, sometimes an assistant manager, a flight-planner/navigator, a mechanical engineer, the CV-990 facilities manager, and the ADDAS programmer.

Experiment Installation and Checkout

As individual scientist or team leader, the experimenter plans certain activities for the two- to three-week preflight period at Ames. In some form, they include assembly, operational checkout, and calibration; this process is augmented by the safety inspections outlined earlier. Any required changes to meet safety standards must be accomplished (with ASO assistance, if required) before installation on the aircraft.

Installation of components and subassemblies is normally done by the experimenter, assisted by ASO personnel and others in special mechanical and electrical hookups. At this time, the experimenter must verify that his equipment is operating satisfactorily on the aircraft power system, on the CV-990 ADDAS computer system, and in the presence of other electrical devices; if not, he is responsible for devising a remedy, by one means or another. The ASO manager and his support personnel stand ready to assist as time permits, but the experimenter provides the direction.

The interfaces between ASO management and the experimenter reach a personal level during the installation period. All ASO staff assigned to the mission are now working full time on it, many spending almost all their time in the ASO laboratory or on the aircraft rather than in their offices. During this period, the aircraft (either the CV-990 or the Lear Jet) is usually parked in a back corner of the hangar, adjacent to the buildings housing the ASO offices and laboratory; a communications link is provided between the offices and the aircraft cabin. The shop facility of the Metals Fabrication Branch, which handles the physical installation of the experiments, is 50 meters away on the other side of the hangar. The Flight Operations Branch, which provides the flight crew is also housed in the hangar building. Thus, the aircraft and all the organizations, personnel, and facilities directly involved in the operation are concentrated under one roof (see fig. 3-A), which enables the ASO manager to keep in close touch with the progress of the installation and gives the experimenter ready access to support capabilities as needed.

Inflight Mission Responsibilities

A formal experimenters' meeting is held just before the first data flight. The expedition plan is reviewed; and flight plans, their priorities, and logistics arrangements are discussed. Once a CV-990 flight series begins, an experimenters' meeting is held between successive flights for discussions of prior results and plans for the next flight. These meetings are attended by all the experimenters, the ASO support group, and representatives of the flight crew and the ground crew.

During the flights, the common, continually open intercom channel provides an effective real-time interface between the mission manager and the experimenters' team. When the flight program occurs at a remote base, the interface among the expedition members often is greatly enhanced by virtue of common housing, dining, and recreational facilities, which encourage impromptu encounters and discussions.

The in-mission role of the experimenter is roughly the same in both the Lear and the CV-990 programs. He operates and maintains the experiment, with the support of his operations team (if any) and ASO personnel as available. In the Lear Jet program, he will perform some of the duties of a mission manager: requesting the desired flight conditions, specifying the target of observation, reviewing the flight plan with the pilots, and working closely with them in flight to assure the best viewing opportunities. Throughout the mission, he keeps abreast of the research data to facilitate planning for subsequent flights. He accedes to the command pilot in matters concerning the safety of flight operations, and works closely with the Lear Jet manager in maintaining the flight schedule.

In the CV-990 program, on the other hand, overall mission operation is supervised by the mission manager, while the command pilot is responsible for aircraft safety and operations. The experimenter functions as a member of a group of scientists, each taking an active part in the mission. The mission manager keeps the scientists informed on the progress of the flight and the mission, so they may plan their work for maximum benefit; in turn, he must be informed when an equipment problem occurs so he can assist in corrective action.

During the inflight observation period, the level of the experimenter's activity varies widely with the experiment from an occasional look at the data to a continuous monitor-and-adjust mode. The number and rank of experiment personnel vary considerably. Most experiments involve one or two people; one large complex experiment was attended by a team of six. Available information on team composition and leadership is summarized in table 4-A. Direct participation of the principal investigator (P.I.) is shown to be a normally accepted practice, but it is interesting to note that such participation decreased as the team size increased — from 80 percent for one-man teams to a low of 30 percent for teams having three or more members.

In the event of a malfunction, the experimenter must try to locate and resolve the problem in time to resume data recording. Frequently, the problem is relatively minor, and with some adjustment or unit replacement the operation can be resumed, even if the data are somewhat degraded. The CV-990 experimenter has a greater opportunity for success in correcting a malfunction than does his counterpart in the Lear Jet; by its nature, the CV-990 mission allows the experimenter more time and room to work in, as well as the assistance of an ASO electronics technician. On both types of aircraft, however, the majority of inflight failures of a more serious nature are repaired on the ground between flights (Section 8).

Almost without exception, the airborne experimenter makes provision for a quick look at his research results. A monitor oscilloscope or a strip chart recorder is commonly used, and the ADDAS record is sometimes scanned for real-time results. Preliminary data reduction is accomplished between flights, unless this activity is precluded by the need for equipment maintenance, and film records are developed and examined. Through these means, the experimenter achieves a high degree of self-sufficiency in his work, and enhances the success of the mission.

Postmission Activities

At the conclusion of a mission, the experimenter removes his equipment from the aircraft and packs it for shipment to his laboratory. CV-990 scientists fill out their data package with copies of ADDAS printouts and magnetic tapes as required for future reference, and often arrange with fellow experimenters to exchange information.

Documentation of research results as such is not required by ASO, although the experimenter may be obligated by the terms of a funding grant from NASA to submit a technical summary. (The technical monitor of most such grants is the ASO program manager.) Out of professional courtesy, most experimenters keep the ASO manager informed of their findings, both informally and with copies of scientific papers and publications.

In a very real sense, preparation for a mission often begins with the end of the previous one. The experimenter must evaluate his results, plan any changes or recalibration of equipment, troubleshoot problems and effect repairs, and otherwise assure the quality of his research. The ASO manager in turn makes a point of keeping in touch with experimenters to discuss their

TABLE 4-A. MAKE-UP OF EXPERIMENTER TEAMS

SIZE OF TEAM	NO. OF TEAMS		TEAM LEADERS					OTHER MEMBERS	
			P.I.*						
	NEW	REPEAT	NEW	REPEAT	ASSOC. SCIENTIST	OTHER PROFESS.	TECHNICIAN	PROFESSIONAL	TECHNICIAN
1	3	12	2	10	3	0	0	0	0
2	5	16	4	10	4	1	2	12	9
3	4	7	3	5	3	0	0	8	14
>3	1	6	1	1	5	0	0	24	4
TOTALS	13	41	10	26	15	1	2	44	27

* AS LISTED IN PROPOSAL

TEAM LEADERSHIP

P.I.*	ASSOC. SCIENTIST	OTHER PROFESS.	TECHNICIAN
67%	27%	2%	4%

TEAM COMPOSITION

ASSOC. SCIENTIST AND OTHER PROFESS.	TECHNICIAN
62%	38%

results and informally lay the groundwork for future missions. On the basis of their data evaluations and discussion with ASO staff, experimenters will plan experiment improvements in anticipation of future flight opportunities, and in both the Lear Jet and the CV-990 programs, a substantial portion of the research teams return for further work. (The cycle time for the Lear Jet can be only a few weeks, whereas for the CV-990 it is months to a year or more, depending on the phenomenon to be observed.)

There are a number of inputs to postmission evaluation and planning for future work. Immediately after the flights, for example, the ASO manager confirms that the experimenter has obtained whatever aircraft support data he needs (navigational data, experimenter's data out of the ADDAS, and other aircraft performance data). He may serve as a clearinghouse for the exchange of significant events and "first-look" data among the experimenters. He may help to arrange a symposium at which the experimenters report their findings, and he will issue postmission Experimenters' Bulletins as they are warranted.

Recommendations for the Shuttle Sortie Program

1. A close working relationship should be established between experimenters and management staff and maintained throughout the entire program.
2. Management staff should be small but have full knowledge of the project and the authority to provide experimenters with quick, decisive answers.
3. Offices of the management staff and of the major supporting group should be located as close as possible (preferably within the same building) to the place where the experiments are installed in the Sortie Lab (or the payload carrier) so that they are readily accessible to the experimenters.

Section 5

EXPERIMENT HARDWARE DESIGN, DEVELOPMENT, AND TESTING

Shuttle Sortie missions will require a variety of experiments capable of reliable operation for at least five to seven days. This section outlines experiment hardware requirements, level of development, and complexity, as derived in an evaluation of data obtained from experiments flown in the Airborne Science program during the ASSESS study phase, April to November 1972, which included 79 experiments distributed over 22 missions and 119 flights, for a total of 505 experiment-flights. Experiments flown during the ASSESS period were also evaluated in terms of constraints imposed on experiment design and construction by the aircraft environment and safety considerations, assembly procedures, and testing, both at the experimenter's laboratory and following installation of the equipment in the aircraft. Differences between the Lear Jet and the CV-990 are noted.

Assessment of Experiment Hardware

Hardware Classifications and Level of Development

For purposes of evaluating experiment hardware requirements, a level of detail was established that identified blocks of equipment providing a major functional service and that could be uniformly applied to all experiments under study. These blocks of equipment were usually packaged separately and could be identified in the aircraft installation of the experiment. Where the package of equipment and the functional role were not integral, the package of equipment was established as the component. Each major component thus defined was further classified according to the source from which it was obtained. In some marginal cases, the predominant hardware source was the deciding factor. (A detailed identification of the individual components is included in the appendixes.)

Hardware classifications were based on the following definitions:

<u>Off-the-shelf</u>: cataloged commercial equipment

<u>Modified-commercial</u>: off-the-shelf equipment modified by a commercial firm or the experimenter's staff

<u>Custom-commercial</u>: equipment produced to a set of specifications by a commercial firm

<u>Experimenter-built</u>: equipment made in the experimenter's home facility

Each experiment was also characterized as to its state of development and its complexity. The former is an indicator of successful data acquisition with a relatively trouble-free, low-effort operation; the latter is a measure based on the number of equipment pieces involved.

Table 5-A specifies, on a per-experiment basis, the percentage of components in each major experiment group that are off-the-shelf, modified, custom, and experimenter-built. Several trends are evident from these data. First, the majority of experiments have more than one-half off-the-shelf components; mission averages varied from 34 to 79 percent, with overall averages similar for Lear Jet (59 percent) and CV-990 experiments (55 percent). Those lowest in off-the-shelf equipment relied most heavily on custom-commercial sources; more than one-third of their components were of this type. Modified-commercial units were seldom used, in fact, none at all were observed in Lear Jet experiments. Experimenter-built items averaged less than one out of four, with a noticeably larger amount used in Lear experiments. As illustrated in the appendixes, the experimenters clearly preferred to use off-the-shelf components wherever possible and to build their own interconnecting terminal boards and switching panels as required. Experimenter-made components often were associated with the detecting or sensing device of the experiment.

Information gathered from experimenters indicated that, in general, Lear Jet experiments were not so highly developed as those on the CV-990. As shown in the data summary, only 14 percent of the experiments on the Lear Jet were judged to be highly developed, while 63 percent of those on the CV-990 were in this category.

DATA SUMMARY

Aircraft	Experiment development state distribution		
	Low	Medium	High
Lear Jet	43%	43%	14%
CV-990	24%	13%	63%

Experiment complexity also varied with the aircraft; as indicated in the next summary, Lear Jet experiments were mostly of medium complexity, in contrast to those of the CV-990 where complexity tended to be medium to high.

DATA SUMMARY

Aircraft	Experiment complexity distribution		
	Low	Medium	High
Lear Jet	18%	82%	0%
CV-990	24%	47%	29%

TABLE 5-A. SUMMARY OF EXPERIMENT CONSTRUCTION

RESEARCH PROGRAM	MISSION	NO. EXPMTS.	TYPE OF CONSTRUCTION, % OF TOTAL			
			OFF-THE-SHELF	MODIFIED COMMERCIAL	CUSTOM COMMERCIAL	EXPERIMENTER BUILT
LEAR JET	ALL	17	59	0	17	24
CV-990	AIDJEX	13	42	9	43	6
	OCEAN COLOR	13	79	1	13	7
	AUGUST 1972	7	59	11	16	14
	METEOR SHOWER	16	34	8	36	22
	NOVEMBER 1972	13	70	6	4	20
	ALL CV-990	62	55	7	24	14

Equipment-Related Parameters

Table 5-B summarizes data on equipment-related parameters obtained during the study phase of the ASSESS program. These parameters include experiment weight, volume, power, cost, and number of operating personnel.

The accuracy of the data varied according to their source. The volume data were obtained primarily by measurement and hence are fairly accurate. Weight and power data are based on experimenter measurements and estimates.

The cost data, obtained largely from experimenter estimates, vary widely, and range from only hardware costs for most experiments to the full spectrum (in just a few cases) of items associated with an experiment development program. As an aid in interpreting these data, a detailed cost breakdown was prepared for one of the most complex and expensive experiments (table 5-C). This experiment is characterized as being in an early stage of development and contains a large number of predominantly off-the-shelf and custom-commercial components.

The data in table 5-B provide a preliminary measure of the magnitudes and distribution of the parameters listed in a variety of experiments. The environmental factors and interior configuration of the aircraft in which these experiments were flown are sufficiently similar to those proposed for the Shuttle Sortie Lab as to give the cost data some utility in the initial planning of experiments for the space laboratory. The cost items in table 5-B are subject to the reservations noted; the detailed breakdown in table 5-C may provide some guidance in the planning process.

Experiment cooling

Cooling is required to maintain equipment temperatures within acceptable limits. In most cases, it is necessary to remove the heat equivalent of all or most of the power supplied to the experiment. For experiments in which detectors and cold-load references must be cooled to cryogenic temperatures, the excess heat from these components is a small fraction of the heat generated by the experiment and thus can be handled by a cryogenic sink. Heat that is not absorbed by a cryogen is transferred to the cabin air by natural and fan-produced forced convection. For the laser-containing experiments, where high-density heat dissipation occurs, mechanical refrigeration was used. Experiments that used mechanical refrigeration or cryogenic, rather than the more common natural and forced convection cooling, are listed with relevant system data in table 5-D. The two laser experiments that had mechanical refrigeration also used cryogenic systems.

Components of some experiments flown on the CV-990 exceeded acceptable temperature limits and required temporary fixes. As indicated in table 5-E, the most common method to mitigate the over-temperature condition was to duct cooling air from the aircraft ventilation system to the component. One experiment used dry ice packed around the overheated component.

Any overheating condition in an airborne experiment would tend to be aggrivated in the Shuttle environment because of the lack of natural convection currents in an orbiting vehicle. For

TABLE 5-B. EQUIPMENT RELATED PARAMETERS

EXPERIMENT	VOLUME $(m)^3$	WEIGHT (kg)	POWER (kW)	IN-FLIGHT PERSONNEL	COST ($)
LEAR JET EXPERIMENTS					
GROUP 1 (VISIBLE ASTRONOMY)	0.57		0.5	1	26,500 (1)
GROUP 2 (METEOR DUST)	0.20			2 and 1	18,600 (1)
GROUP 3 (IR ASTRONOMY)	0.23	225	1.5	2	
GROUP 4 (IR ASTRONOMY)	0.31	225	1.5	2	86,000 (2)
GROUP 5 (IR ASTRONOMY)	0.23	180	1.7	2	115,000 (2)
GROUP 6 (IR ASTRONOMY)	0.62			2	43,000 (1)
GROUPS 7 AND 8 (IR ASTRONOMY)		195	0.45	2	
CV-990 EXPERIMENTS					
19.35 GHz IMAGING MW RADIOMETER				1	35,000 (1)
1.42 GHz MW RADIOMETER	0.07	56		1/3	
4.99 GHz MW RADIOMETER	0.07	64		1	30,000 (1)
37 GHz MW RADIOMETER	0.07	40		1/3	35,000 (1)
10.69 GHz MW RADIOMETER				1/4	40,000 (1)
MICROWAVE SPECTROMETER				1/4	
SOLAR PHOTOMETER		7		1/4	
RS-310 IR IMAGER				1/3	
9.3 AND 31.4 GHz MW RADIOMETERS (2 EXPERIMENTS)				1/4	40,000 (1)
LASER GEODOLITE				1/3	
SINGLE AND MULTICHANNEL IR RADIOMETER	0.93	100	0.2	2/3	
Al_2O_3 HYGROMETER	0.02		0.58	1	
2 EBERT SPECTROMETERS AND IR PHOTOMETER (3 EXPERIMENTS)	0.91			2 1/2	
MULTICHANNEL OCEAN COLOR SENSOR				3	
3 MULTICHANNEL DIFFERENTIAL RADIOMETERS		33		1	5,000 (1)
DIFFERENTIAL TELEVISION			0.23	1	50,000 (1)
TWO IR RADIOMETERS	0.91	91	0.17	1	17,000 (1)
SURFACE COMPOSITION MAPPING RADIOMETER (SCMR)				1 1/2	
ATMOSPHERIC SAMPLING SYSTEM (ASP)	0.76	345	2.0	2	
STRATOSPHERE AIR SAMPLING (SAS)	0.57	91	1.5	2	150,000 (1)
LASER TRUE AIR SPEED SYSTEM (TAS)			0.18	2	40,000 (2)
RAPID SCAN EBERT SPECTROMETER	0.91			2	
CLEAR AIR TURBULENCE (CAT)	3.31	940	7.72	6	445,000 (1)
IR SKY EMISSION	1.13	180	0.35	2	
METEOR SPECTROSCOPY (2 EXPERIMENTS)		102	0.01	2	
METEOR SPECTROSCOPY AND CHEMICAL RELEASE (6 EXPERIMENTS)	2.11	400	1.0	2	325,600 (2)
METEOR SPECTROSCOPY AND CHEMICAL RELEASE (2 EXPERIMENTS)	0.41	189	0.58	1	96,000 (2)
METEOR SPECTROSCOPY	0.37	165	1.45	2	
CHEMICAL RELEASE PHOTOGRAPHY				1	
AURORAS AND SKY BRIGHTNESS (2 EXPERIMENTS)				2	
RANGE:	0.02-3.31	7-940	0.01-7.72	1/4-6	5000-445,000 (1)
TYPICAL:	0.58	150	1.0	2	

NOTES: (1) Hardware cost
(2) All costs

TABLE 5-C. SAMPLE COST BREAKDOWN FOR COMPLEX EXPERIMENT

ITEM		COST(THOUSANDS)	COST(% OF TOTAL)
DESIGN		$ 60.0	8.5
HARDWARE		444.9	65.1
EXTERNAL FAIRING AND WINDOW	40.5		
OPTICS AND LASER	200.4		
POWER SUPPLIES	51.4		
COOLING SYSTEM	1.2		
LASER MONITOR ELECTRONICS	2.6		
DETECTOR AND SIGNAL ELECTRONICS	148.8		
RECORDERS	20.0		
ASSEMBLY AND CHECKOUT		75.0	10.6
IN-HOUSE TESTING		25.0	3.5
FLIGHT PREPARATION AND TESTING		100.0	14.3
	TOTAL	704.9	100.0

TABLE 5-D. EXPERIMENT SPECIALIZED COOLING SYSTEMS

EXPERIMENT (MISSION AND NUMBER)	COOLING SYSTEM	COOLING REQUIREMENT
	MECHANICAL REFRIGERATION	
CLEAR AIR TURBULENCE (AUGUST 1972, 3)	REFRIGERATION SYSTEM FOR LASER	DISSIPATES 100-200 WATTS
TRUE AIRSPEED SYSTEM (OCEAN COLOR, 13)	REFRIGERATION SYSTEM FOR LASER	DISSIPATES ~ 200 WATTS
	CRYOGENICS	
RS-310 IR IMAGER (AIDJEX, 10, OCEAN COLOR, 6)	LIQUID NITROGEN COOLING FOR DETECTOR	~ ½ LITER PER FLIGHT (6 HOURS)
SURFACE COMPOSITION MAPPING RADIOMETER (OCEAN COLOR, 9)	LIQUID NITROGEN COOLING FOR DETECTOR	~ 1 LITER PER FLIGHT (6 HOURS)
TRUE AIRSPEED (OCEAN COLOR, 13)	LIQUID NITROGEN COOLING FOR DETECTOR	~ LITER PER FLIGHT (6 HOURS)
FAR INFRARED SKY EMISSION (AUGUST 1972, 4)	LIQUID NITROGEN, HELIUM AND HELIUM 3 COOLING FOR DETECTOR (DOUBLE JACKET)	HELIUM 3 CYCLED AND HELD; ~ 2 LITERS NITROGEN PER FLIGHT (6 HOURS) (LIQUID HELIUM AND USED TO LIQUEFY HELIUM 3 ON THE GROUND)
CLEAR AIR TURBULENCE (AUGUST 1972,3)	LIQUID HELIUM FOR COOLING DETECTOR	~ 1 LITER PER FLIGHT (6 HOURS)
4.99 GHz MICROWAVE RADIOMETER (OCEAN COLOR, 3)	LIQUID NITROGEN TO COOL COLD-LOAD REFERENCE	~ 4 LITERS PER FLIGHT (6 HOURS)
19.35 GHz MICROWAVE RADIOMETER (OCEAN COLOR, 1)	LIQUID NITROGEN TO COOL COLD-LOAD REFERENCE	~ 2 LITERS PER FLIGHT (6 HOURS)
37 GHz (ZENITH) MICROWAVE RADIOMETER (OCEAN COLOR, 1)	LIQUID NITROGEN TO COOL COLD-LOAD REFERENCE	~ 2 LITERS PER FLIGHT (6 HOURS)
MICHELSON INTERFEROMETER (LEAR 4)	LIQUID NITROGEN FOR COOLING DETECTOR	~ 2 LITERS PER FLIGHT (2 HOURS)
INTERFEROMETER (LEAR 6)	LIQUID NITROGEN FOR COOLING DETECTOR	~ 2.5 LITERS PER FLIGHT (2 HOURS)
CRATING SPECTROMETER (LEAR 7)	LIQUID NITROGEN FOR COOLING DETECTOR	~ 2 LITERS PER FLIGHT (2 HOURS)
GRATING SPECTROMETER (LEAR 8)	LIQUID HELIUM AND NITROGEN FOR COOLING DETECTOR	~ 5 LITERS* (GOOD FOR 15 HOURS) 3 LITERS LN_2 INITIAL COOL-DOWN
FABRY-PEROT SPECTROMETER (LEAR 3)	LIQUID HELIUM AND NITROGEN FOR COOLING DETECTOR	~ 2 LITERS PER FLIGHT* (2 HOURS) 3 LITERS LN_2 INITIAL COOL-DOWN
IR RADIOMETER (LEAR 5)	LIQUID NITROGEN AND HELIUM FOR DETECTOR	~ 2 LITERS OF LIQUID HELIUM ~ 3 LITERS OF LIQUID NITROGEN FOR INITIAL COOL-DOWN (GOOD FOR 6 HOURS WITH PUMPING)

* ABOUT 50 PERCENT LOST DURING FILLING

TABLE 5-E. EXPERIMENT OVER-TEMPERATURE PROBLEMS

EXPERIMENT	COMPONENT	COOLING SOLUTION
DIFFERENTIAL TELEVISION SYSTEM (OCEAN COLOR, 5)	COLOR TV MONITOR	CABIN COOLING AIR DUCTED TO OVER-TEMPERATURE COMPONENTS
	POWER SUPPLY	CABIN COOLING AIR DUCTED TO OVER-TEMPERATURE COMPONENTS
CLEAR AIR TURBULENCE (AUGUST 1972,3)	HIGH VOLTAGE POWER SUPPLY AND ONE OSCILLOSCOPE	NONE, OVER-TEMPERATURE ACCEPTED
STRATOSPHERIC AIR SAMPLING (AUGUST 1972, 1)	GAS PUMP	COOLED WITH DRY ICE

the same reason, some experiments that were adequately cooled on the CV-990 flights would tend to develop overheating problems on the Shuttle. Thus, data from CV-990 experiments on problems of overheating and means of solving them may not be directly applicable in Shuttle planning.

