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SPACE TRANSPORTATION SYSTEM AS SEEN BY AN ASTRONAUT

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Abstract

The astronaut's role in space transportation is embodied in the Space Shuttle and its associated payload operations. This next-generation spacecraft represents the man-in-space system through the 1980's. A discussion of man's role in the Space Shuttle Program requires some reference to previous manned programs, as many tasks have foundations in the past. Generally, the work astronauts perform can be divided into piloting, experiments/payloads, and "other duties as assigned," which includes such tasks as systems management, extravehicular activity, and housekeeping. The emphasis on man's role will alter somewhat as the Shuttle system progresses from the initial test phase to the operational phase. The Shuttle is designed for automatic guidance, navigation, and control (GN&C), and the need for active piloting will decrease with system maturity. With the shift to onboard autonomous operation, the system management role will expand. Direct tasks with delivery/recovery and laboratory/observatory payloads will continue to expand throughout the program. The Shuttle assures man a role in space through the 1980's. The specific tasks include those involved with previous manned spacecraft as well as some new ones that are primarily associated with payloads. There will be a shift in emphasis regarding the astronaut's tasks as the Shuttle system matures.

I. Introduction

Most designers envision the astronaut's contribution on a space transportation system as that which is neither technically feasible nor cost effective to replace by automation. This is a reasonable conclusion for those whose logic is Earthbound. However, one must remember that to simply carry man along incurs a penalty in providing such necessities as life support, nutrition, and waste management systems, as well as a multitude of personal equipment. The opening statement should be inverted to read: use man wherever reasonable to garner a return on the overhead investment to allow him to exist. The reverse slant is the key to realizing man's utility. The designer would prefer to not be encumbered with the poorly defined and sometimes ineffectual human interface described by traits called skill and personality. For example, he will never get any criticism from an automatic control system. Thus, man will lose by default in many instances unless the motivation is to use man first where reasonable.

The near-term role of astronaut crewman is centered on the Space Shuttle, which represents the man-in-space system through the 1980's. This next-generation spacecraft is the first system specifically designed for space transportation in a commercial sense. Major elements of this system (Fig. 1) are the Orbiter, Space Shuttle main engine (SSME), external tank, and solid rocket booster. As the name implies, the goal of the Space Shuttle is to provide a means for "shuttling" payloads to and from orbit and to do this less expensively than the current family of boosters. Obviously, the Shuttle must be capable of handling a wide variety of payloads.

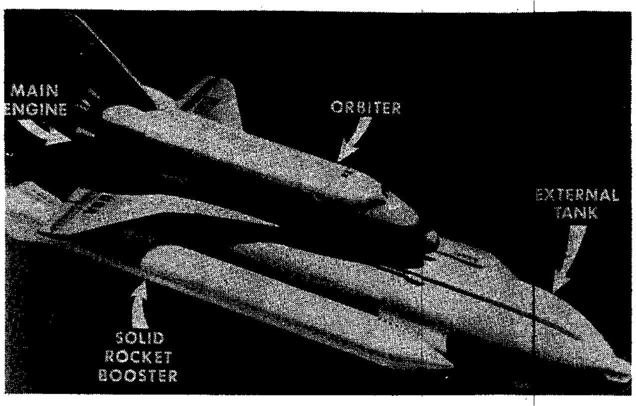

Fig. 1 Space Shuttle system.

To discuss man's role in the Space Shuttle Program warrants a review of previous manned programs to highlight what the astronaut's role and performance have been historically. The work flightcrews have performed can be divided into piloting tasks, experiment/payload tasks, and "other duties as assigned." The latter category includes such tasks as systems management, extravehicular activity (EVA), and housekeeping.

II. Piloting Tasks

A summary overview of the piloting or "stick and rudder" job that encompasses the dynamic phases of launch, rendezvous, docking, and entry/landing is given in Table 1. During the launch phase, the astronaut's role has covered the full range from "grit teeth" on Mercury to full backup guidance/navigation with partial backup control in Apollo. In actual flights, a manual takeover was never required, so the crew's role turned out to be one of trajectory monitoring and waiting, poised for something to go wrong. An indication of the astronaut's potential performance was demonstrated in several simulations; although he never performed as well as an automatic system, the performance loss caused by manual operation was negligible (Table 2). Another facet of the launch phase aside from GN&C problems is the potential hazard from the catastrophic mix of highly reactive materials used by the rocket engines to provide thrust. This hazard warrants an abort capability. Before the Mercury program, it was argued that a human might not be able to function either physically or emotionally; therefore, the range of astronaut abort capability varied from fully automatic with manual backup in Mercury to all manual thereafter. Exceptions were the Apollo and Skylab flights, which had an automatic abort capability provided during the first 2 minutes of flight.