Experiment Design

Experiments flown in the Airborne Science program, unlike those in unmanned satellites, operate in a shirt-sleeve environment with the experimenter available to adjust, maintain, and repair his experiment during flight. Under these circumstances, it is possible to trade off the advantages of conventional design and construction practices against the increased risk of inflight problems. Standardized components can be used in experiment construction, and precautions to ensure the high maintainability and reliability of the experiment as well as requirements for costly, extensive, and detailed preflight testing and documentation, assume far less importance. The ASO need only impose constraints to ensure the safety of the crew, and operational checks to assure compatibility of experiments with the aircraft systems and with each other. Apart from these considerations, the experimenter is totally responsible for the success or failure of his own experiment.

A wide choice of alternatives in the design concept and the construction methods has been exercised in the experiments flown in the Airborne Science program. This range of options is a result of the variety of agencies funding the various experiments and their objectives in doing so, rather than the nature of the organization (e.g., industrial firm, government, or university laboratory) producing the experiment. A prototype of the equipment to be flown on satellites, for example, would demand extensive design, fabrication, and testing efforts on the part of the producing entity to meet the rigorous requirements of the funding agency. It is generally true, however, that industrial firms produced those experiments on which rigorous requirements are imposed, while those with lesser requirements were produced in government or university laboratories. Of the experiments observed during the ASSESS study phase, about 40 percent were produced by industrial firms and the remaining 60 percent by either government or university laboratories.

The experiment design requirements to be discussed first – those imposed by the aircraft, aircraft equipment, and the experiment hardware – apply to all experiments, irrespective of their source. These general constraints are outlined first, followed by a discussion of the typical procedures involved in the preparation of experiments by investigators from university and government laboratories, who have been responsible for the majority of experiments flown in the Airborne Science program.

The Aircraft Environment and Experiment Design

The safety of the crew and the aircraft is a major consideration in experiment design. Additional requirements depend on the performance, power, payload capability and equipment of the aircraft.

Safety provisions, which are mostly concerned with restraining the experiment in the aircraft under specified g loading, are specified in terms of allowable weight and overturning moment for equipment mounted in standardized equipment racks, which attach directly to the aircraft seat tracks (section 6). A proposed installation that exceeds these allowable values must be preceded by a stress analysis, furnished by the experimenter, which is used by Ames engineering personnel to determine requirements for additional equipment restraints (section 4). Stress analyses are also required for any other units not mounted in the equipment racks.

The Lear Jet imposes more stringent limitations than the CV-990 on the weight, space, and power available to an experiment. A maximum total weight in excess of 410 kg, allocated for the investigator and his experiment, will prevent the aircraft from reaching an altitude of 15 km. In addition, the small cabin accommodates only one experiment and, at most, two experimeters. Maximum power of 14 kVA is available. The CV-990, on the other hand, can accomodate from 8 to 12 experiments with their operators, and provides a maximum power of 54 kVA. (Details of aircraft capabilities are provided in section 6.)

The Airborne Digital Data Acquisition System (ADDAS) on the CV-990 handles some recording and computing functions that otherwise would have to be incorporated in the experiment design (section 7). This system displays the flight parameters for the experimenter on a continuous basis and also accepts the experimenter's data for onboard storage and computation.

Hardware Limitations on Experiment Design

The level of engineering effort required to prepare a given experiment for flight will vary. An experiment may be in a form suitable for airborne operation, it may require some modification, or it may require development or substantial reconfiguration. As indicated in the data summary, half of the experiments (48 percent) observed during the ASSESS study phase required development. The 36 percent that were ready to operate included many which were originally developed for ground-based research and had been in use for several years. If the experiment is ready to operate or requires minimum modification and can fit within the spatial accomodation of the aircraft, the basic configuration of the experiment controls the physical arrangement of its components. If the experiment is new, however, its configuration will be controlled primarily by the size and number of off-the-shelf and custom components, and by the spatial accomodations of its location on the aircraft.

The configuration of off-the-shelf and custom components is fixed; if the components cannot be mounted within a rack, their shape establishes the predominant configuration of the equipment. They can sometimes be mounted on top of the rack, which becomes a support platform (fig. 5-A). The experimenter-built components, such as electronic assemblies and data-handling systems, usually can be mounted within the standard equipment racks, and therefore have little influence on the experiment configuration (figs. 5-B and 5-C).

DATA SUMMARY

Experiment category	Percent of total experiments
Required development	48
Required modification	16
Ready to operate	36

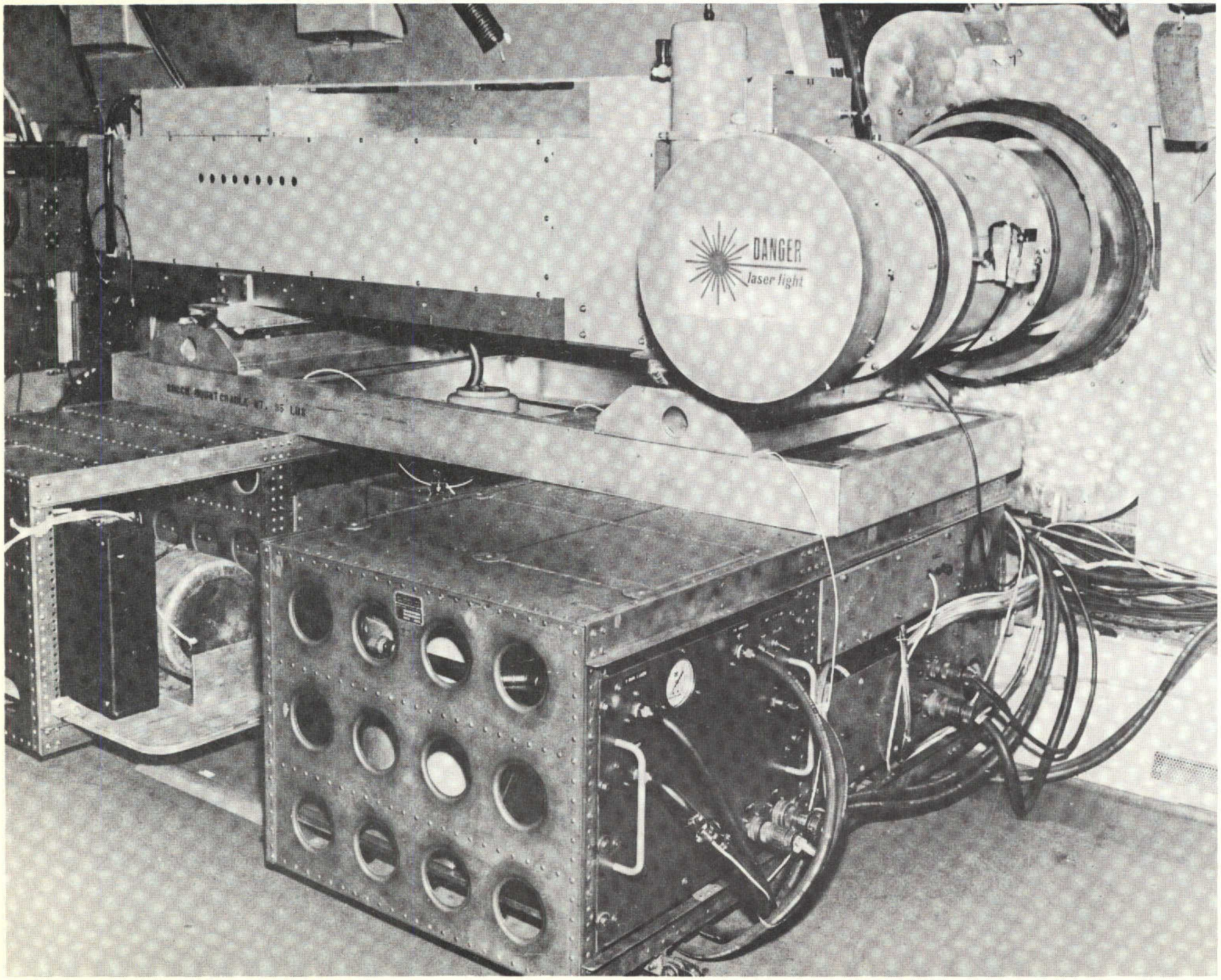


Figure 5-A. Rack-mounted experiment in CV-990 aircraft.

Figure 5-B. Typical installation in CV-990 equipment rack.

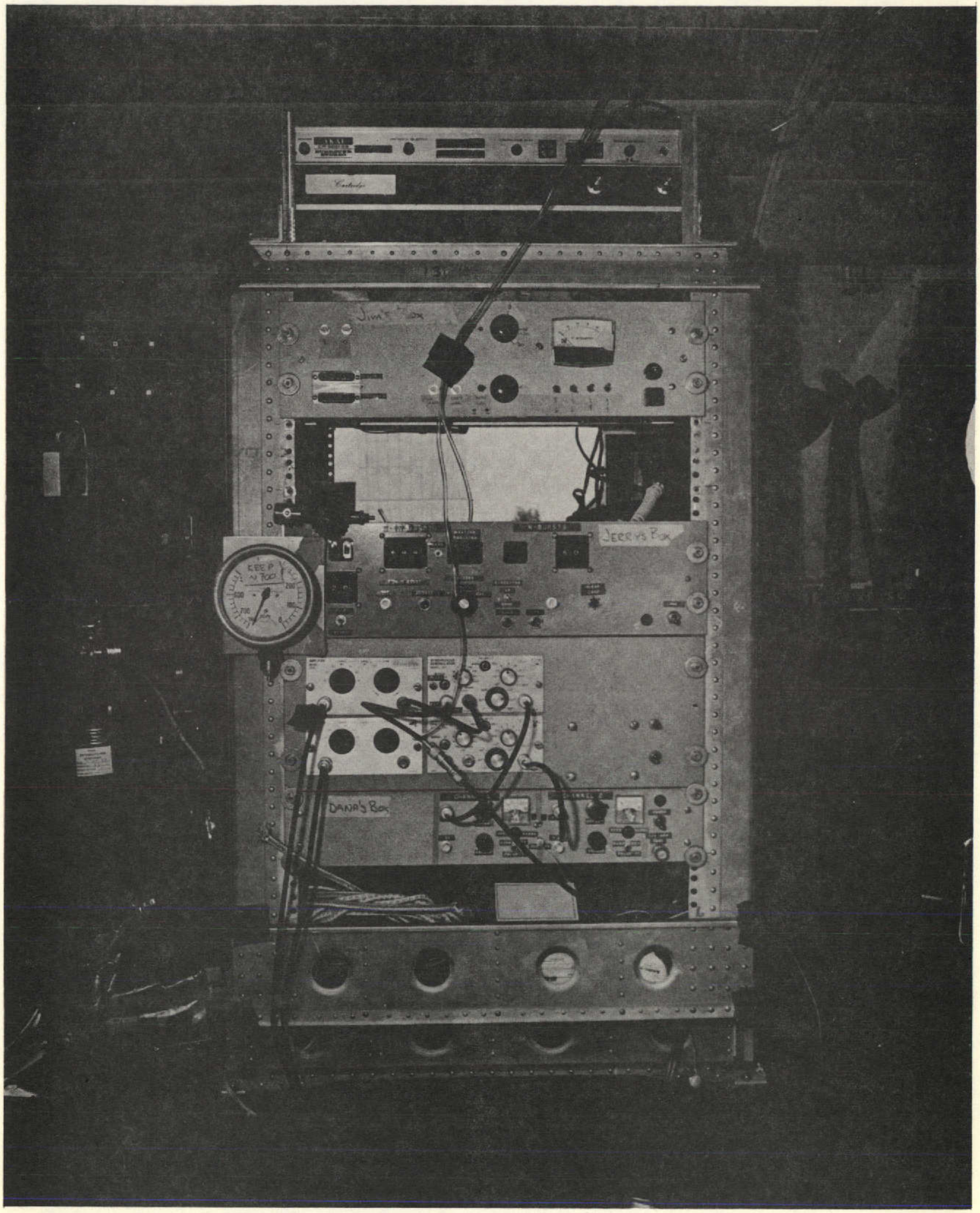


Figure 5-C. Typical installation in Lear Jet equipment rack.

Experiment Development

Staffing

The typical experiment development group comprises the principal investigator and his assistant, augmented as necessary by support and specialized personnel. The principal investigator may have conceived the experiment or have been an active associate of its developer. He is totally responsible for the design and construction of his equipment and for compliance with the requirements established by the ASO.

The small number of personnel required to design, assemble, and test the experiment minimizes the need for documentation, drawings, and specifications. Sketches, and block and circuit diagrams are usually the primary documentation required to maintain communications within the group and for procuring additional material and technical assistance. Occasionally, formal engineering drawings will be prepared for this purpose.

Communication between the experiment development group and the ASO on administrative details is maintained by the principal investigator and the ASO manager. Communication of technical information is usually accomplished by the cognizant personnel from each group.

Components Selection and Testing

The experimenter may construct all new equipment for his experiment; he may use equipment he has available from previous experiments; or he may procure commercial or custom equipment. In most cases, the experimenter uses a combination of these sources.

Off-the-shelf components are the least costly and most readily available. If the investigator cannot achieve a desired result with off-the-shelf equipment, his next choice usually is customized commercial equipment; in most instances a complete new unit is specified and built, less often an existing commercial unit will be modified.

When a specialized component has to be developed (e.g., an IR detector for astronomical observations) it is not infrequent that the experimenter has the required skills to produce either a better or a less expensive component than he can buy. Usually, such development effort is limited to the detecting or sensing device of the experiment, with additional effort going into the associated cooling apparatus and mounting holder. The detection device is usually electronic, and the experimenter will assemble it using largely commercially available parts. Beyond this, the usual procedure is to assemble off-the-shelf, custom, and any developed components into a system with interconnecting terminal boards and custom-made switching panels to meet the unique requirements of his own experiment.

Most components are tested by the experimenter at his laboratory, although some specialized, procured components are tested by the components manufacturer. This effort generally consists of basic operational tests using common electronic measuring equipment such as volt-ohm meters, oscilloscopes, and frequency counters. Thermal, vibration, and other environmental tests are often used with components for engineering models of experiments being developed for application to commercial aircraft or satellites. About 6 percent of the experiments reviewed during the ASSESS study phase were of this type.

Experiment Development Time

Experiments used extensively at ground-based laboratories have been installed in aircraft and flown in a matter of days; many of the camera experiments used in the Meteor Shower mission fall in this category. The opposite extreme is the sequential development of a 30-cm infrared telescope over a period of five years. In this case, the instrument was producing valuable astronomical data within two years of inception, but was continually being improved over the five-year span. The other experiments fall between these extremes, with the typical experiment requiring from about five months to a year to complete.

The major factors in development time are the complexity of the experiment and whether the experiment is advancing the state of the art in its field of application. One example is the time required to develop a complex stabilized IR telescope, compared to that required to develop the individual sensor packages that attach to the telescope. Preparation of the sensors now takes about five months; to develop the telescope to its present state of refinement took about five years. An experiment pushing the state of the art – for example, the clear air turbulence experiment – required more than three years to develop to the first-data stage because of the necessity of resolving many new problems.

Historically, the time period for the development of a typical experiment observed in this ASSESS study is short in comparison to most experiments used in satellites. This demonstrated efficiency of experiment development is a consequence of the experimenter in-flight concept and the attendant procedures implemented in the Airborne Science program.

Experiment Testing and Checkout

An important consideration in the planning of Shuttle Sortie missions is the amount of effort that an experimenter expends to verify, to his own satisfaction, that his experiment performs reliably and to the accuracy required by his research objectives. The major portion of this activity (and to the greatest depth) normally occurs in the home laboratory, where individual components and functional units can be tested prior to integration, and where special equipment is available for tests of the complete system. Pre-installation activity at Ames is usually at the checkout level – operational and calibration checks. Once the experiment is installed in the aircraft, the influence (if any) of aircraft electrical and avionic systems on the experiment, as well as electrical interference between experiments, must be evaluated. Finally, the checkout flight exposes the equipment to the entire mission environment for the first time.

Airworthiness and flight safety checks follow a parallel development under the direction and approval of Ames personnel. If the experimenter has done his homework well, the initial assembly, the post-installation inspection, and the inflight checkout will confirm the mechanical and electrical integrity of the installation.

The planning and execution of these testing and checkout activities is the responsibility of the experimenter. This fact and the varied research objectives of the experiments caused a wide variation in the amount of developmental and preflight testing among the experiments observed during the ASSESS study phase.

Testing in the Experimenter's Laboratory

Laboratory testing ranges from none to an occasional, extensive program approaching the full spectrum of satellite test procedures. At the low end of the scale are experiments that have been used extensively in ground observations or in flight, and whose reliability is known beyond question (e.g., much of the camera equipment used on the CV-990 Meteor Shower mission). Higher on the scale are those that have flown before but have new components or have been modified. Next are the newly developed experiments, which must be proven reliable. At the top of the testing scale are a few engineering models of experiments, being developed for use in satellites or commercial aircraft, that have been through an extensive testing program. Two extreme cases of this type were observed to require more than 100 man-days of testing.

Table 5-F identifies the type and average amount of testing effort for these experiment groups. Something like one man-day was spent on experiments that had been in frequent use, new experiments had an average of 5 man-days of testing, and engineering development models averaged 10 man-days (not including the two mentioned above). This amount of effort is really insignificant by comparison with any current space experiments, yet in ASO programs it has proven adequate for all but a few cases, reflecting the individual experimenter's ability to make a realistic assessment of the testing effort actually required.

Much of this testing effort represents operational (shakedown) testing of the complete experiment, with some time devoted to calibration. On seven experiments, tests of thermal, vibration, and radio-frequency sensitivity were performed. In some 15 other cases there were one or two environment-simulation tests to determine the response of the detector unit to vibration, temperature, gas composition, or electrical interference. One experimenter recorded sound levels in the aircraft cabin and played them back at his experiment to test the audio sensitivity of his equipment. Except for the thermal, vibration, and radio-frequency interference evaluations, most of the tests used simple equipment, such as optical targets with collimated light sources, electrical-measuring equipment like volt-ohm meters, oscilloscopes, and calibration equipment such as constant-temperature sources. In at least one case the calibration signal output was recorded and a computer was used to analyze the data.

Examples of problems exposed in these tests include slow detector response, electrical overheating, or vacuum leaks – all malfunctions that could be readily corrected in the laboratory but not in flight. For further details see section 8 and appendixes A through D.

Testing at Ames Research Center

Pre-installation tests. All experiments flown in the Airborne Science program are carefully checked before flight, regardless of the amount of testing accomplished at the home laboratories. The first experiment check is usually an operational test in the ASO laboratory to ascertain

TABLE 5-F. PRE-MISSION EXPERIMENT TESTING

EXPERIMENT CLASS	% OF TOTAL NO.	TESTS AT HOME LABORATORY			TESTS AT AMES		
		COMPONENTS AND SUBSYSTEMS	COMPLETE EXPERIMENT	AVERAGE MAN-DAYS (APPROX.)	EXPERIMENT ONLY	EXPERIMENT IN AIRCRAFT	AVERAGE MAN-DAYS (APPROX.)
ENGINEERING DEVELOPMENT MODEL	15	OPERATION AND ENVIRONMENT	OPERATION CALIBRATION ENVIRONMENT	10	OPERATION CALIBRATION SAFETY	OPERATION AND CALIBRATION A/C INTERFACES ENVIRONMENT SAFETY	5
NEW EXPERIMENT	6	OPERATION AND SOME ENVIRON-MENT	OPERATION AND CALIBRATION	5	SAME	SAME	2
FLOWN BEFORE; MODIFICATIONS OR ADDITIONS	49	OPERATION AND OCCASIONAL ENVIRONMENT	OPERATION AND CALIBRATION	2	SAME	OPERATION CALIBRATION ENVIRONMENT SAFETY	< 1
GROUND-BASED; NEW TO AIRCRAFT	16	OPERATION	OPERATION	<1	SAME	OPERATION AND CALIBRATION A/C INTERFACES ENVIRONMENT SAFETY	1
FLOWN MANY TIMES; NO CHANGES	14	NONE	OPERATION	<1	OPERATION	OPERATION CALIBRATION ENVIRONMENT	1/2

possible damage during shipment. These tests of the complete experiment system are performed, where possible, with the experiment installed in the equipment rack, approximately as it will be when flown. Complete-system tests for Lear Jet IR astronomy experiments must await installation on the aircraft, since the government-furnished telescope they use is installed on the aircraft.

Postinstallation tests. The next testing opportunity follows installation in the aircraft and is intended primarily to uncover installation-induced electrical interference from the aircraft or, in the case of the CV-990, from other onboard experiments. Checkout is made on the CV-990, both as experiments come aboard and are connected into the aircraft electrical system, and when the installation is completed. Interference problems are, in general, readily resolved with the assistance of experienced ASO personnel. It is common practice to make a final calibration of the complete experiment system at this time.

For experiments using the ADDAS system, the interface between the system and the experiment is not checked until the last stages of experiment installation; final verification of the computer program (when used to process signals from the experiment) is determined on the checkout flight.