Table 1 Astronaut capability

Phase	Program				
	Mercury	Gemini	Apollo	Skylab	Shuttle
Boost					
Control	None	Backup G&N	Backup G&N Partial backup control*	Backup G&N Partial backup control*	Backup guidance
Abort	Backup manual	Manual	Automatic for modes 1A/1B,** manual otherwise	Automatic for modes 1A/1B,** manual otherwise	Manual
Rendezvous	None				
Tracking		Manual	Automatic	Automatic	Automatic
Maneuvers		Manual	Manual	Automatic	Automatic
Braking		Manual	Manual	Manual	Manual
Docking	None	Manual	Manual	Manual	Manual
Major engine firings					
Control	None	None	Backup manual	Backup manual	Partial backup*
Start/stop	None	None	Backup manual	Backup manual	Partial backup*
Entry					
Retrofire	Manual backup	Manual backup	Manual backup	Manual backup	Partial backup manual*
Control	Manual backup	Manual through Gemini X Backup manual through Gemini XII	Backup manual	Backup manual	Partial backup manual*
Landing	None	None	None	None	Partial backup manual*

*Partial - no complete separate path or function.
**Modes 1A/1B - low altitude aborts.

Table 2 Automatic/manual control boost performance

System	Mission	Insertion velocity		Perigee		Apogee	
		m/sec	ft/sec	km	n. mi.	km	n. mi.
Automatic	Apollo 8	7793	25 567	184.5	99.6	185.2	100.0
Automatic	Apollo 9	7794	25 570	184.6	99.7	186.5	100.7
Automatic	Apollo 10	7793	25 568	184.6	99.7	185.7	100.3
Automatic	Apollo 11	7793	25 568	183.2	98.9	185.9	100.4
Automatic	Apollo 12	7792	25 566	181.1	97.8	185.4	100.1
Automatic	Apollo 13	7792	25 566	183.9	99.3	185.7	100.3
Manual	Simulation	7796	25 578	189.3	102.2	212.4	114.7
Manual	Simulation	7797	25 581	181.9	98.2	185.4	101.1
Manual	Simulation	7795	25 574	177.2	95.7	188.5	101.8
Manual	Simulation	7802	25 596	190.7	103.0	210.4	113.6
Manual	Simulation	7800	25 590	175.9	95.0	190.7	103.0
Manual	Simulation	7798	25 584	196.3	106.0	200.0	108.0
Manual	Simulation	7792	25 564	170.4	92.0	188.9	102.0

Rendezvous can be considered in the light of three tasks: pointing at the target, marking, and execution of burn maneuvers to include braking. With a few exceptions, this operation has been performed manually. The Apollo and Skylab vehicles had an automatic pointing capability, the Gemini and lunar module spacecraft radars provided automatic marking, and command module active maneuvers were automatically executed if performed with the service propulsion system (SPS) engine. Stationkeeping, which is a task similar to formation flying with aircraft, has always been a manual task, as has docking.

Major engine-burn maneuvers were nominally planned to be executed using whatever portion of automatic GN&C was inherently provided. For the Mercury and Gemini spacecraft, that represented control only, whereas Apollo had full automatic capability. The solid rocket retrofire packages used on Mercury and Gemini could be sequenced automatically or manually and continued until the fuel was depleted. Apollo engine maneuvers were primarily executed automatically. However, in all programs, the astronauts actively performed the backup function in this dynamic phase. The crew performed GN&C functions and manual engine start/stop, both for demonstration and for actual in-flight needs. Automatic control system problems on the Mercury 6, 7, and 9 missions required manual control for retrofire. Maneuvers were executed manually for demonstration purposes on the Apollo 7 and 9 flights and for actual need during the aborted Apollo 13 lunar mission. Three of the six total burn maneuvers on Apollo 13 were completely manual; otherwise, the automatic systems functioned well and the crew acted as monitors.

Automatic entry was planned for all Mercury flights; because of system failures, it was accomplished only on the Mercury 8 mission. For all other missions, entry control was either fully manual or manually assisted. It is difficult to assess pilot performance, but it bettered the automatic system fuel consumption in every case. Conversely, all Gemini entries through Gemini X were planned and flown manually. The last two missions used the automatic RE-ENT mode. The comparison data shown in Table 3 and Figure 2 indicate that the automatic system performance is comparable to manual control but is more repeatable.

Table 3 Gemini entry performance

Mission	Miss distance		Significant comments
	km	n. mi.	
II	26	14	Footprint shift
III	111	60	Lift-drag reduction
IV	81.5	44	Footprint shift, inoperative computer
V	168.5	91	Invalid position update
VI-A	13	7	No radar below 55 000 m (180 000 ft)
VII	11.8	6.4	Lift-drag reduction
VIII	2.6	1.4	Emergency entry
IX-A	.7	.38	
X	6.3	3.4	
XI	4.9	2.65	Automatic entry
XII	4.8	2.6	Automatic entry

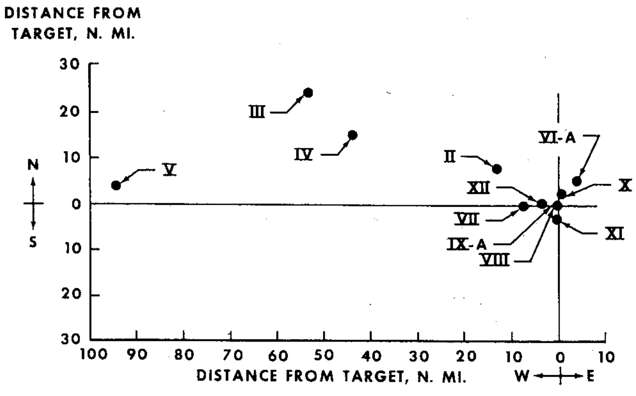

Fig. 2 Gemini relative landing points.

The Apollo Program reverted to Mercury logic in planning for all entries to be automatic. By that time, the automatic-system state of the art assured good performance, and all Apollo entries were performed automatically. Man was again in the role of monitor, awaiting a failure that never came.

What conclusions should be drawn concerning piloting tasks or the more basic question of automatic or manual? The span from Mercury to Apollo has clearly shown automatic systems to be superior with the exception of rendezvous/docking and overall flexibility. Automatic control is more accurate, can better handle reduced control margins, requires less fuel and control authority, and is more repeatable. The astronaut is more flexible overall and can do the job with fewer parts of the systems still operable. For example, the Apollo 14 docking problem was overcome by repetitive attempts that increased closure rates. Two midcourse corrections on Apollo 13 were made by alining on the cusps of a half Earth out the front window and the Sun through the Apollo optical telescope when the shortage of electric power did not permit the luxury of the automatic system with its array of power-consuming black boxes. Had an automatic lunar landing been attempted, the system could have "blindly" landed the lunar module with near-perfect attitude and descent rate on either the biggest rock or in the deepest hole on the Moon. All lunar landings were manually controlled.

III. Experiment/Payload Tasks

The scope of man's role in space in experiment/payload activities has grown continually (Fig. 3). From the beginning of Project Mercury, the crewman has been used to take photographs, make visual observations, and serve as an experiment himself for medical science. In Gemini, the role expanded to include that of a technician; the crew pushed and pulled levers or installed or removed brackets and/or packages. Apollo, through extensive preflight training for lunar orbit observations and lunar surface field geology, marked the first planned application of man as a practicing scientist. Skylab represented the greatest use of astronauts as trained practicing scientists with the flexibility to set up and maintain more than 50 different medical, scientific, engineering, technological, and Earth resources experiments.