The effort during these two phases of preflight testing ranges widely, from a few man-hours for calibration of a stratospheric air sampling experiment to 20 man-days for operational tests on a clear air turbulence experiment. Averages for the test effort expended on experiments are shown in table 5-F to vary from one-half to 5 man-days.

The experimenters usually furnish all required test equipment. In some cases, this capability is built into the experiment; on occasion, the ASO has furnished test equipment such as oscilloscopes and optical targets as well as photographic dark rooms and film processing facilities. Table 5-G indicates the type of support requested by experimenters during the preflight (and flight) periods by numbers of experiments requiring Ames manpower, extra parts, equipment, or facilities for preflight testing, experiment installation and mission ground support. Except for the Meteor Shower mission, relatively little support was supplied by Ames for missions during the ASSESS observation period. The Meteor Shower mission was unique in the large amount of specialized hardware required for mounting the experiments in the aircraft (appendix D).

Problems occurring during preflight testing at Ames are minor electronic failures, electrical pickup or interferences, and overheating of electronic packages. These types of problems are quickly resolved or so minor that their effects can be accepted by the experimenter.

Inflight tests. The mechanical integrity of each installation is verified by cognizant Ames personnel during the pilot check flight (no experiments aboard), which precedes the checkout flight. The checkout flight (with all experimenters aboard) may be a daytime engineering flight on the Lear Jet to check out the performance of subsystems in an astronomy experiment, or a flight in the CV-990 to exercise mission procedures in a flight plan and over targets that represent closely those to be observed in the data flight. In fact, the Lear Jet experimenter or the CV-990 mission manager may choose to incorporate this checkout activity in the first data flight, if locally based. In any event, the experimenter is allowed a day or two in which to make last-minute modifications to his equipment before the next scheduled flight; more often than not this time is well used.

TABLE 5-G. AMES EXPERIMENT SUPPORT

MISSION	TOTAL NO. EXPMTS.	PREFLIGHT TEST SUPPORT			EXPERIMENT INSTALLATION SUPPORT			MISSION GROUND SUPPORT		
		NO. EXPMTS. REQUIRING			NO. EXPMTS. REQUIRING			NO. EXPMTS. REQUIRING		
		MAN-POWER	PARTS	EQUIP. & FACILI-TIES	MAN-POWER	PARTS*	EQUIP. & FACILI-TIES	MAN-POWER	PARTS	EQUIP. & FACILI-TIES
AIDJEX	13	←NO INFORMATION→						0	0	3
OCEAN COLOR	13	0	0	1	9	2	3	0	0	1
AUGUST 1972	7	0	0	0	2	1	1	1	1	1
METEOR SHOWER	16	3	0	9	13	15	8	6	1	8
NOVEMBER 1972	13	0	0	2	2	2	2	←NO INFORMATION→		
LEAR JET	17	0	0	5	3	2	2	0	0	1

* PRIMARILY MOUNTING HARDWARE

Applications to the Shuttle Sortie Program

The experimenter who has much prior experience in airborne research or who uses an experiment he has frequently operated in ground-based research will seldom engage in more than a few hours of operational checkout. Conversely, certain engineering development models of experiments for potential use in aircraft or satellite applications may require many hours of environmental testing. On the average, however, a testing effort of 1 to 15 man-days appears commensurate with the research environment, and for this very reason is probably far less than would be undertaken for a Shuttle Sortie experiment.

Two points are of special significance: First, the ASO testing program is entirely at the discretion of the experimenter, except for flight-safety requirements, with ASO management acting in an advisory capacity. Second, in this relatively unrestrained situation, the average research scientist is a competent judge of the effort required to develop a successful airborne experiment, and he is sufficiently motivated by the anticipated research rewards to carry his experiment through to completion. By inference, and given the same general approach to experiment management, the greater challenge and rewards of Shuttle research should elicit a heightened response from participating scientists, limited only by their own institutional support.

Section 6

AIRCRAFT CHARACTERISTICS AND EXPERIMENT INTERFACES

The airborne environment differs from a ground-based laboratory in a number of important respects, including structural vibration, experiment power available, electrical noise, space and weight restrictions, and ambient pressure. These and other parameters influence both experiment design and operational procedures. Over the past several years methods have been developed in the Airborne Science Office (ASO) programs to aid the experimenter in matching his experiment with the special requirements of airborne operation and to ensure its successful performance in flight. Adaptation to the aircraft environment nonetheless poses a hurdle for the first-time experimenter.

Experimenters' handbooks for both the Lear Jet and the CV-990 aircraft discuss in detail many of the constraints imposed by flight and safety considerations on experiment design, as well as the interface characteristics of each aircraft and the support facilities provided for the experimenter. Design constraints are reviewed in this section. The various interfaces involved in airborne research experiments are identified, and examples are given of equipment problems peculiar to the airborne environment. Interface requirements of the CV-990 data-processing system are noted in section 7.

Aircraft Characteristics

Observation Time

The capabilities of each aircraft limit the maximum time available at altitude for scientific observations. Tradeoffs can be made among such factors as gross weight, payload, time, altitude, and range. For the CV-990 aircraft at the maximum takeoff gross weight of 108,000 kg, the payload varies up to 18,600 kg. At this weight, the range of the CV-990 is 4600 km; fuel capacity limits the aircraft's maximum range to 6100 km with a 9,500 kg payload. Maximum altitude depends on gross weight, which in turn fuel-limits the available observing time. For a typical payload of 6,300 kg, the variation of observing time with altitude varies from over 6 hours at 10 km to 2 at 12.2 km (fig. 6-A). The payload-time trade-off is about 5-1/2 minutes per 1000 pounds. The maximum operating altitude to date has been 13.7 km with a 2700 kg payload.

The Lear Jet has a maximum gross takeoff weight of 6,100 kg with a nominal payload of 450 kg and a range of 3000 to 3200 km. Again, maximum altitude is limited by gross weight, and observing time is fuel-limited from 2-1/2 to 1/2 hour as shown in figure 6-A. Thus, except for operation at near-maximum altitudes, observation times in either aircraft are sufficient for a quick look at the data and, if indicated, minor changes in flight plan. One advantage

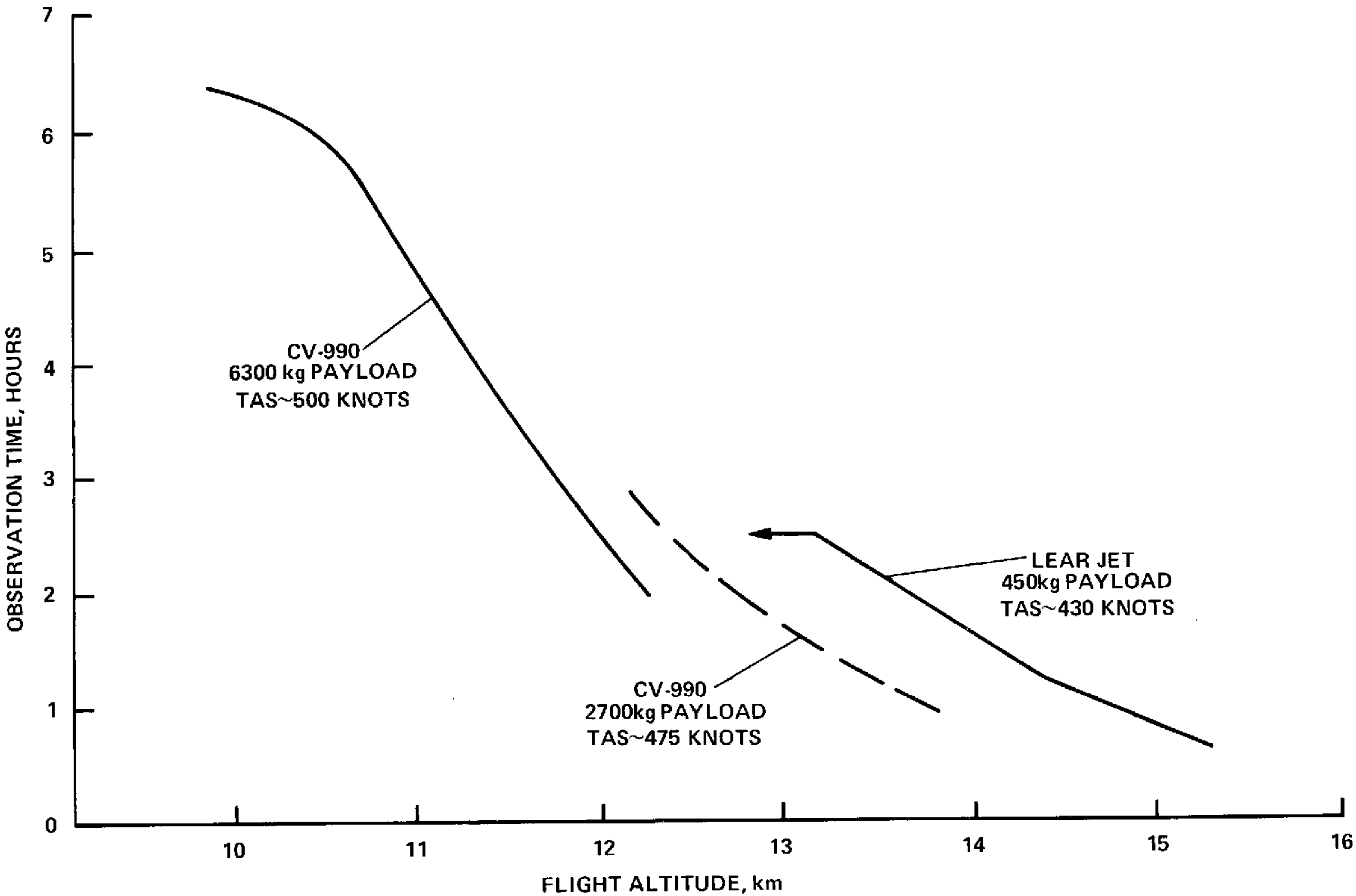


FIGURE 6-A. EXPERIMENT OBSERVATION TIME

of the CV-990 is that if an experiment problem develops, the experimenter may be able to effect a repair and resume operation during the flight.

Cabin Environment

The CV-990 cabin and cargo and electronic compartment are normally pressurized to about 2.45 km equivalent altitude when the airplane is at 12.2 km. The humidity in the cabin during flight averages about 10 percent and the temperature is held between 19° C and 24° C. It is possible to hold the cabin temperature within ±1° C of its nominal desired value. However, different parts of the cabin can vary in temperature by several degrees depending on air flow patterns and the location of heat-producing equipment. The experimenter is expected to supply any auxiliary heating or cooling devices required by his equipment (see section 5).

The temperature of the Lear Jet cabin air is about 22° C and the humidity about 5 percent. Cabin pressure is equivalent to an altitude of 2.45 km or less at aircraft altitudes up to 12.2 km in normal operation; when an open-port telescope is used the cabin-to-outside differential pressure is only 0.29 atm (4.25 psi) at all aircraft altitudes. In this case, and for all normal flights above 12.8 km, oxygen masks must be worn by experimenters during the entire flight. Experiments in either aircraft must be designed to operate at the stated ambient cabin pressures.

Aircraft Vibration

With very few exceptions, aircraft vibration has not seriously affected experiment operation. Under the transient conditions of takeoff and landing when vibrations are most severe, electronic circuit cards have been dislodged, hardware loosened, and electrical connections shaken off. In some cases, the quality of star images has been degraded slightly in flight by high-frequency vibrations. Some representative measurements of vibration power levels for a rack-mounted camera located near the center of gravity of the CV-990 aircraft are summarized below. At this location, peak values of g^2/Hz are around 10^{-4}; on the mounting rail in the cabin floor, the values are more like 10^{-3}; and at the most forward and aft experimenters' stations they are somewhat higher yet. (A definitive specification of the vibration spectra for ASO aircraft is in preparation.)

DATA SUMMARY

Direction	Peak values of power, g^2/Hz	Frequency, Hz
Fore-aft	7.0×10^{-5}	28
	1.2×10^{-4}	44
	7.0×10^{-5}	122
Up-down	1.1×10^{-4}	29
	1.3×10^{-4}	44
	5.6×10^{-5}	122
Left-right	3.6×10^{-4}	8
	1.3×10^{-4}	45
	3.7×10^{-5}	122

Limited information for the Lear Jet aircraft indicates vibration power levels about 10^{-4}, an order of magnitude less than those given for the CV-990, with the peak occurring at a frequency near 20 Hz.

The vibration environment of the aircraft has been the subject of increasing interest in recent experiment planning. Some experimenters are now considering the use of vibration isolators in the design of their equipment.

Aircraft Stability

The standard autopilot controlling the heading and the altitude of the CV-990 aircraft nominally limits motion to within ±2 degrees in pitch, roll, and yaw in smooth air. By special tuning of the autopilot (in advance) for an anticipated altitude, airspeed, and loading, the stability can be enhanced for relatively short time periods as follows:

Period, sec	Roll, arcmin	Pitch, arcmin	Yaw, arcsec
5	±12	±3	±6
100	±42	±6	±12

Gyro-controlled, two-axis image stabilizers (heliostats) are available to the experimenters. The linear stability of the line of sight is ±10 arcsec rms for periods of 180 seconds or more, and ±0.5 arcsec rms for periods of a few seconds, even in light turbulence.

The Lear autopilot system can be tuned to limit aircraft excursions in smooth air to less than ±1 degree in roll, pitch, and yaw. Additional platform stability can be obtained with the gyro-stabilized mirrors described above.

Aircraft Interfaces and Constraints on Experiment Installation

Load Factors

To assure sufficient internal strength of equipment to be installed in either of the research aircraft, a stress analysis is required for each experiment (section 4). Since construction defects usually cannot be corrected during installation, an experimenter may be required to withdraw at the last moment if his equipment does not meet the stated aircraft safety standards.

The load conditions listed below, applied one at a time, must not produce a stress in any element of the equipment (including racks, instruments, pallets, tie-down brackets, and carry-on-items) beyond the accepted yield point for the construction material. It is not required that alinement, calibration, or other instrumental functions be maintained under these conditions.

DATA SUMMARY

Load direction	Load factors, g: CV-990 and Lear Jet passenger cabins	CV-990 cargo areas
Forward	9.0	1.5
Down	7.0	7.0
Up	2.0	2.0
Side	1.5	1.0
Aft	1.5	1.0

Standard Equipment Racks

Standard equipment racks, which attach directly to the aircraft seat tracks, are available for the experimenter's use in assembling his equipment, either at his home facility or on arrival at Ames. (Other special mountings may be designed.) The racks will accept standard 19-inch (48.3 cm) electronic panels. (In special cases, it is possible to attach small units directly to the window frames of the CV-990 aircraft; ASO approval is required before any such use is planned.) The maximum allowable load for each track attachment is specified, as is the unit floor loading in aircraft cargo compartments.

The standard, double-bay equipment racks (fig. 6-B) for the CV-990 can accept a weight of 91 kg (200 pounds) per bay, provided the overturning moment for all components within the rack does not exceed 92 m-kg (8000 inch-pounds). Standard and "low-boy" racks may be used as support platforms; the loads and moments that result are subject to individual stress analyses. In the Lear Jet, the standard racks will accept 91 kg (200 pounds) of equipment, mounted inside or on top. The maximum allowable overturning moment is 55 m-kg (4800 inch-pounds).

The CV-990 rack configuration allows mounting of equipment fore and aft; on the Lear Jet, the equipment is positioned facing the center of the cabin. The location of equipment racks relative to CV-990 view ports is shown in figure 6-C.

A principal instrument frequently used on the Lear Jet is a 30-cm open-port telescope (fig 6-D), which is mounted in a special hatch replacing the portside passenger window and is supported by a framework mounted to the seat rail.

Aircraft structural fasteners must be used for all structural members and be secured by self-locking nuts or safety wire. Welding of structural members must conform to the MIL-T-5021C Specification. The use of eccentric holes or slots for mounting adjustments is not acceptable.

Space and Weight Constraints

On the CV-990, space is a limiting factor more often than weight, but neither constraint is serious. As many as 22 standard equipment racks may be installed in the cabin area, and additional space is available for experiment equipment in the two cargo compartments, the forward avionics

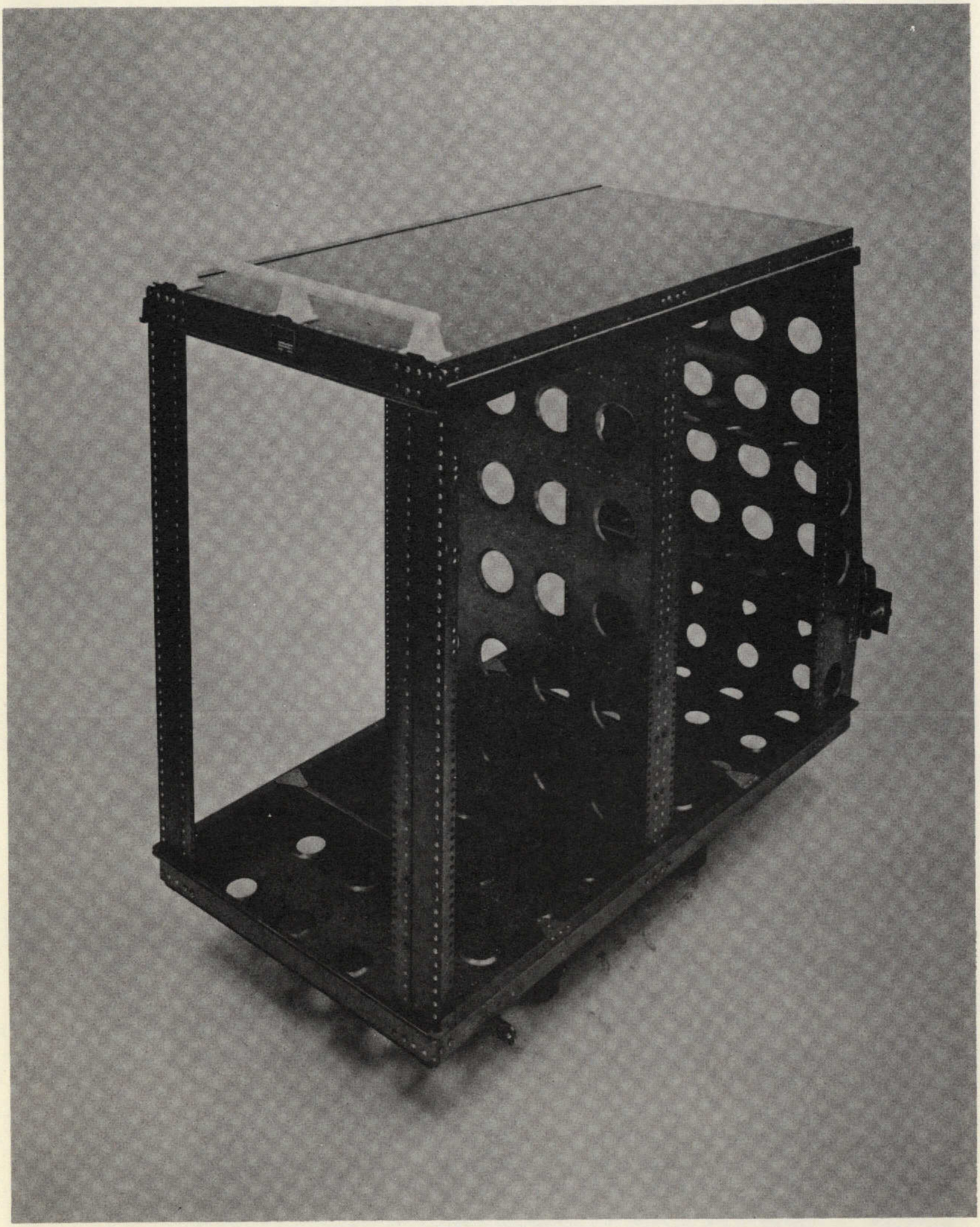


Figure 6-B. The CV-990 standard equipment rack.

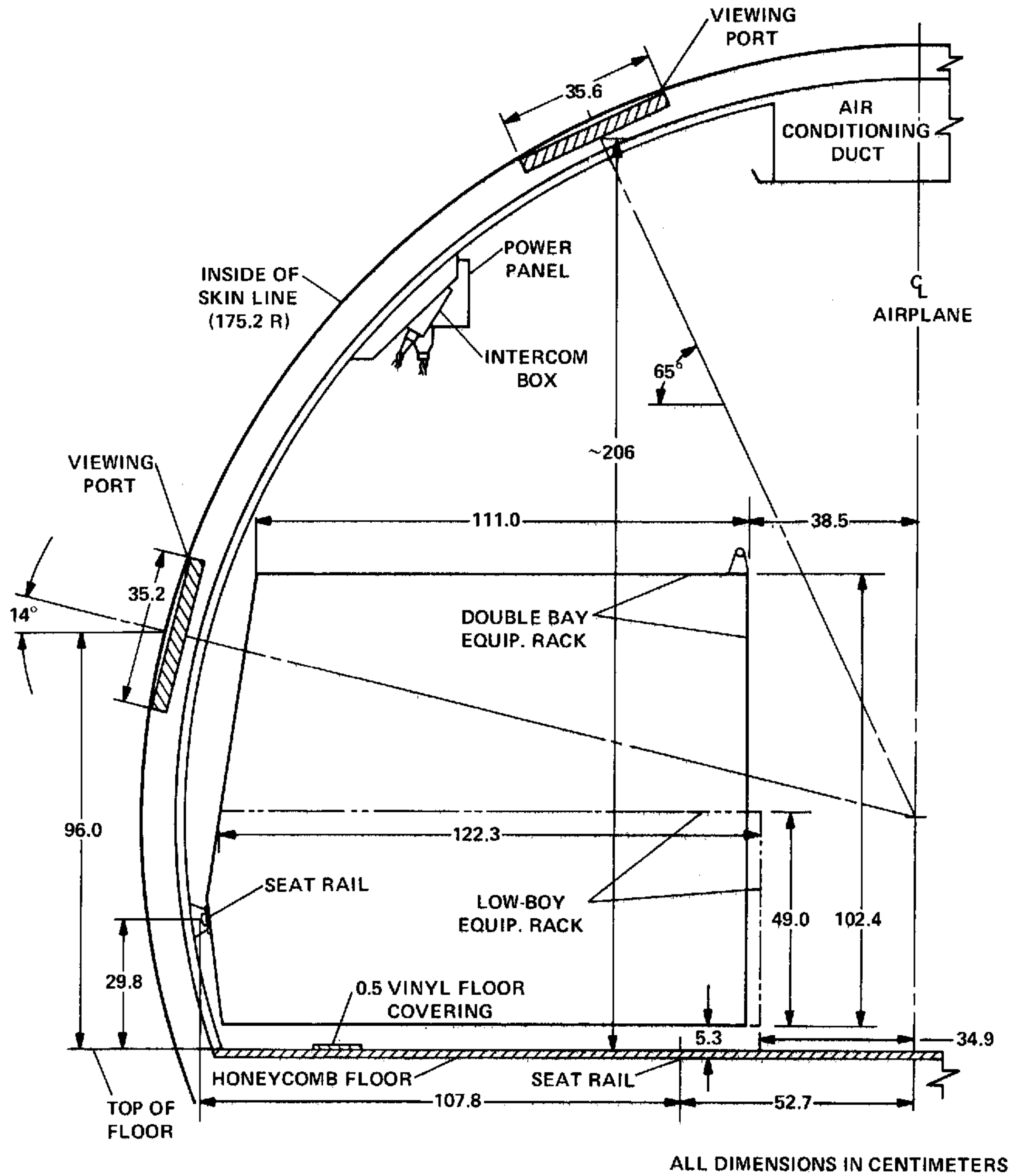


FIGURE 6-C. RELATIVE LOCATIONS OF EQUIPMENT RACKS AND VIEW PORTS, CV-990

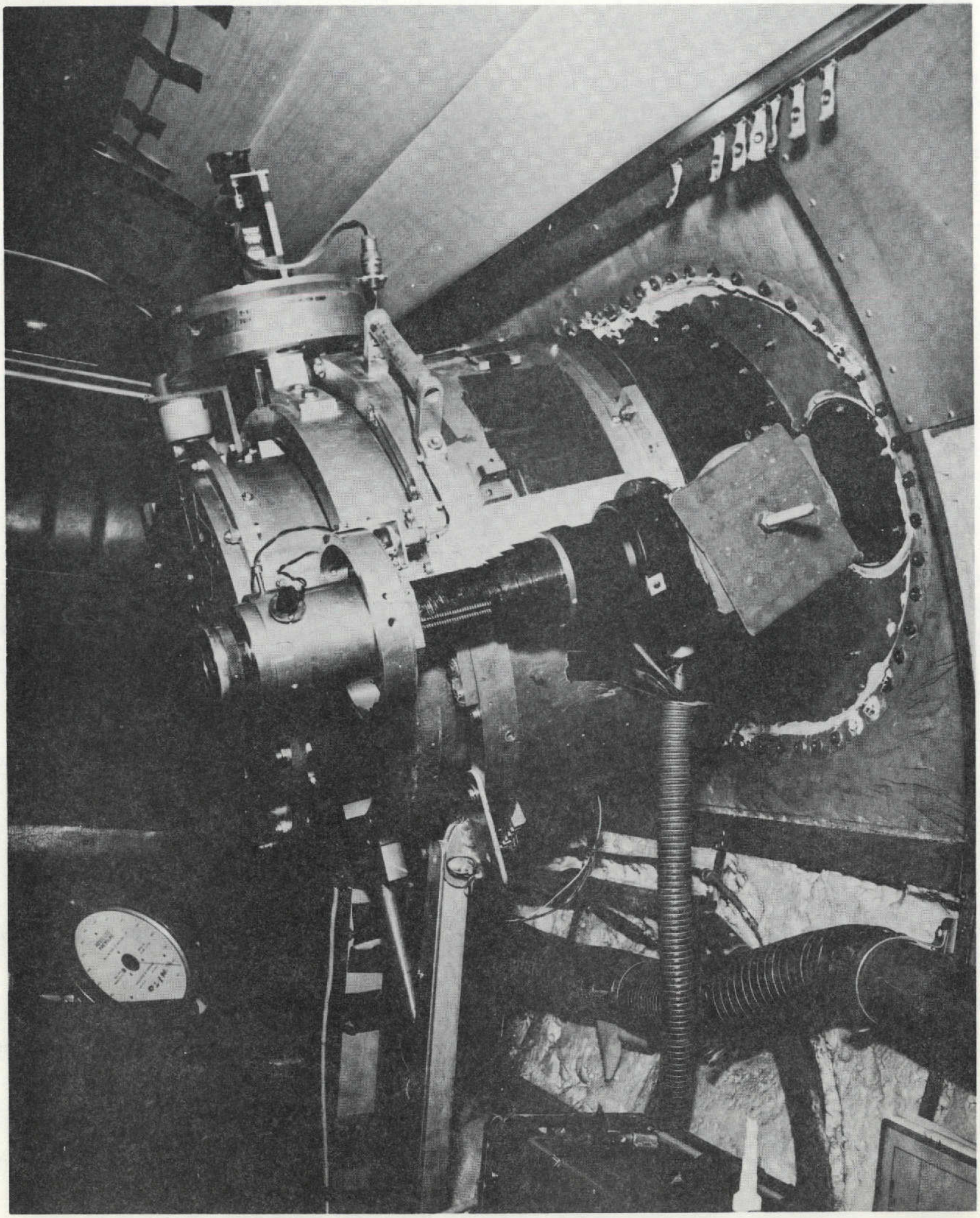


Figure 6-D. Infrared telescope in Lear Jet cabin.

compartment, and the unpressurized tail section. External custom mounts and fairings can be added to meet special requirements. The regular passenger windows and special ports can be fitted with metal plates for the support of special gear, such as a radiometer or an air-sampling probe.

Overall experiment weight is seldom a limitation on the CV-990. An average of 450 kg per experiment, or a total of 6,300 kg of scientific equipment, can be easily accommodated. Most experiment installations weigh much less than 450 kg each. One rare exception was a two-experiment, three-operator installation for flight at 13.7 km altitude; in this case, the total payload (all cabin equipment) was limited to 2700 kg. This capacity is comparable to that of the Shuttle Sortie Lab where experiment weight allowances of 3600 kg may be possible.

The Lear Jet is severely limited in both space and weight of experiment installations. The cabin volume is 4.25 cubic meters, about the minimum in which two people can work, and the weight of two experimenters and equipment should not exceed 410 kg. Any excess weight will reduce the ceiling altitude of the aircraft and thereby hamper astronomical observations in the far-infrared region.

Electrical Power

The basic specifications for experimenters' electrical power in the CV-990 are:

400 Hz ±1% at 200/115 V ±1.5%, 3-phase; 40 kVA available.

60 Hz ±0.25% at 115 V ±1%, single phase; 22 kVA available.

28 VDC, up to 0.50 kVA per unit; regulation depends on type of unit supplied.

The basic power source in the CV-990 is the aircraft engine 400-Hz generator; solid-state converters supply 60-Hz power. These converters do not have transient-overload capacity to accommodate equipment starting surges, and the accuracy and stability of the 60-Hz frequency are not sufficient for precise timing or other uses where an exact, stable frequency is required. The aircraft structure is the ground return for all power systems.

The basic power source in the Lear Jet is the 28-VDC aircraft engine generator, which supplies 200 amperes (maximum) for use as 28 VDC, or for conversion to 60-Hz and 400-Hz power by the use of inverters. These inverters are not part of the standard weight budget of the aircraft and must be included as weight of the experiment. The aircraft structure is the ground return for all systems.

High-voltage leads and components of experimental equipment must be sufficiently well insulated to prevent flashover. The normal cabin pressure in the CV-990 corresponds to 2.45 km pressure altitude, and breakdown distances are at least one-third greater at this reduced pressure than at sea level. In the Lear Jet even more care is required. When an open-port telescope is used the cabin altitude is approximately 7.6 km. At this pressure, breakdown distances are double those at sea level, and breakdowns have resulted from this increase in flashover distance at reduced pressure.

Sources of Interference

Avionics equipment. The aircraft avionics equipment is a possible source of interference to experiments. The frequency ranges of the various radio and radar equipment are listed in table 6-A. Experimenters are advised to design their equipment to prevent spurious response at these frequencies and to limit any output from their systems (e.g., telemetry) to 100 mW.

TABLE 6-A. FREQUENCY RANGES OF AIRCRAFT AVIONICS EQUIPMENT

Equipment	Range
CV-990	
Low frequency ADF	190 to 1750 kHz
High frequency	2.0 to 30.0 MHz
Very high frequency	118 to 135.9 MHz
Ultra high frequency	225 to 30.9 MHz
Marker beacon	75.0 MHz
Loran A	1.8 to 2.0 MHz
Doppler radar	8800 MHz
Weather radar	9375 MHz (X-band)
Radar altimeter	4200 to 4400 MHz
DME	1025 to 1150 MHz
Beacon receiver	9310 MHz
Lear Jet	
Low frequency	0.19 to 1.6 MHz
Very high frequency	108.0 to 150.8 MHz
Marker beacon	75 MHz
Weather radar	9310 and 9775 MHz

Experiments. In the CV-990, the mission manager operates the panel controlling the distribution of power to experiments. Arrangements can be made, within power limits, to group related experiments or to isolate an individual experiment on a separate converter, to avoid intermittent power surges or other undesirable phenomena.

On occasion, an electrical interference between adjacent experiments will develop. If a potential problem of interference is not recognized and avoided through changes in cabin layout, the experimenter will detect the problem during installation and checkout, and must then devise a solution that may be less satisfactory. The mission manager can provide support in this area, but a simple fix may not be possible.

Optical Systems

Twenty-one special viewing ports have been installed in the CV-990 fuselage at various elevations and longitudinal locations; 13 ports are at 65° elevation on the left side of the aircraft (fig 6-C), 2 are for zenith viewing, and 6 for nadir observations. In addition, nine of the standard passenger windows have been modified for special-purpose applications. These ports and windows are intended primarily for the installation of optical quality glass; defrosting systems and safety features are provided. Windows of several materials are available for use by experimenters; rarely the experimenter will furnish his own for special applications.

Each CV-990 optical window assembly (complete with frame and gaskets) is subject to environmental testing prior to installation, including application of a pressure differential of 1.84 atm (27 psi) at room temperature, and 1.31 atm (19.2 psi) with a 89° C (160° F) temperature differential. Optical data maintained on most of these windows include reflectance, transmittance, flatness, parallelism of faces, and the strains introduced in flight by the differential pressure between the cabin and outside atmosphere.

Auxiliary equipment includes optical wedges for use with 65° windows to allow zenith viewing, and the gyro-stabilized mirrors (33-by 57-cm oval) mentioned earlier.

In the Lear Jet aircraft, there are three cabin windows, two to starboard and one to port. Optical windows up to 36 cm in diameter may be mounted in special hatches designed for this purpose. Cabin air is ducted to the window area to prevent condensation. Optical windows are stocked and optical data files are maintained; the same environmental tests are performed.

On both aircraft, external surfaces that are in the field of view of optical devices have been painted a dull black to minimize the reflection of sunlight into optical detection systems. For astronomy missions, cabin curtains and individual shields afford protection from light at crew stations, and from adjacent experiments.

The Experiment/Investigator Interface

By the time an experiment is ready for shipment to Ames, the operational, reliability, and environmental tests are essentially completed. Maintenance units, special tools, and spare parts have been assembled. From now on, in a very real sense, the experimenter will be isolated from his accustomed sources of support and solely responsible for the outcome of his research. Under these circumstances, a two-man team is desirable; it permits a degree of specialization and is insurance against unforeseen problems. In practice, both men work together much of the time, so that each is familiar with the basic procedures in the other's specialty. Teams of principal investigator and scientist assistant, or scientist and technician are most common. In all but the most simple experiment, when problems occur during a mission, both men can be fully occupied with between-flight maintenance.

Once the mission is under way, the work day adjusts to the flight schedule. Each experimenter checks the operation of his equipment before each flight and usually spends some time calibrating and adjusting. Much of this is done in the hour before flight, and the remainder at scheduled periods when the experimenters have access to the aircraft on the ground. Inflight operation of CV-990 experiments is usually a full-time job, not so much in direct operation as in monitoring the performance and the data records. Lear experiments, on the other hand, often require full-time operation. Wide variations have been observed, however, from a simple experiment with occasional attention by a technician to a very complex one with four professionals and two technicians in attendance.

With regular monitoring, any fault in the equipment is quickly noted and correction procedure can begin immediately. Opportunities for repair are more favorable on the CV-990 than on the Lear Jet because of accessibility (space to work) and the presence of a support electronics technician. In either case, the experimenter carries basic tools and a few spare parts. As shown in section 8, most ordinary problems in experiments are repaired either in flight or in time for the next flight.

Section 7

INFORMATION HANDLING FOR AIRBORNE SCIENCE MISSIONS

Prime responsibility for handling the data rests with the experimenter. He must predict the nature of his data and either provide suitable units for recording and handling data as part of his experimental equipment or arrange with the Airborne Science Office (ASO) data-systems manager for data handling in the onboard computer system of the CV-990. Frequently he will do both. Thus, the variety of data-handling techniques is nearly as great as the number of experiments observed. In this area, the mission manager is available to consult and advise on the details of an experimenter's data plan, and can arrange for the experimenter to borrow some types of data recording apparatus, such as a CP-100 magnetic tape recorder, an audio tape recorder, and oscilloscopes.

The ASO is responsible for the operation (hardware) and programming (software) of the Airborne Digital Data Acquisition System (ADDAS) on the CV-990. This system is available to the experimenter for recording and limited processing of research data. At his own option, the experimenter may use the ADDAS as his primary recording system and provide suitable monitors and/or backup recorders as part of his own equipment. Alternately, the experimenter may choose to provide his own primary recorders and use the ADDAS as a backup. In those cases where ADDAS recording is not possible (e.g., video-tape or photographic film records) the computer still provides a valuable service for the experimenter in the form of a time-correlated record of events and aircraft flight parameters. Experimenters who use the ADDAS are responsible to match their data to the signal input requirements of the computer system.

On the Lear Jet, there is nothing analogous to the ADDAS and the entire responsibility of data recording and handling is left to the individual experimenter. In this case, the responsibility of the ASO is limited to providing the necessary power to operate the experimenter's data system.

Experimental and Support Data

There are two main categories of data recorded by the experimenter: the basic experimental data and support data. Typically, an experiment has a sensor that produces a signal, which may be recorded directly or be operated on by the experiment electronics – for example, amplified or converted to a digital or audio frequency – before being recorded. The simplest type of data system records only such a signal. More complex systems also record such parameters as power-supply voltages, gain settings, internal temperatures, and the like.

Many experiments, particularly those flown on the Lear Jet, record an audio channel on magnetic tape to preserve comments by the experimenter about the operation of the experiment. By this means, the experimenter can record experimental parameters other than the basic signal, particularly if such experimental parameters do not change rapidly. On the CV-990, a wide spectrum of data from aircraft instruments is processed by the ADDAS and displayed on the aircraft television monitors. If an experimenter needs a real-time record of this information, these signals can be transmitted directly to his own recording system. Timing signals from the CV-990 aircraft master system also are available in several codes to permit time correlation with other experimenters and/or with the ADDAS printout of aircraft parameters.

Several experiments on the Lear Jet have used a four-channel audio tape as the basic data record. When this is done, a standard monitor frequency is often recorded on one channel. In this way, compensation may be made for wow and flutter caused in part by transients in the aircraft power supplies.

Aircraft Data-Handling Facilities

ADDAS

ADDAS on the CV-990 provides centralized recording of experimenter data and limited real-time computation of experimental results. To accommodate this system, it is desirable to convert experiment outputs to ±10 VDC signals, although other forms can be accepted at a lower input rate. Two input signal analog-to-digital converters are used:

1. A 0 ±10 V multiverter with a 18-kHz rate.
2. A crossbar scanner, which accepts voltage inputs from 100 mV to 1000 VDC, 1 to 1000 VAC at frequencies from 50 to 100 kHz; resistance inputs from 100Ω to 10MΩ frequency inputs from 5 Hz to 200 kHz with amplitude range of 0.1 to 100 V rms. Maximum throughput is 30 channels per second for the same type of input, 15 channels per second for mixed voltages and resistances, and one channel per second for frequency measurement.

All input signals are digitized and stored on magnetic tape. Experimenter comments can be recorded along with the data, by typewriter input. A high-speed printer provides a hard-copy record of experiment and selected aircraft parameters for use in postflight data examination. Data-processing requirements must be specified well in advance of the mission so the ASO data systems manager can coordinate the various requests and program the ADDAS as necessary.

The computer system provides for a total of 48 input/output channels and is presently fitted with a 16,000 word memory, with capability for an additional 16,000 words. Programming choices are Real Time Executive, Basic Fortran, and ALGOL.

The full data output of the aircraft inertial navigation system (INS) is entered on the magnetic tape through the computer, with update every 1.2 seconds. The program or calibration function held in memory for any experiment can be modified by means of the ADDAS teleprinter and keyboard.

Computer outputs are in the form of a digital magnetic tape, which is compatible for in-house computer processing by the experimenter; hard-copy printout of selected experiment and aircraft parameters; and a punched paper tape. Figure 7-A is a block diagram of the entire computer system.

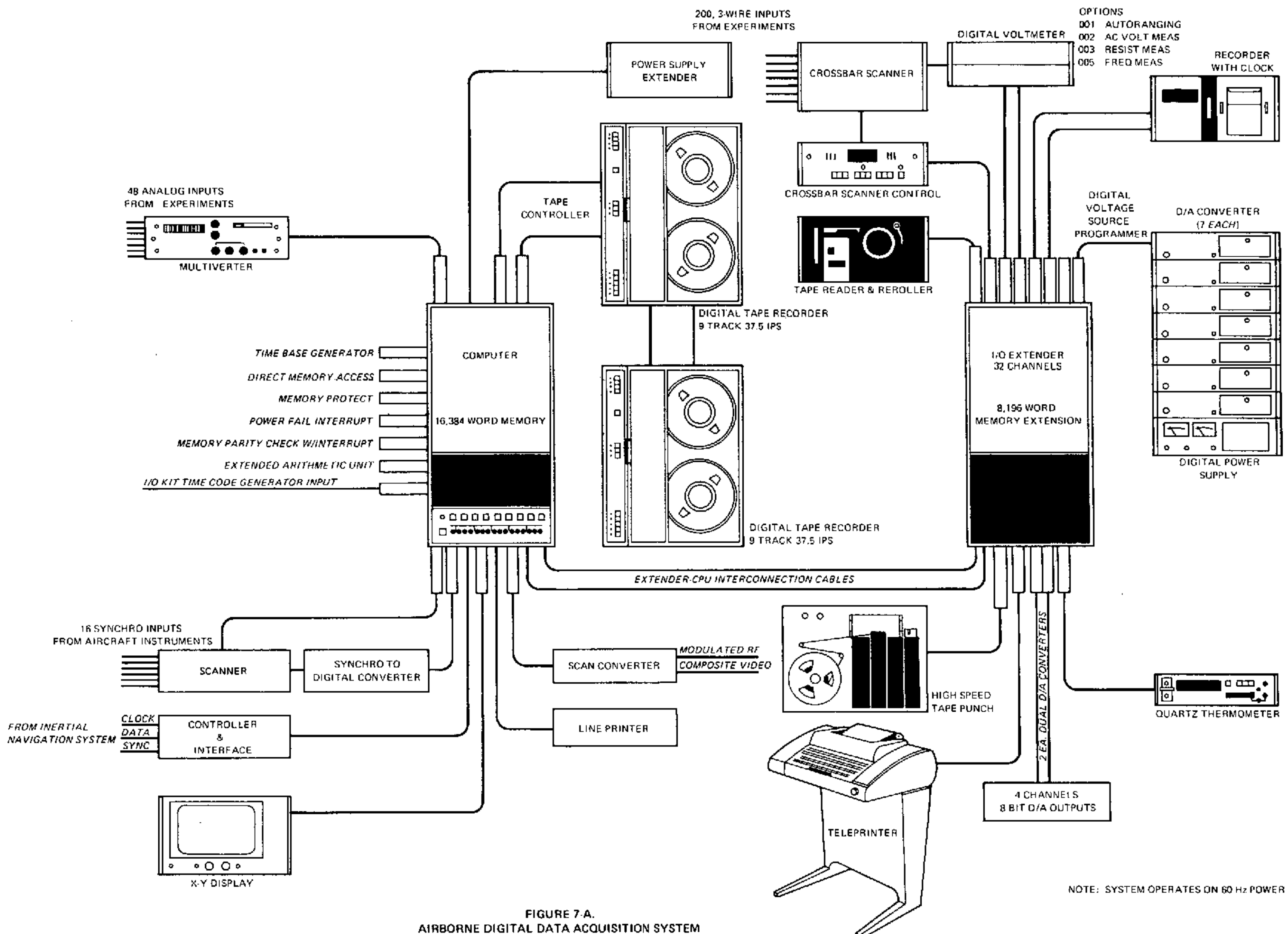


FIGURE 7-A.
AIRBORNE DIGITAL DATA ACQUISITION SYSTEM
(ADDAS)

Support Information Systems

The CV-990 carries a time-code generator to provide time-of-day signals to the computer system and experimenters. The TCG clock is synchronized with time signals broadcast from NBS radio WWV or equivalent stations. The time error is less than 0.1 msec per day. In addition, a variety of electrical time codes and timing pulses can be distributed to the experiment stations.

The output from a selected group of aircraft flight instruments also can be distributed to an experimenter's equipment through amplifiers on the timing rack. Flight instrument outputs supplied in this way include: static and total air temperatures, true airspeed, pressure and radar attitudes, and pitch and roll. Other flight-profile information – cabin altitude, ground speed, heading, latitude and longitude – is stored on the ADDAS record.

Data are displayed on closed-circuit TV monitors positioned in appropriate locations in the cabin. Data of interest to several experimenters (15 parameters) are presented along with selected aircraft parameters. The display can be updated as often as every 1.2 seconds. Other available information systems and equipment are:

1. A closed-circuit TV camera mounted in the right wheel well, which provides a downward-looking image that can be displayed on the TV monitor at the experimenter's station.
2. A continuous record of aircraft stability obtained by a wide-angle, rate-integrating gyroscope system, with outputs of roll, pitch, and yaw, along with a time signal, recorded on a strip chart.
3. A wide variety of photographic recording equipment for experiment support, as requested.

Data-Handling Techniques

The average experiment uses both an indicator (e.g., voltmeter, pressure gage, pulse-height analyzer) and a recorder (e.g., movie camera, tape recorder). The indicator provides instantaneous values and immediately shows the operator if anything is wrong. The distinction between an indicator and a recorder is not always clear; both functions may be performed by one unit. A strip-chart recorder, for example, also permits immediate viewing, and a pulse-height analyzer indicates pulse heights as they are measured and counts total numbers in various height categories. When equipped with a camera, a cathode-ray oscilloscope indicates an instantaneous signal and makes a permanent record. The number of units used in experiments observed during the ASSESS study period varied from as many as six major indicators and six recorders in the clear-air turbulence experiment, to a hand-held solar photometer with a single indicator.