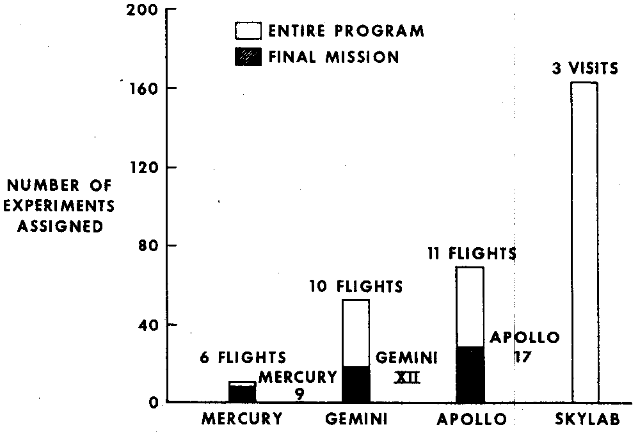

Fig. 3 Experiments.

Inclusion of in-flight experiments in Project Mercury was limited for several reasons. The basic program goal was to demonstrate that man could survive in space and adequately perform tasks in support of spacecraft operation - a piloting and systems management role. Added constraints were limited flight time, weight, volume, and consumables. Despite these limitations, the experiment payload weights increased from 11 pounds on Mercury 6 to 62 pounds on Mercury 9. Of the six general classes of experiments, the astronaut played a significant, active role in three: visual acquisition and perception, general photography, and medical experiments.(1) The data from the visual acquisition and perception experiment led to formulation of requirements for the lunar module tracking light used on Apollo rendezvous. Crew preflight photography training as was done for the later Apollo and Skylab meteorology and geology work was not provided; thus, except for "common sense" photography of sites that looked interesting, the Mercury astronauts primarily followed the flight plan in photographing horizons, weather, terrain, and dim light phenomena. The medical experiment was supported by taking preflight and postflight physicals and by existing in flight to provide a living subject for the usual array of sensors. This protocol was followed until the advent of Skylab with 16 medical experiments.

An impressive 54 experiments, some flown several times, were conducted in the Gemini Program. Fifty of these experiments did not exercise man's capability very far, except for the corollary difficulties encountered during EVA. The astronaut's role was mechanical, with the primary emphasis on setting up the experiment correctly, performing it at the correct time, and pointing it in the proper direction. The exceptions were experiments D-5, D-9, and T-2, in which the astronaut used a hand-held sextant to conduct onboard navigation. Another experiment, D-12, Astronaut Maneuvering Unit, would have been an extension of piloting skills but was never exercised.(2)

Apollo offered the first use of the crew as active, frontline scientific observers. From both lunar orbit and the lunar surface, astronauts assimilated information, made judgments, and qualitatively reported and documented data to validate their observations. This performance was supported by extensive preflight training in geology, particularly after Apollo 11 when the basic program goal was achieved. The stretched-out launch schedule provided time for much needed additional training. The success of turning astronaut pilots into field geologists is well documented with thousands of photographs and air-to-ground voice transcriptions from the lunar surface. On the last Apollo mission, the reversed flexibility of man was demonstrated by Dr. Harrison Schmitt, a scientist astronaut geologist who also performed as a first-rate pilot.

A total of 70 experiments were flown on the Apollo missions, but, with the major exceptions previously discussed, the astronauts were relegated to serve as engineering technicians. Some notable examples were the command and service module scientific instrument module (SIM) bay activities from lunar orbit, and lunar surface EVA activities other than field geology. The SIM bay contained a variety of camera equipment and sensors that required an astronaut to activate, deactivate, deploy, stow, remove covers, and, finally, to perform an EVA between Earth and Moon to retrieve film canisters. For the most part, these were rote tasks following written checklists and flight plans, with flexibility permitted if something failed. Almost any activity on the lunar surface was hard physical labor because of the encumbrance of a pressure suit. All crews experienced fatigue after wearing the suit for 4 to 7 hours. Everything used had to be first unstowed and some had to then be set up in operable form. Two of the major operations involved the lunar roving vehicle (LRV) and the Apollo lunar surface experiments package (ALSEP). The LRV deployment required 46 procedural steps to be operational, and approximately 50 Boyd bolts had to be released to set up the ALSEP in addition to the placement, alinement, and switch activation tasks. Also contributing to the pressure on the crewman were the EVA time constraints because of the backpack consumables and the lunar module constraints relative to total stay time on the lunar surface.