For experiments in which the basic information is optical imagery (auroral observation, meteor observation and spectroscopy, for example), the images are recorded directly on photographic film. No quick-look capability can be provided and there is little or no possibility of additional recording by other means, although time correlation often can be indicated on the film. Basic visual imagery also can be recorded on video tape for display on television monitors, which are available to all experimenters on the CV-990.

CV-990 experimenters are strongly encouraged to record their data on the ADDAS, in addition to the recording capability incorporated in their own experiment. The ADDAS record then can serve as a backup in case of problems with the experimenter's own gear; data of interest to other experimenters also are available via the ADDAS printout.

The ADDAS has the capability for real-time operation on an experimenter's data to provide a calculated result. For example, a calibration curve can be programmed into ADDAS to convert a transducer voltage to a temperature reading, which can then be input along with other recorded and stored data to compute a desired test result. Table 7-A indicates that ADDAS was used for computation or data recording in 53 percent of the CV-990 experiments, while 56 percent had quick-look indicators and 86 percent their own recording system. On the Lear Jet, 71 percent of the experiments were equipped with indicators, as well as with recorders.

Postflight Data Handling

Following a flight on the CV-990, experimenters receive an ADDAS printout of pertinent aircraft parameters, time, and selected experimental data points. The experimenter uses this information in evaluating the adequacy of his measurements and planning operational procedures for the next flight.

Occasionally (table 7-A), an experimenter will provide auxiliary data-handling equipment for postflight data processing (e.g., see appendix A). Some have provided small computer facilities for that purpose. These usually operate on magnetic-tape records. A common and simple form of postflight data processing is the development of photographic film, which must await the completion of the flight.

Applications to the Shuttle Sortie Program

Despite the diversity of data handling methods used in 79 airborne experiments observed, certain procedural elements are common to most and will likely have counterparts in Shuttle research. For effective planning and control of experiment operations, the experimenter must have a real-time indication of data quality and a permanent record for review at the end of the observation period. He may obtain this record from his own built-in unit or from a central, on-board recording system; in either case, a time correlation is required with vehicle parameters and with other related experiments. Some experimenters will require nearly real-time data processing to evaluate results, while others may perform substantial processing of raw data between observation periods. A very few may require on-ground processing of the raw data, but most should be adequately serviced by a modest on-board computer facility. In airborne

TABLE 7-A. EXPERIMENTER USE OF ONBOARD COMPUTER (ADDAS), INDICATORS AND RECORDERS FOR DATA HANDLING

AIRCRAFT	MISSION	NUMBER OF EXPERMTS.	DATA TO ADDAS			OWN INDICATOR	OWN RECORDER	ON-GROUND DATA EQUIPMENT (2)
			ALL	RECORD ONLY	RECORD AND COMPUTE			
CV-990	AIDJEX	13	11 85%	0	11 85%	3 23%	12 92%	2 15%
	OCEAN COLOR	13	9 69%	4 31%	5 38%	11 85%	11 85%	0
	AUGUST 1972	7	4 57%	1 14%	3 43%	7 100%	5 71%	0
	METEOR SHOWER	16	3 19%	2 13%	1 6%	4 25%	14 (1) 87%	0
	NOVEMBER 1972	13	6 46%	3 23%	3 23%	10 78%	11 85%	1 8%
	CV-990 TOTALS	62	33 53%	10 16%	23 37%	35 56%	53 86%	3 5%
LEAR JET	ALL	17	NA	NA	NA	12 71%	17 100%	7 41%

(1) 12 PHOTOGRAPHIC AND VIDEO TAPE RECORDS
(2) NOT INCLUDING DEVELOPMENT OF PHOTOGRAPHIC FILM

experience, most of the experimenters used the flight parameter-time correlation supplied by the on-board ADDAS computer, about 40 percent relied on some data processing during the flight, and less than 20 percent required special processing on the ground, other than the development of photographic film.

Section 8

EXPERIMENT PERFORMANCE AND RELIABILITY

During the ASSESS observation period from April 1 to November 15, 1972, the performance of 79 airborne experiments and the activities of some 126 experimenters were monitored. A total of 119 data flights were made, 76 in the Lear aircraft and 43 in the CV-990; the corresponding numbers of experiment-flight units were 76 and 429, respectively.[1] In this section, experiment performance is evaluated in terms of the frequency and severity of equipment malfunctions; their impact on the research schedule and the quality and quantity of data obtained; and the ability of the experimenter to resolve problems and maintain his experiment in working condition.[2] The role and importance of such factors as preflight testing and component origin is also explored. Experiment performance is rated by a reliability factor based on experiment flight units (EFU) – that is, one experiment on one flight.

Observed Experiment Performance

Types of Problems

The number and type of problems encountered in all data flights during the 7-1/2 month observation period are summarized in table 8-A, by aircraft program. The total number of problems is presented in six source categories: experimenter furnished equipment, experimenter error, government furnished equipment, aircraft utilities, other aircraft systems, and flight environment. In both the Lear Jet and CV-990 research programs, experimenter equipment and experimenter errors accounted for three-fourths or more of all problems. On the Lear Jet, aircraft systems (operations) problems accounted for the larger proportion of aircraft-related difficulties because of the Lear's much heavier flight schedule; on the CV-990, the more complex services (utilities) accounted for a larger share of problems.

For the two programs, about 60 percent of problems were in electronic and electrical equipment; about 30 percent were of a mechanical nature; and the remaining 10 percent were optical. On the basis of equipment function, the distribution of problems in the experimenter's own equipment was different for the two programs, with the Lear leading in inlet systems (29 percent)

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[1] Only the first flight of the CV-990 November 1972 mission, with 13 experiments (2 of these were not operated during the flight), was monitored. The totals given include this flight.

[2] Despite the substantial numbers of experiments and flights observed herein, there are some instances in the following analyses when sample sizes are too small to justify firm conclusions. Observations are continuing to increase sample size.

TABLE 8-A. SUMMARY OF ALL PROBLEMS ENCOUNTERED ON DATA FLIGHTS

ITEM	LEAR JET PROGRAM		CV-990 PROGRAM	
	NO. PROBLEMS	PERCENT	NO. PROBLEMS	PERCENT
TOTAL	77	100	201*	100
EXPERIMENTER'S EQUIPMENT	48	62	155	77
EXPERIMENTER ERROR	9	12	11	6
GFE FOR EXPERIMENT	6	8	0	0
A/C – EXPMT. UTILITIES	5	6	30	15
AIRCRAFT SYSTEMS	7	9	3	1
FLIGHT ENVIRONMENT	2	3	2	1
PROBLEM DISTRIBUTION BY TYPE, %	TOTAL PROBLEMS	EXPMTR'S. EQUIP.	TOTAL PROBLEMS	EXPMTR'S. EQUIP.
MECHANICAL	27	25	31	29
OPTICAL	16	13	7	6
ELECTRONIC	45	60	49	53
ELECTRICAL	12	2	13	12
PROBLEM DISTRIBUTION BY FUNCTION, %	EXPERIMENTER'S EQUIPMENT		EXPERIMENTER'S EQUIPMENT	
INLET SYSTEM**	29		5	
DETECTOR	23		16	
SIGNAL CONDITIONERS	15		25	
RECORDERS	19		28	
POWER AND CONTROL UNITS	14		19	
AIRCRAFT INTERFACE	0		7	
PROBLEM DISTRIBUTION BY OCCURRENCE, %	EXPERIMENTER'S EQUIPMENT		EXPERIMENTER'S EQUIPMENT	
NEW	73		55	
REPEAT	27		45	

* INCLUDING 12 FROM THE CV-990 NOVEMBER 1972 MISSION

** EXPERIMENT COMPONENTS THAT CONVEY THE INCOMING ENERGY OR SAMPLE TO THE DETECTOR and sensors (23 percent), while on the CV-990 data recording systems (28 percent) and signal conditioners (25 percent) were in the majority.

On the Lear, nearly 75 percent of the problems were new, in the sense of their first occurrence during a mission; on the CV-990, new and repeat problems were almost equally divided.

Problem Impact on Research

Table 8-B summarizes the experimenter's equipment problems according to their direct impact on experiment performance during the flight on which they occurred, and in terms of the timing of equipment repair and flight opportunities missed. All Lear experiments are grouped together; the CV-990 missions are listed separately.

Evaluation of the data in table 8-B indicates 38 percent of the CV-990 problems had no effect on the data obtained, while for the Lear, only 8 percent of the problems did not adversely affect the experimental data. Only 5 percent of the experiment problems resulted in complete data loss on the CV-990, compared to 27 percent of problems for the Lear. These differences in problem impact on the research indicate that the two research programs have some fairly basic differences. The most obvious of these are related to the flight situation. Shorter flight times, very limited space available, and the difficulty of working while using life-support equipment all combine to encourage the termination of a Lear Jet flight when a problem occurs. On the CV-990, the flight continues, giving the experimenter time to work on the problem. Other differences will be discussed as the data on experiment performance are analyzed in more detail.

The equipment repair record in table 8-B shows that 16 percent of the experiment problems were repaired during flight, 32 percent more were repaired before the succeeding flight, 42 percent took longer to repair or were never completely resolved, and 10 percent occurred on the last flight of the mission (and were repaired later). Note that the 42 percent that were deferred did not have a proportionate impact on research; in most of these cases, the experimenter found some way around the difficulty and continued to do research. Of the seven experiments that could not be repaired in time to operate on the next flight, four were repaired in time to rejoin the mission later and three were terminated. A total of 22 flight opportunities was missed.

Equipment repairs aboard the CV-990 aircraft were surprisingly infrequent; only one out of five experiment problems was repaired during flight. In large part, the nature of the research impact associated with the problem was the determining factor in decisions to make inflight repairs. Table 8-C is a breakdown of repair decisions as a function of research impact. Relatively few of the problems having an insignificant impact on the quality or quantity of data recorded were repaired. Although many of these caused inconveniences, repair was deferred for one or more flights when the research product was acceptable (68 percent). Problems resulting in degradation or loss of data were given more attention. Of the seven problems that caused a complete loss of data, three were repaired without loss of flight opportunity.

Table 8-D summarizes the impact of other classes of problems on the research programs. Experimenter errors (20) generally caused some data loss, although half of them were resolved in flight. Aircraft utilities gave rise to a substantial number of minor problems (26) that had little impact on experiment performance, while aircraft systems on the Lear Jet caused four out of the five aborted flights observed during this period.

TABLE 8-B. IMPACT OF EXPERIMENT PROBLEMS ON DATA ACQUISITION

PROGRAM	MISSION (NO. FLTS.)	NO. EXPMTS.	NO. EXPMT. PROBS.	RESEARCH IMPACT (ONE FLIGHT)				EQUIPMENT REPAIR			OCCURRED ON LAST FLIGHT	NO. EXPMTS. MISSED FLT. OPPORTUNITY	TOTAL NO. FLIGHT OPPORTUNITIES MISSED
				NONE	DATA DEGRADED	DATA LOSS	ALL DATA LOST	IN FLIGHT	FOR NEXT FLIGHT	DEFERRED*			
LEAR JET	ALL (76)	17	48	4 (8%)	10 (21%)	21 (44%)	13 (27%)	3 (6%)	22 (46%)	17 (35%)	6 (13%)	2	6
CV-990	AIDJEX (8)	13	33	16 (49%)	10 (30%)	7 (21%)	0	1 (3%)	5 (15%)	23 (70%)	4 (12%)	0	0
	OCEAN COLOR (15)	13	53	13 (25%)	14 (26%)	22 (41%)	4 (8%)	17 (32%)	21 (40%)	13 (25%)	2 (4%)	2	5
	AUGUST 1972 (9)	7	33	14 (43%)	2 (6%)	15 (45%)	2 (6%)	6 (18%)	8 (24%)	13 (40%)	6 (18%)	2	7
	METEOR SHOWER (10)	16	24	11 (46%)	2 (8%)	10 (42%)	1 (4%)	3 (13%)	6 (25%)	14 (58%)	1 (4%)	1	4
	ALL **	49	143	54 (38%)	28 (19%)	54 (38%)	7 (5%)	27 (19%)	40 (28%)	63 (44%)	13 (9%)	5	16
ALL OBSERVATIONS **		66	191	58 (30%)	38 (20%)	75 (39%)	20 (11%)	30 (16%)	62 (32%)	80 (42%)	19 (10%)	7	22

* MOSTLY MINOR PROBLEMS WITH SMALL IMPACT ON DATA RECOVERY
** NOVEMBER 1972 MISSION NOT INCLUDED

TABLE 8-C. DISPOSITION OF EXPERIMENT PROBLEMS
CV-990 RESEARCH PROGRAM*

RESEARCH IMPACT OF PROBLEM	NUMBER OF PROBLEMS OBSERVED	REPAIRED IN FLIGHT	REPAIRED FOR NEXT FLIGHT	REPAIR DEFERRED	OCCURRED ON LAST FLIGHT (NOT REPAIRED)
NONE	54	5 (9%)	9 (17%)	37 (68%)	3 (6%)
DEGRADE DATA	28	10 (36%)	9 (32%)	7 (25%)	2 (7%)
SOME DATA LOSS	54	12 (22%)	19 (35%)	15 (28%)	8 (15%)
ALL DATA LOST	7	0	3 (43%)	4 (57%)	0

* NOVEMBER 1972 MISSION EXCEPTED

TABLE 8-D. IMPACT OF OTHER PROBLEMS ON DATA ACQUISITION
LEAR-JET AND CV-990 PROGRAMS

	NUMBER	RESEARCH IMPACT (ONE FLIGHT)					REPAIRED IN FLIGHT
		NONE	DATA DEGRADED	DATA LOSS	ALL DATA LOST	ABORT FLIGHT	
EXPERIMENTER ERROR	20	3 (15%)	2 (10%)	13 (65%)	2 (10%)	0	10 (50%)
GFE FOR EXPERIMENT	6	0	2 (33%)	3 (50%)	1 (17%)	0	1 (17%)
A/C – EXPMT. UTILITIES	35	26 (74%)	1 (3%)	7 (20%)	0	1 (3%)	8 (23%)
FLIGHT ENVIRONMENT	4	0	0	4 (100%)	0	0	2 (50%)
AIRCRAFT SYSTEMS	10	2 (20%)	0	3 (30%)	1 (10%)	4 (40%)	2 (20%)
ALL	75	31 (41%)	5 (7%)	30 (40%)	4 (5%)	5 (7%)	23 (31%)

Experiment Reliability Analysis

For analysis purposes, an experiment that develops a problem during a flight is considered unreliable on that flight; if more than one problem develops, the one having the greatest impact on the research determines the degree of unreliability. The reliability factor (RF) for an experiment is RF = 1 - EPU/EFU, where EPU is an experiment-problem unit defined as one unreliable experiment on one flight, and EFU is the experiment-flight unit introduced earlier. In this analysis, three degrees of reliability were considered: one for flights with no problems, another for flights in which all data were obtained, and a third for flights with a partial data return. Reliability factors were calculated from the data in table 8-B, and are given in table 8-E.

Table 8-E shows a total of 152 problem units compared to 494 flight units, for a ratio of about 1 to 3, as indicated by the overall, no-problem reliability factor of 0.68. If the defintion of reliability is relaxed to allow problems that caused no loss of data, the overall reliability factor is 0.80; that is, the average experiment obtained complete data records on 80 percent of its flights. The RF = 0.95 for partial data return indicates that 95 percent of all experiments yielded some useful data and only 5 percent failed completely. In terms of aircraft, the RF for full data return varied from 0.64 for the Lear (all missions) to 0.94 for the CV-990 Meteor Shower expedition.

These data on experiment reliability indicate the level of research effectiveness that can be achieved when the experimenter is directly involved in the flight program. Experiments assembled from relatively unsophisticated components and subjected to relatively little preflight testing have been shown to perform their research functions on two of three flights with no noticeable malfunctions. Furthermore, despite experiment malfunctions, in four of five cases there was no loss of data, and in 19 out of 20 there was at least some useful data obtained. Considering only the CV-990, which is more representative of Shuttle-type payloads, in only 2 percent of all flight opportunities was there a complete experiment failure with zero data return.

Elements of Experiment Reliability

The ultimate in-flight performance of an airborne experiment is the product of various physical constraints and human judgments that enter into the design, development, and preflight testing of the research equipment. From observations during the ASSESS study phase, certain elements that characterize the experiment development process and hardware have been evaluated and related to inflight performance, using the all-data reliability factor defined earlier. These performance-related elements include preflight testing, experimenter flight experience and components construction.

Preflight Testing

The experimenter always has an opportunity to check out his equipment in the aircraft environment, both on the ground and in flight. Other than requiring the verification of flight safety of an experiment, by testing if necessary, the role of the ASO in laboratory and preflight testing is entirely supportive.

TABLE 8-E. EXPERIMENT RELIABILITY FACTORS

AIRCRAFT	MISSION	DATA FLIGHTS	EFU	EPU	EXPERIMENTER'S EQUIPMENT RELIABILITY FACTOR		
					NO PROBLEMS	ALL DATA	PARTIAL DATA
LEAR	ALL	76	76	33	0.56	0.64	0.88
CV-990	AIDJEX	8	98	17	0.78	0.90	1.00
	OCEAN COLOR	15	165	52	0.71	0.85	0.98
	AUGUST 1972	9	38	29	0.28	0.58	0.91
	METEOR SHOWER	10	117	21	0.86	0.94	0.99
	TOTAL	42	418	119			
	EXPERIMENT AVERAGE				0.71	0.85	0.98
	ALL	118	494	152	0.68	0.80	0.95

EFU = EXPERIMENT – FLIGHT UNIT
EPU = EXPERIMENT – PROBLEM UNIT (ONE OR MORE PROBLEMS ON ONE FLIGHT)
RF = 1 – EPU/EFU

Table 8-F summarizes the observations of preflight testing for both research aircraft. The distinction is made between testing at the experimenter's home laboratory and at the ASO facility. The data are broken down into operational and environmental testing; components and completed-assembly testing; and level of effort in terms of man-days and the use of pre-mission checkout flights.

For both aircraft programs, the major testing effort was operational – that is, to verify the functional performance of equipment in the laboratory. The record shows that Lear experimenters did little environment-related testing before a mission, whereas more than a third of the CV-990 experiments were subjected to at least some minimal amount of environmental-related testing. About one-fourth of all experiments were tested in a pre-mission checkout flight; the remaining CV-990 experiments were flight checked during the first data flight of each mission.

The high incidence of operational tests and the low incidence of environmental-type tests appears directly related to the large percentage of repeat experiments. Only 21 of the 79 experiments were new to the flight environment; the other 58 had flown at least once before and presumably had the environmental problems resolved either before or during that mission; of the 21 new experiments, 20 were subject to some environment-related testing.

The effect of preflight testing on experiment performance is summarized for both aircraft programs in table 8-G. The level of effort observed is based on both the number of test areas and the man-days of effort from table 8-F. Evaluation of the data shown reveals an anomaly in the level of testing effort and demonstrated experiment reliability in flight. Logically, the group of repeat experiments (with a high level of testing effort) receiving an average of about 7 man-days each in 4.7 test areas, having the benefits of both flight experience and relatively extensive testing, should have produced the best inflight performance record. In fact, the reverse was true, with an increase of problems and a lower reliability factor. Further examination traced much of this discrepancy to seven experiments, each of which had been modified substantially since a previous successful flight experience. The reliability factor for this group of seven experiments was 0.42. Excluding this group from the other 15 experiments which had not been modified since the last flight series resulted in an all-data reliability factor of 0.82, which is more in line with the factors for the other test groups.

Test Data Evaluation

The data on preflight testing, viewed in the broadest sense, suggest that the best preflight test is a previous flight experience, which subjects the experiment to all operational and environmental factors. Of more direct significance, however, is the fact that the performance of new experiments was equal to that of repeat experiments, presumably because of a test effort of five man-days that included environmental factors. Thus, with adequate preflight testing the first-time experimenter can achieve results comparable to those of the experienced observer.

A significant number of experiments require additional testing between missions to maintain or improve performance. Changes in hardware must be verified, with the result that a test effort similar to that for a new experiment is undertaken on a level commensurate with the extent of the modifications. Again, however, actual flight experience is probably the most effective test program.

The average pre-mission test effort for 66 experiments was close to four man-days, and the corresponding data return was complete in 396 out of 494 experiment flights (all-data R.F. = 0.80).

TABLE 8-F. PRE-FLIGHT TESTING OF EXPERIMENT EQUIPMENT

RESEARCH PROGRAM MISSION	RESEARCH GROUP	EXPMT. STATUS	EQUIP. PROBLEMS PER EFU	ALL-DATA R.F.	PRE-MISSION TESTS OF EQUIPMENT: HOME LABORATORY — MAN DAYS	HOME LAB — OPERATIONAL COMP.	HOME LAB — OPERATIONAL ASS'Y.	HOME LAB — ENVIRONMENTAL COMP.	HOME LAB — ENVIRONMENTAL ASS'Y.	ASO LABORATORY — MAN DAYS	ASO LAB — OPERATIONAL COMP.	ASO LAB — OPERATIONAL ASS'Y.	ASO LAB — ENVIRONMENTAL COMP.	ASO LAB — ENVIRONMENTAL ASS'Y.	CHECK FLIGHTS
LEAR JET (ALL)	1a	REPEAT	0	1.00	1	+	+	0	0	1	0	+	0	+	0
	1b	REPEAT	0	1.00	1	+	+	0	0	1	+	+	0	0	0
	2a	REPEAT	0.67	0.67	½	+	+	0	0	1	0	+	0	+	1
	2b	REPEAT	2.00	0.67	½	+	+	0	0	½	0	+	0	0	0
	2c	REPEAT	1.14	0.86	½	+	+	0	0	½	0	+	0	0	0
	3a	REPEAT	0	1.00	–	+	0	0	0	1	–	+	0	0	0
	3b	REPEAT	0.33	0.67	–	+	0	0	0	½	–	+	0	0	0
	3c	REPEAT	1.00	0	–	+	0	0	0	1	–	+	0	0	0
	4a	REPEAT	0.75	0.50	5	+	+	0	0	½	0	+	0	0	0
	4b	REPEAT	0.75	0.50	5	+	+	0	0	½	–	+	–	0	0
	4c	REPEAT	0.13	0.87	5	+	+	0	0	½	–	+	–	0	0
	4d	REPEAT	0.17	0.83	5	+	+	0	0	½	–	+	–	0	0
	4e	REPEAT	1.57	0.14	5	+	+	0	0	1	+	+	–	+	1
	5	REPEAT	0.40	0.60	1	+	0	0	0	½	+	+	0	0	0
	6	REPEAT	0.50	0.75	5	+	+	0	+	2	+	+	–	+	1
	7	NEW	1.00	0.33	½	+	+	+	0	2	+	+	0	0	0
	8	REPEAT	0.33	0.67	2	+	0	+	0	1	+	+	0	+	1
TOTALS	17	–	–	–	–	17	12	2	1	–	6	17	0	5	4

+ SOME TESTING DONE
0 NO TESTING DONE

TABLE 8-F. PRE-FLIGHT TESTING OF EXPERIMENT EQUIPMENT (CONTINUED)

RESEARCH PROGRAM (MISSION)	RESEARCH GROUP (EXPMTS.)	EXPMT. STATUS	EQUIP. PROBLEMS PER EFU	ALL-DATA R.F.	PRE-MISSION TESTS OF EQUIPMENT										
					HOME LABORATORY					ASO LABORATORY					
					MAN DAYS	OPERATIONAL		ENVIRONMENTAL		MAN DAYS	OPERATIONAL		ENVIRONMENTAL		CHECK FLIGHTS
						COMP.	ASS'Y.	COMP.	ASS'Y.		COMP.	ASS'Y.	COMP.	ASS'Y.	
CV-990 (AIDJEX)	1 (1 TO 5)	REPEAT	0.05	0.97	–	+	+	–	–	–	–	+	0	0	0
	2 (6 TO 9)	REPEAT	0.19	0.84	2	+	+	+	+	–	–	+	0	0	0
	3 (10 & 11)	REPEAT	(10) 3.0 (11) 0	1.0	–	+	–	0	0	–	–	+	0	0	0
	4 (12)	REPEAT	0	1.0	–	+	–	–	–	–	–	+	0	0	0
	5 (13)	NEW	1.0	0.50	*	+	+	–	–	0	0	0	0	0	0
CV-990 (OCEAN COLOR)	1 (1 TO 3)	REPEAT	0.22	0.93	2	–	+	0	0	1/2	0	+	0	0	0
	2 (4)	REPEAT	0.73	0.93	1/2	+	+	0	0	1/2	0	+	–	+	0
	3 (5)	REPEAT	0.73	0.80	10	+	+	0	0	15	0	+	–	+	0
	4 (6 & 7)	REPEAT	0.03	0.97	1/2	0	+	0	0	1/2	0	+	0	0	0
	5 (8)	NEW	0.20	1.0	6	+	+	–	0	6	–	+	+	0	0
	6 (9)	NEW	0.91	0.40	>10	+	+	+	+	10	+	+	–	+	0
	7 (10)	REPEAT	0.53	0.53	1/2	–	+	–	+	1/4	0	+	0	0	0
	8 (11)	NEW	0.47	0.60	20	+	+	+	0	2	+	+	–	–	0

TABLE 8-F. PRE-FLIGHT TESTING OF EXPERIMENT EQUIPMENT (CONTINUED)

RESEARCH PROGRAM (MISSION)	RESEARCH GROUP (EXPMTS.)	EXPMT. STATUS	EQUIP. PROBLEMS PER EFU	ALL-DATA R.F.	PRE-MISSION TESTS OF EQUIPMENT										
					HOME LABORATORY					ASO LABORATORY					
					MAN DAYS	OPERATIONAL		ENVIRONMENTAL		MAN DAYS	OPERATIONAL		ENVIRONMENTAL		CHECK FLIGHTS
						COMP.	ASS'Y.	COMP.	ASS'Y.		COMP.	ASS'Y.	COMP.	ASS'Y.	
CV-990 (OCEAN COLOR) (CONT.)	9 (12)	NEW	0	1.0	10	+	+	+	0	0	+	+	0	0	0
	10 (13)	REPEAT	0	1.0	3	+	0	0	0	1½	+	+	0	0	0
CV-990 (AUGUST 1972)	1	REPEAT	1.0	0.40	120	+	+	+	0	2	+	+	+	0	0
	2	REPEAT	1.0	0.44	20	+	+	+	0	2	+	+	+	0	0
	3	NEW	0.50	0.87	310	+	+	0	+	20	+	+	+	0	0
	4	REPEAT	1.0	0.83	30	+	+	+	+	1	–	+	+	0	0
	5	REPEAT	0.50	0.50	0	0	0	0	0	1/4	0	0	+	0	0
	6	NEW	1.0	1.0	11	+	+	+	0	½	+	+	+	0	0
	7	REPEAT	1.0	0	14	+	+	0	0	1	–	+	+	0	0
CV-990 (METEOR SHOWER)	1 (1, 4, 6)	NEW	0.03	0.97	*	0	+	0	+	5	+	+	0	+	1
	1 (2, 3, 5)	NEW	(2, 3) 0 (5) 0.40	1.0 0.70	*	0	+	0	0	4	+	+	0	+	1
	2 (7, 8)	NEW	0	1.0	*	+	+	0	+	1	+	+	0	+	1
	3 (9, 10)	REPEAT	(9) 0.50 (10) 0	0.60 1.0	*	+	+	0	+	2	+	+	0	+	1
	4 (11)	NEW	1.0	1.0	*	+	+	0	+	2	+	+	0	+	1
	5 (12)	REPEAT	0.29	1.0	0	0	0	0	0	1	+	+	0	+	1

TABLE 8-F. PRE-FLIGHT TESTING OF EXPERIMENT EQUIPMENT (CONCLUDED)

RESEARCH PROGRAM (MISSION)	RESEARCH GROUP (EXPMTS.)	EXPMT. STATUS	EQUIP. PROBLEMS PER EFU	ALL-DATA R.F.	PRE-MISSION TESTS OF EQUIPMENT										
					HOME LABORATORY					ASO LABORATORY					
					MAN DAYS	OPERATIONAL		ENVIRONMENTAL		MAN DAYS	OPERATIONAL		ENVIRONMENTAL		CHECK FLIGHTS
						COMP.	ASS'Y.	COMP.	ASS'Y.		COMP.	ASS'Y.	COMP.	ASS'Y.	
CV-990 (METEOR SHOWER) (CONT.)	6 (13 & 14)	(13)REPEAT (14) NEW	0	1.0	*	+	+	0	+	2	+	+	0	+	1
	7 (15)	REPEAT	0	1.0	0	0	0	0	0	1/2	+	+	0	+	1
	8 (16)	REPEAT	0.20	0.80	0	0	+	0	0	1/4	0	+	0	+	1
CV-990 (NOVEMBER 1972)	1	REPEAT	1.0	0	1/2	+	+	0	0	0	0	0	0	0	0
	2	REPEAT	1.0	0	A	+	+	+	0	1/4	0	+	0	0	0
	3	REPEAT	3.0	0	A	+	+	+	0	2	+	+	+	0	0
	4	REPEAT	1.0	0	A	+	+	+	0	0	0	+	0	0	0
	5	REPEAT	1.0	1.0	A	+	+	+	0	1/3	0	+	0	0	0
	6	REPEAT	–	–	B	+	0	0	0	1/4	0	+	0	0	0
	7	REPEAT	–	–	B	+	0	0	0	0	0	+	0	0	0
	8 (8 TO 11)	REPEAT NEW	(8, 9) 0 (10,11) 1.0	1.0 0	B A	0 +	+ +	0 0	0 0	2	0 +	+ +	0 0	0 0	0 0
	9 (12)	REPEAT	1 0	0	B	0	+	0	0	3	+	+	0	0	0
	10 (13)	NEW	2.0	0	A	+	+	+	+	–	0	+	0	0	0
TOTALS	62	–	–	–	–	43	53	16	19	–	27	59	9	19	16

A = ABOVE AVERAGE
B = BELOW AVERAGE
* = PRIOR USE FOR GROUND-BASED OBSERVATIONS

TABLE 8-G. IMPACT OF PRE-MISSION TESTING*

EXPERIMENT TEST GROUP	NUMBER IN GROUP	EXPMT. FLIGHT UNITS	PROBLEMS PER EFU	ALL DATA RELIABILITY FACTOR	TESTING EFFORT MAN-DAYS		TEST AREAS (FROM TABLE 8-F)	
					AVERAGE	RANGE	AVERAGE	RANGE
NEW EXPERIMENT, LOW LEVEL OF TESTING EFFORT	1	2	1.0	0.50	0	–	2.0	–
NEW EXPERIMENT, HIGH LEVEL OF TESTING EFFORT	17	127	0.32	0.85	~5 (1)	~2 TO 22	5.2	4 TO 7
REPEAT EXPERIMENT, LOW LEVEL OF TESTING EFFORT	26	225	0.33	0.88	0.8	0 TO 2	2.6	0 TO 4
REPEAT EXPERIMENT, HIGH LEVEL OF TESTING EFFORT	22	140	0.47	0.70	~7 (2)	~3 TO 31 (2)	4.7	3 TO 7
ALL	66	494	0.37	0.80	~4 (1) (2)	0 TO 330	4.0	0 TO 7

(1) 16 EXPERIMENTS; OMIT ONE WITH 330 MAN-DAYS
(2) 21 EXPERIMENTS; OMIT ONE WITH 122 MAN-DAYS
* NOT INCLUDING CV-990 NOVEMBER 1972 MISSION

Thus, it is not obvious that a higher level of preflight testing is justified for most airborne research experiments. Particularly intensive testing did not always produce an experiment of high reliability, but such experiments almost never failed to yield a substantial return of research data.

Experiment performance as a function of preflight testing is separated by aircraft in table 8-H for comparison of the two programs. While the overall preflight testing effort was the same for both aircraft, the overall performance of experiments on the CV-990 was somewhat better. As noted earlier, the Lear-Jet program features relatively short lead times, short flight series, more research opportunities, and a single experiment. The CV-990 program, on the other hand, featured longer and often remote-based missions, multiple experiments, longer experiment lead times, and infrequent research opportunities. During a CV-990 mission, support services are limited and the experimenter is required to adjust to the flight schedule of the research group. Thus, he has more time for preparation and is motivated to develop an experiment for relatively lengthy operation with lower maintenance requirements. In this sense, the CV-990 program is more akin than the Lear Jet to proposed Shuttle Sortie Lab operations.

Experimenter Flight Experience

Prior flight experience in ASO programs, particularly with the same basic experiment, should contribute to an improved performance record. The influence of flight experience on experiment performance is summarized in table 8-I.

In evaluating experiment performance, the number of problems per EFU and the all-data reliability factor, when taken in concert, permit analysis of the merit of increasing the flight experience of a research group through a succession of flight series. Improved performance is indicated by a decrease in problems per EFU and/or an increase in all-data reliability factor. Three research groups (Lear groups A and D and CV-900 group E) showed a clear-cut improvement in succeeding flight series. The expected improvement in experiment performance with added flight experience was again shown initially by Lear group B; however, an unresolved operational problem throughout the last flight series seriously degraded data acquisition. One other group – Lear group C – showed continued improvement with each additional series until major new components were introduced on the last series; then problems climbed and experiment performance deteriorated markedly. Similarly, research groups B, C, and D on the CV-990 established good performance records on the first flight series (two were perfect), but again the addition of major new components led to poor performance. No trend was evident from observations of the remaining research group (CV-990 group A); the experiment performance started and remained high throughout the four flight series. Only two of the nine research groups had no experience with the Airborne Science Office program prior to the ASSESS observation period. No conclusions are apparent from the observations of these two groups as to the disadvantages of lack of prior flight experience.

Two trends are indicated from these results. First, flight experience is beneficial to the experimenter and a high rate of data return is a realistic goal with repeated use of an experiment. Second, the consequences of a major change in basic experiment components (such as the sensor unit) are often underrated by the experimenter, and large data losses can occur in subsequent flights.

TABLE 8-H. EFFECT OF PRE-MISSION TESTING BY AIRCRAFT PROGRAM

AIRCRAFT	NUMBER OF EXPERIMENTS	LEVEL OF PREFLIGHT TESTING		AVERAGE ALL-DATA R.F.	AVERAGE PROBLEMS PER EFU
		LOW	HIGH		
LEAR	17	7 (41%)	10 (59%)	0.64	0.63
CV-990	49*	20 (41%)	29 (59%)	0.85	0.31

* NOT INCLUDING NOVEMBER 1972 MISSION

TABLE 8-I. INFLUENCE OF FLIGHT EXPERIENCE ON EXPERIMENT PERFORMANCE

AIRCRAFT	RESEARCH GROUP	PRIOR FLIGHT EXPERI-ENCE	FLIGHT SERIES	NO. OF FLIGHTS	EXPERIMENT PROBLEMS		EXPERIMENT ALL-DATA RELIABILITY FACTOR	NOTES
					NO.	NO. PER EFU		
LEAR JET	A	YES	1	3	2	0.67	0.67	
			2	3	6	2.00	0.67	
			3	7	8	1.14	0.86	
	B	YES	1	2	2	1.00	0	
			2	3	1	0.33	0.67	
			3	4	5	1.25	0	1
	C	YES	1	2	2	1.00	0.50	
			2	4	3	0.75	0.50	
			3	8	1	0.13	0.88	
			4	6	1	0.17	0.83	
			5	7	11	1.57	0.14	3
	D	NO	1	3	2	0.67	0.67	
			2	6	2	0.33	0.67	
CV-990	A	YES	1	8	0	0	1.00	
			2	15	1	0.07	0.93	
			3	5	5	1.00	1.00	2
			4	10	0	0	1.00	
	B	YES	1	8	0	0	1.00	
			2	15	8	0.53	0.53	3
			3	3	3	1.00	0	3
	C	NO	1	15	7	0.47	0.60	
			2	9	9	1.00	0.44	3
			3	1	3	3.00	0	3
	D	YES	1	2	0	0	1.00	
			2	5	5	1.00	0.40	3
			3	1	1	1.00	0	3
	E	YES	1	8	24	3.00	1.00	2
			2	15	1	0.07	1.00	

NOTES:

1 – UNRESOLVED OPERATIONAL PROBLEM
2 – MINOR EQUIPMENT PROBLEMS REPEATED EVERY FLIGHT
3 – MAJOR NEW COMPONENTS

Construction of Components

The relationship between experiment components construction and overall performance during flight is a matter of considerable interest. Substantial savings are realized by the use of standard laboratory instruments and electronic modules in airborne experiments, both in the development of the equipment and interfacing with the aircraft.

The construction of airborne research experiments observed during this ASSESS study phase is discussed in section 5, where the percentage makeup (by component source) of individual experiments was averaged for each mission. Here, the total number of components making up all experiments has been divided into the same four source categories, which are given in the following data summary as the proportion of components in each category.

DATA SUMMARY

		Source of components, percent of total			
Research program	Number of experiments	Off-the-shelf	Modified-commercial	Custom-commercial	Experimenter-built
Lear Jet	17	66	0	10	24
CV-990	49	64	6	20	10

The data for the CV-990 airplane, in this data summary and in all following tabulations, include all but the November mission, which was omitted because the limited observation of experiment problems was not considered representative of the total mission.

It is readily apparent from these data (as it was in section 5) that experimenters relied heavily on off-the-shelf components in both the Lear and CV-990 programs: about two-thirds of the components used were in this category. Combinations of off-the-shelf with custom-commercial units, neither of which required direct fabrication effort by the experimenter or his staff, accounted for about 80 percent of all experimental equipment.

Separation of the experiment components into functional categories by type of construction gives the distribution shown in table 8-J. The table shows that experimenters favored almost exclusively off-the-shelf sources for recorders. For the CV-990 program, the experimenters also relied heavily on off-the-shelf sources for signal-conditioning components and to a lesser extent for sensor components. The majority of miscellaneous components for both programs also were off-the-shelf.

At this point, it is of interest to examine the performance record of experiment components during the missions. The distribution of experiment problems encountered for the various component sources is summarized below.

TABLE 8-J. COMPONENTS SOURCES BY FUNCTION

RESEARCH PROGRAM	NUMBER OF EXPERIMENTS	COMPONENTS	SOURCE OF COMPONENTS, PERCENT			
			OFF-THE-SHELF	MODIFIED-COMMERCIAL	CUSTOM-COMMERCIAL	EXPERIMENTER-BUILT
LEAR JET	17	SENSORS	32	0	32	36
		SIGNAL CONDITIONERS	48	0	4	48
		RECORDERS	100	0	0	0
		ALL OTHER	55	0	14	31
CV-990	49	SENSORS	49	12	34	5
		SIGNAL CONDITIONERS	75	2	20	3
		RECORDERS	92	4	4	0
		ALL OTHER	53	3	13	31

DATA SUMMARY

Research program	Number of experiments	Number of components	Total number of problems	Problem distribution by component source: Off-the-shelf	Modified-commercial	Custom-commercial	Experimenter-built
Lear Jet	17	129	48	7	0	11	30
CV-990	49	400	143	107	3	28	5

These results show that the ratio of total problems to number of components was nearly identical for the two programs (0.37 for the Lear Jet program and 0.36 for the CV-990 program). However, the problem distribution reveals two entirely different trends: the majority of problems (63 percent) encountered in the Lear Jet program developed in experimenter-built equipment, whereas most of the problems (75 percent) in the CV-990 program came from off-the-shelf units. This difference in source of problems is a reflection of the inherent differences between the two research programs.

To permit a more detailed examination of the difference in problem source for the two programs, the experiments and attendant problems were separated into their functional components. This breakdown is given in table 8-K. Because of the small number of problems experienced with modified-commercial components, this category was omitted in the table. Similarly, to simplify the comparisons, ten experiment/aircraft interface problems with off-the-shelf items were also omitted. Table 8-K also gives a broad division of the proportion of components that function in an active or a passive role, and the attendant problems.

Table 8-K supports the data in the above data summary showing that for the Lear Jet program, a disproportionate number of problems grew from experimenter-built components (30 problems in 28 active components). Inlet systems, in this case a telescope or other large optical device, were plagued with the greatest number of problems – 12 problems in 4 components. Most of these problems were found to be associated with operational difficulties resulting from the aircraft-environment situation – for example, ice or condensation on optical surfaces, light leaks into the optical system, telescope misalignment, telescope travel restricted by limit stops, and a jammed spectroscopic grating. Most of these would not be likely to occur in a Shuttle operation.

Two other types of experimenter-built components, signal conditioners and power and control systems, had a high incidence of problems. The signal conditioners were electronic devices that were frequently constructed on a low budget by graduate students who may not have been highly qualified electronic assemblers. It is not surprising that such devices would suffer a greater-than-average number of problems. The problems associated with power and control components were related to the telescope yaw-and-roll-control systems.

Off-the-shelf components in the Lear program remained remarkably trouble-free. This category constituted two-thirds of the total components for the 17 experiments observed, yet caused only 15 percent of all Lear experiment problems.

TABLE 8-K. PERFORMANCE OF FUNCTIONAL COMPONENTS RELATED TO TYPE OF CONSTRUCTION

TYPE OF CONSTRUCTION	CLASS OR FUNCTION	LEAR JET (17 EXPMTS.)		CV-990 (49 EXPMTS.)	
		NUMBER OF UNITS	NUMBER OF PROBS.	NUMBER OF UNITS	NUMBER OF PROBS.
OFF-THE-SHELF	ACTIVE	85	7	260	94
	PASSIVE	0	0	15	3
	SENSORS	6	2	45	13
	SIGNAL CONDITIONER	14	0	46	30
	INLET SYSTEM	12	0	23	2
	POWER & CONTROL	25	1	92	12
	RECORDER	28	4	69	40
CUSTOM COMMERCIAL	ACTIVE	12	11	70	20
	PASSIVE	1	0	15	8
	SENSORS	6	8	31	6
	SIGNAL CONDITIONER	1	0	12	8
	INLET SYSTEM	6	2	26	1
	POWER & CONTROL	1	1	13	12
	RECORDER	0	0	3	1
EXPERIMENTER-BUILT	ACTIVE	28	30	10	4
	PASSIVE	3	0	30	1
	SENSORS	7	3	5	3
	SIGNAL CONDITIONER	14	10	2	0
	INLET SYSTEM	4	12	9	1
	POWER & CONTROL	6	5	24	1
	RECORDER	0	0	0	0

For the CV-990 program, table 8-K again shows the large proportion of problems from off-the-shelf components, in contrast to the Lear experience. The great percentage of problems was centered in signal conditioners and recorders (70 problems in 115 units), both categories of which were relatively trouble-free in the Lear program (4 problems in 42 units). Perhaps the primary reason for the difference in performance of off-the-shelf components is associated with the difference in the two research programs, as suggested earlier. The Lear Jet is used by a relatively small group of experimenters scheduled to fly on a more-or-less regular basis; hence, their more routine equipment, such as off-the-shelf electronic devices and recorders, are fully checked out over time. Also, these devices usually are simple in nature. In contrast, the experimenters who use the CV-990 generally do not have an opportunity to fly missions as frequently as the Lear experimenters. Consequently, the CV-990 missions observed were much less routine than the Lear missions, and the experiment complement was composed of a greater number of first-time components. Furthermore, items such as signal conditioners and recorders for the CV-990 experiments were generally far more complex than the corresponding Lear units. It follows that problems are more likely in complex units than simple ones. These differences are believed to account in large measure for the contrasting problem histories of the Lear Jet and CV-990 programs.

Prior Use, Modifications, Cost, and Complexity

Four additional indicators of performance are given in table 8-L. The first is experiment background, in terms of its use for similar research purposes, either on the ground or in flight. Results show that the 36 (out of 57) experiments having considerable prior use were significantly more reliable, incurring only one-half as many problems per flight, than the other 21, which had little or no prior research record. This characteristic is similar to the "state of development" criterion used in section 5.

When experiments are rated by the amount of modification required for flight, a curious effect is observed: a relatively minor change makes a substantial decrease in all-data reliability factor and a corresponding large increase in problem frequency, while more extensive changes apparently do not have a commensurate influence. Similar effects of changes in experiment components on reliability were noted earlier. This result is a strong argument for preflight testing of modified experiments to eliminate new potential problem areas.

The last two elements, cost and complexity, are more closely related than the others, although there is not always a one-to-one relation; presumably, many low-cost experiments will be relatively simple. The low-cost group has an 0.80 reliability and a relatively low problem rate; the medium range has a 0.72 reliability and nearly double the problem rate. At the high-cost end of the range, the reliability has recovered to the same value as for low-cost experiments and the problem frequency is somewhat lower than for medium-cost experiments. Experiment complexity, as best this could be judged by observation, has relatively little influence on performance. In fact, the very complex experiments have about the same data return as the other groups and a somewhat lower problem frequency.

The CV-990 ADDAS System

The CV-990 ADDAS system is an important adjunct to the experimenter's equipment (sections 5 and 7). Although he is encouraged to furnish his own data recording system, the experimenter may elect to use the ADDAS as either his primary or backup recorder. Its value in this latter role has often been demonstrated when an experimenter's recorder fails. During the ASSESS observation period, the all-data reliability factor for the ADDAS recording system was 0.98; in only one flight out of 43 was any data lost. In this same period, however, there were 47 instances of malfunctions in experimenters' recorders, 20 of which had an adverse effect on the acquisition of research data. In all such cases, a complete data record was still obtained if the experiment was tied into the ADDAS system. Thus the availability of a centralized recording system is regarded by the participating scientists as a valuable asset in the Airborne Science program.

TABLE 8-L. ELEMENTS OF EXPERIMENT RELIABILITY; LEAR AND CV-990 PROGRAMS*

ELEMENT	AMOUNT	NUMBER OF EXPERIMENTS	ALL-DATA RELIABILITY FACTOR	AVERAGE PROBLEMS PER EFU
PRIOR USE IN RESEARCH (GROUND OR FLIGHT)	NONE	7	0.55	0.58
	LITTLE	14	0.62	0.75
	MUCH	36	0.87	0.31
MODIFICATION FOR FLIGHT	NONE	31	0.89	0.30
	LITTLE	16	0.69	0.57
	MUCH	7	0.53	0.65
COST OF EQUIPMENT	LOW	10	0.80	0.30
	MEDIUM	29	0.72	0.56
	HIGH	16	0.80	0.40
COMPLEXITY OF EXPERIMENT (ESTIMATE)	LOW	15	0.81	0.45
	MEDIUM	36	0.76	0.48
	HIGH	14	0.78	0.39

* INFORMATION NOT AVAILABLE FOR ALL EXPERIMENTS

Implications of the Experiment Performance for the Shuttle Sortie Lab

The success of the research programs of the Ames Airborne Science Office stems directly from a full involvement of the experimenter in all phases of the operation. Each participating scientist is responsible for the operation and reliability of his experiment, and to this end he conducts whatever environmental and operational tests are, in his judgment, necessary to assure an acceptable level of in-flight performance. This concept of experimenter responsibility has been observed in action, and the resultant experiment performance analyzed to show how well it works.

With the experimenter at the controls, an airborne experiment of relatively low <u>intrinsic</u> reliability can be maintained operational and productive at a relatively high <u>effective</u> reliability. Equipment malfunctions that result in some loss of data are diagnosed and repaired in flight or prior to the next flight of the series, with few exceptions. Overall, the 66 experiments observed were problem-free on only 68 percent of their flights, yet these experiments managed to return all data on 80 percent of the flights and at least a partial return 95 percent of the time. Complete data loss occurred in only 5 percent of all flight experiences. This record of performance reflects the combined abilities of some 126 experimenters who operated and maintained their equipment in airborne science missions, and identifies a baseline from which to project the performance and reliability of Shuttle research experiments.

Of the factors that influence experiment performance, pre-mission testing is perhaps the easiest to recognize. With a few notable exceptions, preflight testing of the experiments carried on airborne missions is less extensive, by orders of magnitude, than that of unmanned or even Apollo-type space packages. Results show that even a modest program of testing (like a few man-days) nevertheless consistently produces experiments of acceptable reliability. Of direct application to Shuttle planning is the observed fact that first-time experiments, on the average, perform as well or better than repeaters; this relates in part to the higher level of testing done prior to an experiment's first flight compared with subsequent ones.

Flight experience improves performance only if the experiment is not modified between missions. When changes are made, prior flight experience does not assure good performance unless there has been careful preflight testing of the modified experiment.

By experimenter choice, off-the-shelf commercial hardware was the most frequently used; in second place was custom-commercial equipment, closely followed by components made in the experimenter's own laboratory. Equipment malfunctions among off-the-shelf components were related to unit complexity and first-time use in the flight environment. Experimenter-built components of complex optical systems and signal processing units had a relatively high incidence of problems, some related to operational difficulties in flight and others tentatively ascribed to marginal assembly procedures. In flight, the experimenters responded promptly and effectively to correct or to work around equipment malfunctions; with few exceptions, a defective experiment was back in operation by the next flight. In the CV-990 program, data loss was effectively minimized by the use of the central data-collection system (ADDAS), which served as a backup to the experimenters' recorders.

Section 9

THE ASO SAFETY PROCEDURES

From 1965 until the present, the Airborne Science Office (ASO) has managed its programs of scientific observation from high altitude aircraft in conformance with the highest standards of safety, and in those areas of responsibility has maintained a perfect record.[1] Several hundred experimenters have been active in the flight programs; ASO aircraft have logged over 700 flight hours per year and have flown in all types of environments and remote areas of the world. This exemplary record was attributed to the following factors:

- Strict compliance with aircraft maintenance procedures
- Established requirements for experiment design, construction, and installation
- Inflight safety provisions
- Review of the experiment aircraft installation and planned operations by the Airworthiness and Flight Safety Review Board
- Safety briefing given to all aircraft passengers and experimenters
- Preflight inspection of the aircraft and installed experiments
- Aircraft check flights
- Inherent responsibility of the personnel involved

Aircraft Maintenance Procedures

The Ames Aircraft Services Branch provides a systematic maintenance program to maintain the airworthiness of all aircraft assigned to Ames. The maintenance program for the CV-990 is patterned after commercial practices in effect at the time of purchase of this aircraft. The maintenance program for the Lear Jet follows that recommended by the manufacturer.

Although stemming from different sources, both programs are similar. Each aircraft undergoes an extensive inspection and maintenance every hundred hours. A more extensive inspection and maintenance procedure is provided at 500 hours with the Lear Jet and annually with the CV-990. Routine maintenance is carried out at shorter periods and between flights. When the CV-990 is remotely based, the entire ground crew is flown to the location.

[1]The disastrous mid-air collision of the CV-990 during a VFR approach to Moffett Field on April 12, 1973 was found by the investigating board to have been caused by control-tower error; ASO safety procedures and responsibility were in no way involved.

Experiment Requirements

Handbooks prepared for both the CV-990 and the Lear Jet provide the experimenter with aircraft information related to the Airborne Science program. Subjects include safety standards, allowable loads, and required experiment design and installation practices.

The experimenter is responsible for implementing the requirements specified in the Handbooks. The experimenter must submit drawings of his equipment; in some cases, informal sketches and photographs are accepted for relatively simple experiments.

Stress calculations also are required of the experiment installation. Typically, the analysis covers floor and side seat track loads, standard instrument rack loads and distribution, and maximum overturning moments for equipment mounted to the seat tracks. Loads on special fixtures, window mounts and external fairings are analyzed in detail. Occasionally, analyses have been performed by Ames personnel for experimenters who were unable to supply them. Drawings and analyses submitted by the experimenter are reviewed by the ASO mission manager for overall suitability and then referred to the Airworthiness Engineering Group of the Flight Operations Branch for a detailed analysis. This group is responsible for the flight safety of all experiments and works with the mission manager and the individual experimenter to correct design deficiencies early in the development period. They also participate as inspectors and advisors during the installation period, since their final approval of each experiment installation must be recorded prior to flight.

Inflight Safety Provisions

A number of standard procedures and aircraft equipment features are used to minimize potential hazards to onboard personnel during flight. Many of these procedures are similar to those on commercial aircraft and are enforced by the mission manager and the flight crew. Some of the equipment features minimize potential hazards by inadvertent actions of aircraft personnel. The more important provisions are summarized below.

Standard Safety Procedures

1. All movable equipment such as briefcases and cameras must be firmly stowed before takeoff and landing. Unless placed in a storage compartment, such items must be lashed down.

2. Seat belts are to be used during takeoff and landing and at such other times during flight as may be directed by the aircraft commander. Free movement about the cabin is normally permitted.

3. Inflight access to the cargo compartments on the CV-990 is permitted. However, experimenters desiring such access must indicate their movements to the mission manager so that the number of personnel in the cargo area is known at all times. Occupancy of of these areas during takeoff and landing is not permitted.

Aircraft Safety Features

1. Protruding corners of equipment that might be bumped during normal cabin movement are padded to prevent injury. Compliance to this requirement is verified by the aircraft inspector during his routine inspection of the equipment. The possibility of injury is further reduced by arrangement of the experiments for easy access between and around equipment.

2. The electrical grounding of experiments is inspected and approved prior to flight to minimize the possibility of injury to personnel or damage to equipment.

3. Several of the passenger windows and the high-angle, zenith, and nadir windows are fitted with optical glass for experiment viewing on the CV-990. These are periodically tested for strength and stress concentrations under pressure and temperature conditions that simulate the flight environment, and approved for use by the Airworthiness Engineering Group. To prevent window breakage by experimenters working around their equipment, sliding transparent safety covers must be moved in front of the window. External covers on the nadir windows protect them from rocks and debris thrown up during takeoffs and landings.

4. To minimize the fire hazard attending the large amount of electrical and electronic equipment aboard the aircraft on scientific flights, fire extinguishers are mounted on each experimental rack of equipment as well as at other locations on the aircraft. The Airworthiness Engineering Group controls the use of experiment materials and may prohibit those which are flammable.

Flight Plan and Experiment Installation Review

The Airworthiness and Flight Safety Review Board, appointed by Ames management, includes experts from several pertinent disciplines. The Board has a broad overall responsibility for all aspects of flight safety. Prior to every major or unique aircraft mission involving airborne science experiments, this group inquires into special flight planning problems, the installation of experimental equipment, special problems of weight distribution, power availability, the need for cryogenic cooling, and any special procedures peculiar to the mission. Where flight planning involves departures from normal practice, the Board examines the special provisions made for communication and contingencies. Long lead time designs are generally reviewed well in advance of the usual premission review. If remote basing is involved, the Board examines plans to assure that special provisions for such operations have been arranged.

Safety Briefings

The Ames safety briefings are concerned with procedures and equipment to be used after an emergency has occurred. However, the importance of the briefing lies in an enhanced concern for safety by the participants of the mission. On the Lear Jet, new experimenters are required to attend a one-day, high-altitude training course and altitude chamber test, plus a briefing on the Lear Jet support systems and emergency procedures. The high-altitude training course is routinely given at several military installations. The briefings on support systems and emergency procedures are short and informal, and are usually given by the mission manager. Life-support oxygen systems are subject to rigid operational and maintenance rules. The command pilot of the Lear Jet is responsible for adherence to these rules and for the safety of the experimenters in flight.

The briefings given for the CV-990 aircraft are much more extensive than those given for the Lear Jet. They are held before the start of each mission and cover the use of window safety shields, emergency exits, life rafts, life vests, fire extinguishers, and emergency oxygen during sudden cabin depressurization. These briefings are given by the flight engineer and include both a lecture and a demonstration aboard the aircraft.

Special survival equipment on the CV-990 is covered if the mission requires flight over water or arctic areas. For all over-water flights, the aircraft carries life rafts equipped with survival kits, emergency lights with water-activated batteries, and life-jackets. For arctic missions, survival sleds and arctic clothing are provided. Each sled carries emergency rations for two weeks for twenty people. Clothing kits are issued to all mission participants and include a parka, flight suits, cap, mittens, and thermal boots. The arctic clothing may be worn by participants during the mission but must be aboard the aircraft during each flight.

Preflight Inspection of the Aircraft and Installed Experiments

The Aircraft Inspection Branch has the specific responsibility for ensuring the airworthiness of the aircraft and its payload. Two separate inspections are made of the equipment to be installed in either the CV-990 or the Lear Jet. The equipment is first inspected in the ASO laboratory for the proper use of hardware and supporting bracketry. The experimenter is advised how any deficiencies can be eliminated.

Once the equipment has been installed in the aircraft, it is inspected again, particularly to ensure that the equipment mounting hardware conforms to requirements specified in the Experimenter's Handbook, and that the operation of the experiment will not interfere with the safe operation of the aircraft or result in possible injury to the experimenters or other personnel.

Aircraft Check Flights

Following the installation of experimental equipment, one or more pilot check flights are conducted without the experimenters on board. These flights serve as a check of aircraft operation, suitability of equipment mounting, and equipment effect on aircraft performance. This latter check is particularly important when equipment is mounted external to the aircraft. These flights also serve to check additions or changes to aircraft equipment.

Personnel Responsibilities

The ultimate responsibility for ensuring the safe operation of the aircraft rests with all personnel involved in the mission. Some of these personnel are directly involved in identifying and correcting equipment or operational deficiencies that may be safety hazards, and in enforcing aircraft safety regulations and procedures unique to the Airborne Science program. These include the mission manager and pilot in their roles as research coordinator and aircraft commander.

The flight and ground personnel also contribute to the safe operation of the aircraft. Many years of conforming to procedures and regulations of their specialties instills a high degree of safety awareness in accomplishing their duties.

The experimenter is aware of the safety aspects of equipment operation in the airborne environment through the briefing presented at the start of the mission, the always present aircraft environment, and concern for his own personal safety.

Section 10

MISSION DOCUMENTATION REQUIREMENTS

Present space-science programs require hundreds of documents ranging from daily correspondence to reports tracing the history of high-reliability parts. In contrast, the Airborne Science Office (ASO) in the management of its program of scientific observation from high-altitude aircraft uses fewer than 25 documents, which initiate and manage activities from mission inception to experiment approval, through experiment and aircraft preparation, to mission completion. These documents cover: (1) ASO/experimenter communications, and (2) aircraft preparation and mission operation:

ASO/Experimenter Communications Documents

ASO supplied

Primary
- Announcement of Flight Opportunity (AFO)
- Experimenters' Handbook
- Experimenters' Bulletin (CV-990)

Secondary
- Letters to Experimenters

Experimenter supplied

Primary
- Proposal for Flight Experiment
- Equipment Description
- Stress Analyses
- Request for Experiment Support

Secondary
- Progress Reports (Grant recipients)
- Technical Summary (Grant recipients)
- Authorization to Participate (Foreign experimenters)

Aircraft Preparation and Mission Operation Documents

- Aircraft Work Order
- Service Request
- Purchase Request
- Logistics Support Correspondence (CV-990)
- Aircraft Flight Request
- Flight Plans
- Flight Announcement (CV-990)
- Authorization for Personnel to Fly
- Flight Insurance Application
- Aircraft Passenger Manifest (CV-990)

Documents in the first group are unique to the management of the Airborne Science program; the second group contains standard documents required for most flights originated at Ames.

ASO/Experimenter Communications

Announcement of Flight Opportunity

This brief document announces to the scientific community that an airborne research mission is being considered to observe a particular geophysical or astronomical event, or to respond to an outstanding need for scientific information in a particular discipline. Its origin and implementation are described in section 2.

Experimenters' Handbook

Separate handbooks are provided for the Lear Jet and the CV-990 aircraft. Each provides the experimenter with performance and payload capability data, and the required design and installation practices of equipment assigned to the aircraft in question. The experimenter is expected to use handbook information to guide the design and preparation of his experiment and his planning for acquisition of data during the mission flights.

As new aircraft modification and procedural changes occur, replacement sheets are mailed to handbook recipients; more substantial revisions are handled in new editions issued periodically.

Experimenters' Bulletin

This document is the primary communications channel between the ASO mission manager and the several experimenters participating in CV-990 missions; it contains information concerning the countless details and changes occurring as the mission develops.

Lear Jet missions, on the other hand, involve only a single experiment and one team of experimenters. In this case, the communication function is adequately handled by telephone calls and informal meetings between the experimenter and the mission manager.

As early as possible after approval of a CV-990 mission, the ASO manager issues the first Experimenters' Bulletin. One or more additional bulletins may follow, depending on the availability of new information, changes that have occurred before the flight, and the relevance of those changes to experimenter efforts. One or more postflight bulletins may be prepared on interesting mission results prior to formal documentation by the experimenters.

Bulletins issued before the mission typically cover the following types of information:

- Mission description
- Background of the physical phenomena to be observed
- Mission schedule
- Flight route

- Floor plan of the CV-990
- Description of the ADDAS carried on board the CV-990
- Principal investigators for the mission
- Mission management staff
- Insurance notice on coverage of persons on NASA-operated aircraft
- Questionnaire on required supplies, services, flight plans, data recording, and timing requirements of the experimenters

Proposal for Flight Experiment

The research proposal is originated by the prospective experimenter as an unsolicited request, in response to a verbal invitation from an ASO program manager, for example, or in response to an AFO. It covers in appropriate detail both the technical and management aspects of the proposed research program. The AFO should include the scientific objectives and the need for flight observations in their pursuit, the measurement techniques to be used and the expected data return, the flight logistics required, the physical parameters of the test equipment, and any special equipment or environmental constraints. The principal and co-investigators should be identified, as well as the organization and functions of individuals for the case of several coordinated experiments. If financial support is desired by U.S. scientists, a detailed cost breakdown must be submitted with the proposal. Additional detail on the handling of proposals is given in section 2.

Equipment Description, Support Request, and Stress Analyses

Equipment description. The design and construction of experiments is the responsibility of the experimenter. To verify compliance with established requirements for the experiment and its installation, as specified in the Experimenters' Handbook, ASO requires the experimenters to submit drawings of their equipment, including dimensions, materials, bolt types and patterns, and component weights. Sketches or photographs occasionally are accepted in lieu of engineering drawings when the simplicity of the experiment warrants.

Support request. The experimenter usually requires support services such as electrical power, data recording and processing, cryogenic supplies, and ground-based equipment. He may submit a verbal or written request for support, depending mainly on whether he is preparing for a Lear Jet or a CV-990 mission. With the greater informality and the single experiment of the Lear Jet mission, verbal requests often suffice, whereas the more complex CV-990 mission with its multiple experiments usually requires written requests.

Stress analyses. Stress calculations include at least the following elements: loads analysis of floor and side seat tracks, analysis of support and tie-down structure, and analysis of restraining structure for components. On rare occasions, when the experimenter or his organization could not provide the required analyses, the necessary work has been performed by Ames personnel. It is preferred, however, that the experimenter contract for the services of an aircraft stress engineer.

Aircraft Preparation and Mission Operation Documents

Among the documents in this category, the logistics support correspondence, the aircraft passenger manifest, and the flight announcements pertain only to CV-990 aircraft missions. The others apply to both aircraft. The mission manager is responsible for the preparation of these documents.

Aircraft Work Order

A work order is required for each aircraft-related task to be accomplished by Ames or a contractor under Ames supervision. Typically, a work order is required for each change of mission, covering removal of equipment from one mission and installation of equipment for the following one, in addition to routine aircraft servicing. The aircraft work order is a standard ARC form describing the task to be accomplished and authorization for that task; seldom are more than two authorizing signatures required.

Service Request

The service request is used to obtain non-aircraft-related services from Ames support groups. Authorizing signatures vary from one to three depending on the estimated cost.

Purchase Order

The purchase order is used in acquiring equipment and supplies, and occasionally to supply funding in support of experiment development. Authorizing signatures vary from three to six.

Logistics Support Correspondence

Some missions require support away from home base. Arrangements must be made for transportation, personnel accommodations and aircraft services at the remote base. If a remote commercial field is to be used, the ASO contract-support manager will usually make the necessary arrangements through correspondence or personal contact with field personnel. The support manager works under the direction of the ASO mission manager. If the remote site is a military base, the mission manager will use the services of the resident Air Force Liaison Officer for initiating this correspondence. The signature of the mission manager authorizes these documents.

Aircraft Flight Request

This form is used to notify the Flight Operations Branch of requirements for pilots and associated flight crews for a specified period. This authorization document circulates to all support groups concerned with flight preparations and operations; three signatures are required.

Flight Plan

The flight plan consists of a map showing the flight route and such information as aircraft altitude and speed, time, and aircraft headings at various checkpoints along the flight path. Latitude and longitude are also included at these checkpoints for long flight paths such as those flown on the CV-990. Several flight plans may be developed to meet possible contingencies or widely differing requirements of the on-board experiments. In case of CV-990 flights, these plans are developed as a result of mutual agreements between the mission manager, project scientist, command pilot, and navigator. For lear Jet missions, agreement between the mission manager and experimenter is generally all that is required. The ASO navigator is responsible for carrying out the decisions in preparation of these plans. No authorizing signatures are required.

Flight Announcement and Personnel Authorization

The flight announcement provides the time and date of a particular flight. It is usually posted in the aircraft and on bulletin boards convenient to flight personnel and experimenters. For a mission consisting of flights with varying experimental payloads, times and dates of the flight series are posted. Another form provides a record at Ames of the personnel authorized to fly a particular aircraft for a specified time period; one signature authorizes this document.

Flight Insurance Application

Aircraft assigned to ASO are not licensed in a manner acceptable to many insurance companies. As a consequence, some commercially available accidental-death and double-indemnity riders to insurance policies do not provide protection for flights on these aircraft. However, NASA has arranged for insurance that may be purchased by individuals at their own expense.

Aircraft Passenger Manifest

Names of passengers assigned to a particular flight on a CV-990 mission are listed on this document. The mission manager keeps this list current and uses it to verify that the assigned complement of personnel is on board the aircraft at takeoff. This manifest also provides a permanent record of personnel on a particular flight; a new form is filled out, verified, and delivered or mailed to the Flight Operations Branch at the beginning of each flight. Only the signature of the command pilot is required.

Section 11

AIRBORNE SCIENCE METHODS AND SHUTTLE SORTIE PLANNING: A SUMMARY

The ASSESS study of the experiment management practices and operational procedures of the Airborne Science Office (ASO) indicates many program elements of relevance to Shuttle Sortie planning. Some of these elements appear fundamental to man-man or man-machine interactions and thus are directly applicable. Others reflect to some extent the unique set of conditions inherent to the Airborne Science programs, and can best serve as a baseline from which Shuttle Sortie procedures can evolve.

Selection of Experiments

Procedures in the selection of experiments for major airborne science missions are similar to those established for spacecraft programs in the 1960s. In the airborne program, however, the time between experiment selection and flight is far shorter than in the spacecraft program. Airborne experiments are selected 6 to 12 months before flight; even less lead time is needed for individual unrelated experiments that are consolidated into one payload; and "piggyback" experiments often are approved only a few weeks before flight. Rarely is an experiment scheduled more than a year in advance. Such short lead times enhance the timelines of experiments and reduce overall experiment preparation costs.

The handling of unsolicited individual experiments and "piggyback" experiments to fill any excess space on airborne science missions is particularly relevant to the Shuttle Sortie program. A file of such experiments is maintained for reference as the need arises.

An important impact of ASO management in this area is the participation role of the appropriate ASO program manager, who acts in an advisory capacity to a Headquarters evaluation committee. By virtue of his scientific background and intimate knowledge of the aircraft through his function as mission manager, the program manager is able to evaluate proposals for their scientific value as well as their compatibility with the aircraft environment.

Implicit to the decision of the Headquarters committee is the full involvement of the experimenter in the flight program, and his option to include one or more support personnel in the flight operations team. This latter choice is not likely to be a viable option in Shuttle Sortie operations, with the result that experiment design and personnel training practices will differ from those for airborne research. In particular, the choice of experiment operator will be far more critical. In current airborne practice, it is rare that one person is both an accomplished scientist and an expert in equipment maintenance. Therefore, to a greater extent than is now required, the experiment operator for Shuttle must be trained for competent performance in both areas. Following the ASO approach to experiment management, this decision and its implementation would be the responsibility of the principal investigator.

Program Management

The effectiveness of airborne research programs is due in large measure to a geographically and administratively centralized management, which provides the long-range planning and between-mission coordination required for full utilization of the flight vehicles. Science input to program planning is a blend of (1) the recognized need to support programs having national priority, (2) a basic scientific interest in specific natural phenomena, and (3) the express needs of the scientific community. As part of the management group, ASO program managers research the background of candidate scientific areas to ascertain their suitability for airborne research, both as to science and aircraft operations, and their relation to ongoing ASO programs. When a mission is approved, the cognizant program manager assumes the role of mission manager, and has prime responsibility for the entire operation. This continuity of assignment is most productive when the manager is a scientist in his own right, with special training in the mission discipline.

ASO management procedures are designed to accommodate and provide maximum benefits for the user; in a very real sense, the organization exists to perform a service for the scientific community. To the extent that flight safety requirements permit, the procedures are made as flexible and informal as possible. The success of this management approach rests squarely on the experimenter's acceptance of full responsibility for the performance and reliability of his equipment. Logically, this same definition of the experimenter's role should be the basic premise of a user-oriented Shuttle Sortie program. The program would then become one of working with the experimenter in an advisory and supportive role during the design, construction, and testing phases of experiment development, to assure that his equipment will meet safety and interface requirements, to define the environmental hazards to his equipment, and to encourage him (through funding) to plan and carry out a test program to validate experiment performance. Whether or not he does such testing, and to what extent, is presumably his decision, the wisdom of which will become apparent to him in flight. This approach obviously entails some risk, but if ASO experience is a valid guide, the first-time experimenter is willing to spend the time to assure his equipment will perform acceptably in the flight environment.

The ASO management approach outlined in section 3 thus can serve as a basis, both in concept and in practice, for a research management plan tailored to the orbital research environment. The unique features of the ASO approach may be summarized as follows:

1. Complete involvement and participation of the experimenter in the entire project.
2. Experimenter acceptance of total responsibility for the successful operation of his experiment.
3. Use of scientists as program managers.
4. Maintenance of a research environment at all times.

5. Minimum ASO interference in the experimenter's work.

6. Continuity and centralization of management in the same small staff (2 to 6 people), resulting in a single point of contact between experimenter and management throughout the entire mission.

7. Minimum documentation (fewer than 25 mission documents).

8. Participation of the program manager in the research flights as mission manager.

9. Physical proximity of the experiment installation and the flight operations facilities.

This management approach has produced high quality airborne research, at relatively low cost, for a wide spectrum of experiments and experimenters, in single-experiment and multiple-experiment missions, over a period of nine years. The motivated scientist has been shown capable of moving into the flight environment, with full responsibility for his experiment, to accomplish his research objectives on his first airborne mission.

The Experimenter and ASO Mission Management

The conduct of an experiment in the "airborne laboratory" or Shuttle Sortie Lab is analogous to ground laboratory research: similar advantages accrue when the originating scientist is in direct command. The experiment is at all times under his direct control; the authority and responsibility rest with one person who is willing to stake his professional reputation on the outcome, and is motivated accordingly.

When maximum experimenter involvement is combined with a streamlined, informal operations plan that can be implemented by small research groups in a time span of a few months, the base is laid for a program adaptable to experiments from many different scientific disciplines, with a minimum of formal reviews, coordination, and documentation to prepare for a mission. In particular, ASO experience in flight research management in terms of the experimenter's role and his relationship to the ASO program manager is directly applicable to Shuttle Sortie planning and a vital element in the success of the Airborne Science program.

The three main principles of the ASO management/experimenter interface can be summarized as follows:

1. A close working relationship should be established between experimenters and management staff and maintained throughout the entire program.

2. Management staff should be small but have full knowledge of the project and the authroity to provide experimenters with quick, decisive answers.

3. Offices of the management staff and of the major supporting group should be located as close as possible (within the same building) to the place where the experiments are installed in the Sortie Lab (or the payload carrier) so that they are readily accessible to the experimenters.

Experiment Design, Testing, and Installation

Design and Testing

In ASO practice, the design and proof testing of experiment hardware is completely at the discretion of the principal investigator, except that he must comply with flight safety requirements. The Experimenters' Handbook provides most of the safety, aircraft interface, and environmental information needed; specific questions related to the mission are answered by the mission manager. Thus, the experimenter's major concern is (within the stated constraints) to design and build an experiment with the desired measuring accuracy, and to verify by testing that it will operate reliably for periods of several hours at a time, and intermittently for a week to a month. At the same time, he must make provisions to monitor performance, to record data, and to accomplish maintenance functions.

The average, first-time experimenter with the ASO was successful in this effort: in well under a year, and with only 5 man-days of home-laboratory testing, he produced an experiment that obtained valid research data on almost every flight. The experience of ASO, as evaluated in this initial phase of the ASSESS study, demonstrates that in a relatively unrestrained research environment, the average research scientist is a competent judge of the effort required to develop a successful airborne experiment, and he is sufficiently motivated by the anticipated research rewards to carry his experiment through to completion. By inference, and given the same general approach to experiment management, the greater challenge and rewards of Shuttle research should elicit a commensurate response from participating scientists.

There is one aspect of the airborne research program that should be commented on, however. If the research scientist on his own does not have the design skills required to conform to flight safety requirements and to allow for the effects of aircraft environmental constraints, and the appropriate skills are not readily available, he may decide to depend primarily on consultation with the mission manager. While this approach usually proves satisfactory from the standpoint of flight safety, since the ASO has this responsibility and can supply the necessary support, the experiment may not perform as expected in the aircraft environment. Depending on the problem, a last minute fix may be devised before flight or the experimenter may have to contend with the problem throughout the mission. For example, vibration during takeoff or in rough air may loosen connectors and electronic circuit cards; or there may be a continual interference between experiments or from communication gear and power supplies. In the one-to-one, man-experiment ratio prevalent in airborne missions this inconvenience can be tolerated and an acceptable data return can still be achieved; on a Shuttle Sortie mission it might be highly undesirable. Thus, it would appear that Sortie experiments will require more careful monitoring in the design phase, to assure that the experimenter has the necessary support to properly address the known constraints.

Installation and Checkout

Experiments are assembled and installed without the use of mockups or test stands. Sufficient time (up to a week) is allowed for final fitting and cabling on location in the aircraft. This approach is workable because of the detailed instructions given in the Experimenters'

Handbook, the use of standard instrument racks, and the availability of support personnel. The entire process is handled informally, with the experimenter doing much of the mechanical work. Specialists in aircraft utilities and support systems are on hand to assure proper interfacing with the experiment; inspectors continually check the installation for conformance to safety regulations.

When the installation is complete, the experimenter checks out his equipment in the local environment for electrical interference from aircraft systems and adjacent experiments, and makes up whatever optical shielding he thinks necessary. A final opportunity for performance verification occurs during a checkout flight; operational procedures are also practiced and modified as appropriate. After the checkout flight, an additional day or two are allowed for final changes before the start of the mission.

Overall, the on-site preparation time varies from one to three weeks, with from one to four days for final checkout. Shorter times are characteristic of the one-experiment Lear Jet missions. In general, the experimenter who has much prior experience in airborne research or who uses an experiment he has frequently operated in ground-based research will seldom engage in more than a few hours of operational checkout. On the other hand, certain engineering development models of experiments for satellite or aircraft application have required many hours of calibration and in-situ performance evaluation.

Installation and checkout of Sortie-Lab experiments would undoubtedly be more controlled and intensive than for airborne experiments. The same functional elements should prevail, however, and given a similar time scale and experiment complexity, the experimenter could be expected to do most of the checkout and calibration of his own equipment, assisted by local support specialists.

Airborne Experiment Characteristics and Inflight Support

The airborne environment has a number of inherent characteristics that influence both experiment design and operational procedures. These include structural vibration, experiment power available, electrical noise, space and weight restrictions, outside air temperature, and ambient cabin pressure. Methods developed in the Airborne Science program to aid the experimenter in matching his experiment with the special requirements of airborne operation and to ensure its successful performance in flight can serve as a guide to Sortie-Lab designers. The physical parameters of current airborne experiments are representative of the researcher's design approach to a relatively lightly restricted situation.

Physical Parameters and Hardware Cost

Although Lear Jet experiments are limited as to volume, weight, and power, compared with CV-990 experiments, both groups can be characterized by the same numbers. Experiment weights for example, varied between extremes of 7 and 940 kg; a typical weight was 150 kg. Volume similarly varied from about 0.02 to 3.31 cubic meters, the typical value being 0.58. Experiment power had low and high values of 10 watts and 4200 watts, respectively, with 1000 watts being a typical value. With such wide variations in size and power it is not surprising that cost figures differ by an order of magnitude or more. Direct hardware costs (i.e., not including development costs, which can be substantial) ranged from $5000 to $450,000, with a fair number of experiments in the $40,000 region.

Support Personnel and Systems

In keeping with the service-directed aspects of ASO operations the management provides general purpose utilities, information systems, and services to support experiments in flight. Experiment support personnel and systems have a vital role in the conduct of airborne research missions; their use has evolved over a period of several years in response to experimenter requests. As such, the functions they perform are representative of the sorts of activities that will be required to support Shuttle Sortie experiments.

The basic utility is experiment power, available as 400-Hz and 60-Hz AC, and 28 VDC, in varying amounts as required. The total supply is 62 kVA in the CV-990 and 5.6 kVA in the Lear Jet. On occasion, 60-Hz power has been at a premium in both aircraft because of the frequent use by experimenters of standard laboratory components.

Other CV-990 utility/information systems provide timing signals, record and process experiment data, provide visual display of flight parameters, and measure aircraft stability. Each can be interfaced to the experimenter's station to enhance his operation with real-time information on the status of the flight. Continuous contact with the mission manager via the aircraft intercom system alerts the experimenter to upcoming events and changes in flight plan, as well as providing for coordination for and between experiments. All intercom messages are recorded on magnetic tape.

The experiment-support team for a major mission on the CV-990 consists of the mission manager, an assistant manager, the facilities manager, the data systems manager, an electronics technician and an aircraft mechanic. These latter two have assigned duties relative to direct aircraft support, but are available to assist experimenters when needed. The facilities and data-systems managers program, operate, and maintain the central data recording and computing system.

The Lear Jet aircraft does not have equivalent information systems. All data are recorded by the experimenters' equipment, which usually includes an audio recording system used for general information, timing of events, and pilot-furnished parameters. Since the Lear Jet does not carry a mission manager, the experimenter works closely with the pilots to achieve the optimum flight profile for scientific observations.

Auxiliary support systems provided for both aircraft by the ASO include special-purpose optical windows, gyro-stabilized mirrors, and photographic and television recording equipment.

Information Handling

The experimenter must predict the nature of his data and provide suitable units for recording and handling data as part of his experimental equipment. Thus, the variety of data-handling techniques is nearly as great as the number of experiments observed. ASO is available to consult and advise on the details of an experimenter's data plan, and can arrange for the experimenter to borrow some types of data-recording apparatus. Data records from CV-990 airborne experiments are stored onboard during a mission, in the form of chart rolls, magnetic tape, ADDAS printout or photographic film. The experimenter frequently examines his results during flight to verify experiment performance or occasionally to request a change of flight profile; also he may do some preliminary analysis between flights to guide his preparation for the next day. Transfer of research information out of the immediate mission does frequently occur, however, and in some cases generates feedback which may alter mission plans. This may be a telephone call to an associate at the home laboratory to discuss results, or an in-flight radio contact with other scientists whose surface-based observations are coordinated with flight observations in real time. This latter use of aircraft to ground communications occurred in all three of the remote-based CV-990 missions reported herein. In one mission there was an interchange of results between the aircraft and surface ships on a regular basis. Lear Jet flights are locally based and rarely use this mode of communication.

The ASO is responsible for the operation (hardware) and programming (software) of the Airborne Digital Data Acquisition System (ADDAS) on the CV-990. This equipment is used extensively by experimenters as a back-up recorder, and less often as a primary recorder, which provides a time-coded record of research data and aircraft flight parameters in the form of hard-copy printout and compatible magnetic tape. Simultaneously the system provides a visual display (closed-circuit television) of flight parameters and selected research data. These coordinative functions are a valuable input to real-time decisions and planning during a mission, and greatly simplify the post-mission data analysis. The use of the computer system to process raw data in real time as an integral part of the experiment depends on the experiment and its relation to the total payload. A payload may consist of several independent experiments, each with its own recorder, designed so that the operator scans a direct output at his work station. On the other hand, with a payload of coordinated experiments it may be absolutely necessary to process the separate inputs in real time to assess the overall result. Both types of payload have been observed in airborne missions; correspondingly, the onboard computer system is used primarily for its time-coded recording capability in the one extreme, and to its capacity as a data processing unit in the other. It is the experimenter's responsibility to match his data to the input requirements of ADDAS.

On the Lear Jet, the entire responsibility of data recording and handling is left to the individual experimenter. In this case, the responsibility of the ASO is limited to providing the necessary power to operate the experimenter's data system.

Despite the diversity of data-handling methods used in the 79 airborne experiments observed, certain procedural elements are common to most and will likely have counterparts in Shuttle research. For effective planning and control of experiment operations, the Sortie-Lab experimenter must have a real-time indication of data quality and a permanent record for review at the end of the observation period. He may obtain this record from his own built-in unit or from a central, on-board recording system; in either case, a time correlation is required with vehicle parameters and with other related experiments.

Some Sortie-Lab experimenters will require nearly real-time data processing to evaluate results, while others may perform substantial processing of raw data between observation periods as an aid in planning subsequent observations. A very few may require on-ground processing of the raw data, but most should be adequately serviced by a modest onboard computer facility. In airborne experience, nearly all of the experimenters used the flight-parameter/time correlation supplied by the on-board ADDAS computer, about 40 percent relied on some data processing during the flight, and less than 20 percent required special processing on the ground, other than the development of photographic film.

Equipment Performance and Reliability

Each scientist participating in the research programs of the Ames Airborne Science Office is responsible for the operation and reliability of his experiment, and to this end he conducts whatever environmental and operational tests are, in his judgment, necessary to assure an acceptable level of in-flight performance. In the area of equipment performance and reliability, once again the key element has been shown to be experimenter involvement.

Monitoring Equipment Performance

Little use is made of automatic devices to monitor the performance of airborne experiments. This function is usually performed by a member of the experiment team. The Sortie mission cannot afford the luxury of additional personnel for this purpose; an increased emphasis on monitoring devices is to be expected, at the expense of experiment simplicity. In current airborne experiments there is almost always some real-time indicator of performance, and as often as possible a real-time data record is available for inspection.

Repair of Malfunctions

The isolation and repair of equipment faults is one of the most vital functions to be performed by an experiment operator. It is the tradeoff against reliability that in large part justifies the manned experiment. However, by nature this function also requires both a well-designed experiment and a highly trained specialist. It is precisely in this area that the principal investigator is best able to balance the human factors and evaluate the hardware design tradeoffs to arrive at the best compromise for his particular experiment.

Repair experience with ASO airborne experiments is not wholly transferable to Shuttle, both because of the intermittent nature of the flight experience, and because of inflight team specialization and ground support personnel available between flights. Nevertheless, the observed trends are indicative of the experimenter's repair capability. Results show that a complete repair was effected during flight in one problem out of six and that an additional two were completed in time for the next scheduled flight. Thus, 3 out of 6 (or 50 percent) of the equipment malfunctions were repaired in the available time. The remaining 50 percent, with few exceptions, were sufficiently minor that the experimenter was soon able to devise a way to "live with" the problem and continue to produce useful data. Of the 79 experiments observed, only 7 missed a flight opportunity because of delayed repairs, and of these, 4 were able to rejoin the mission in its later stages. It is concluded that airborne experimenters (with rare exception) are able to cope with equipment failures and one way or another keep their experiment producing for the duration of the mission.

Indicators of Equipment Reliability

Equipment reliability among experiments observed in the initial ASSESS study phase is summarized here in terms of a number of indicators.

Flight experience was shown to be beneficial to the experimenter, and, unless an experiment was modified, an above-average rate of data return could be expected with repeated use of an experiment.

The consequences of a major change in basic experiment components (such as the sensor unit) were often underrated by the experimenter, and large data losses sometimes occurred on subsequent flights.

In terms of construction, malfunctions among off-the-shelf components were associated with more complex units and those being used for the first time in flight research. Experimenter-built components of complex optical systems and signal-processing systems incurred more than the average number of problems; in part, these problems were related to operational difficulties (such as alinement and stabilization of optics) but also appear traceable to marginal assembly procedures. Experiments having considerable prior use were significantly more reliable, incurring only one-half as many problems per flight, than those having little or no prior research record.

A relatively minor change makes a substantial decrease in all-data reliability factor and a corresponding large increase in problem frequency, while more extensive changes apparently do not have a commensurate influence. (This result is a strong argument for preflight testing of modified experiments.)

In terms of cost, both low-cost and high-cost experiments had a somewhat better reliability and a lower problem rate than those in the medium-cost range. Experiment complexity appeared to have relatively little influence on performance, suggesting that with sufficient care an airborne experiment of substantial complexity, in common with the simpler ones, will perform in an acceptable manner and yield a high rate of data return. To the extent that these two parameters are directly related, cost will tend to rise with complexity to maintain the same level of performance. Alternately, for similar complexities, increased cost may be an indicator of improved performance. For the present, however, the existing estimates of experiment complexity are too rough and qualitative to permit a valid assessment of these relationships.

The CV-990 ADDAS System

During the ASSESS observation period, the all-data reliability factor for the ADDAS system was 0.98; in only one flight out of 43 were any data lost. In the same period, potential data loss through failure of experimenters' recorders (20) was avoided by use of the ADDAS as a centralized backup recording system. Participating scientists regarded this backup capability as a valuable asset to the Airborne Science program.

Implications for the Shuttle

The record of performance achieved in the Airborne Science program reflects the combined abilities of some 126 experimenters who operated and maintained their equipment in airborne science missions, and identifies a baseline from which to project the performance and reliability of Shuttle research experiments.

With a few notable exceptions, preflight testing of the experiments carried on airborne missions is less extensive, by orders of magnitude, than that of unmanned or even Apollo-type space packages. Results show that even a modest program of testing (a few man-days) consistently produces experiments of acceptable reliability. It is notable that, on the average, first-time experiments performed as well as those which had flown before. This can be explained by the greater amount of testing done prior to an experiment's first mission, and by the adverse effect of experiment modifications (without adequate testing) on subsequent missions.

The ASSESS data on experiment reliability indicate the level of research effectiveness that is possible when the experimenter is directly involved in the flight program. Experiments assembled from relatively unsophisticated components and subjected to relatively little preflight testing performed their research functions on two of three flights with no noticeable malfunctions. Furthermore, despite the observed malfunctions of experimenters' equipment, in four out of five of all experiment flights there was still no loss of data, while in 19 out of 20 there was useful research data obtained. For the CV-990 program where experiment payloads are most representative of the Shuttle Sortie Lab, only 2 percent of the experiment flights were considered failures, and only 3 to 4 percent of scheduled flight opportunities were missed while repairs to equipment were underway.

Flight Planning

Flight planning for airborne missions remains open-ended to accommodate unforeseen events. Lear Jet operations and flight profiles can be planned daily, if need be, to take advantage of results from the previous flight, and inflight changes to extend observation time or to shift to an alternate target are not uncommon. CV-990 schedules are somewhat less flexible, particularly when flights are keyed to natural phenomena, satellite passes, or supporting ground-based observations. Mission schedules as published in the Experimenters' Bulletins are the accepted program of operations, although plans for observation are often modified before or during a flight to adjust to local conditions. To the extent possible in the more complex world of the Shuttle Sortie mission, the scheduling of events should allow for options to meet the normal contingencies of scientific research.

Prior to every major or unique aircraft mission involving airborne science experiments, the Airworthiness and Flight Safety Review Board inquires into special flight planning problems, the installation of experimental equipment, special problems of weight distribution, power availability, the method of cryogenic cooling, and any special procedures peculiar to the mission. Where flight planning involves departures from normal practice, the Board examines the special provisions made for communication and contingencies.

Safety Procedures

From 1965 until the present, the Airborne Science Office has had a perfect safety record in its program of scientific observation from high-altitude aircraft. This record was particularly impressive for a program of such magnitude; ASO aircraft have logged over 700 flight hours per year and have flown in all types of environments and in remote areas of the world. This exemplary record was attributed to the following factors:

- Strict compliance with aircraft maintenance procedures
- Established requirements for experiment design, construction, and installation
- Inflight safety provisions
- Review of the experiment aircraft installation and planned operations by the Airworthiness and Flight Safety Review Board
- Safety briefing given to all aircraft passengers and experimenters
- Preflight inspection of the aircraft and installed experiments
- Aircraft check flights
- Inherent responsibility of the personnel involved

Mission Documentation

ASO management of its Airborne Science program involves fewer than 25 documents, which initiate and manage activities from mission inception to experiment approval, through experiment and aircraft preparation, to mission completion. Once again, close experimenter/management cooperation and the all-encompassing experimenter role are key factors. Mission documents fall into two categories (1) ASO experimenter communications (e.g., AFO, proposal for flight experiment); and (2) aircraft preparation and mission operation (e.g., aircraft work order, flight plans).

NASA--ARC- Coml., Calif.