In contrast to the main goal of Apollo of landing man on the Moon and returning safely within the decade of the 1960's, all the Skylab goals were related to experiments. The four major goals were to study the Earth, the Sun, man, and space technology. In achieving these goals, the astronauts acted in greater depth and for longer periods as scientific observers and technicians operating a variety of equipment. In some isolated cases during previous programs, the crew performed spacecraft repairs; on Skylab, this capability actually saved the mission.

The Skylab astronauts functioned as scientist experimenters on more than 40 experiments. Primary examples are the Apollo telescope mount (ATM), the comet Kohoutek, the zero-gravity flammability (M479), and the materials processing in space (M512) experiments.

The ATM instruments surpassed earlier solar observations by a factor of as much as 50 and spectral resolution by a factor of as much as 100.(3) The astronauts controlled this sophisticated equipment through the display and control panel shown in Figure 4. Because of their advantage in having a real-time display capability not existing on the

Fig. 4 The ATM display and control panel.

ground, the crews were able to select areas of interest that were not otherwise detectable on the ground. The astronauts were also able to recognize solar events of interest and to select the mode or modes that would yield the most valuable data. An example is the documentation of a solar flare event from its birth or rise.

In addition to documenting the comet Kohoutek with film using five different sensors, the astronauts sketched the shape of the comet and described various colorations and light intensities. Crew commentary describing the burning phenomena on 37 specimens complemented the photographic coverage of the zero-gravity flammability experiment. The materials processing in space experiment used an electron beam gun for metals melting and a sphere-forming experiment. The proper settings on the electron beam guns were largely a matter of judgment on the part of the crew.(3) More than 850 crew observations supported by 2000 photographs in an Earth observation experiment confirm man's capability to recognize features, to integrate observations, to reason, and to describe more than is practical on an automatic preprogramed basis.(4)

The Skylab astronauts fulfilled many experiment needs as technician operators as did their predecessors, and they also participated to a significant extent in the areas of real-time planning, film management, experiment pointing, and data management. These latter crew functions came to the forefront because of the nature of Skylab. The long-duration flights permitted relaxed time constraints, the amount of film was an order of magnitude greater than previously, and the variety of experiments allowed the flexibility to shift emphasis if, for example, cloud cover precluded sighting a ground target.

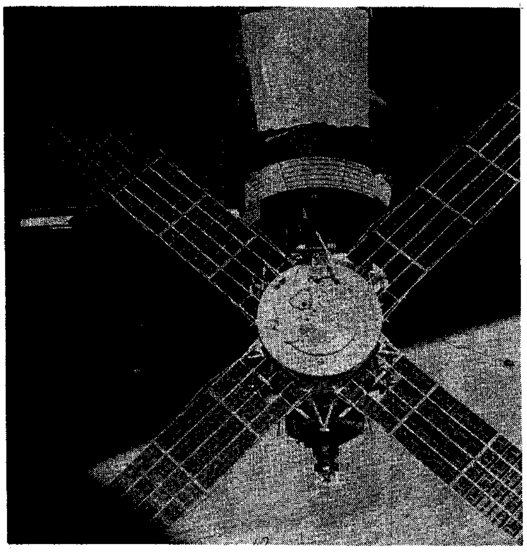

Fig. 5 Skylab parasol sunshade.

Lastly, the contingency situation caused by loss of the orbital workshop thermal shield forced a double rendition of astronaut flexibility in performing workarounds. In overcoming heating problems caused by launch damage, the workshop environment was made habitable by crew deployment of a parasol (Fig. 5) through the solar scientific airlock. This created another problem in that six experiments had been planned to use the airlock made useless by the parasol. The recovery mode was crew EVA. The only originally planned EVA activities involved installation and retrieval of ATM film, but, during the three-mission program, more than 50 additional extravehicular tasks were performed.

Major crew duties under the last category of "other duties as assigned" are systems management, EVA, and housekeeping.

IV. Systems Management Tasks

Systems management includes monitoring for status and consumables management, troubleshooting malfunctions, and effecting repairs where feasible. The Mercury astronauts demonstrated the capability to handle the first two categories. There is strong support from the ground mission control complex; however, the crew must survive in Earth orbit for lengthy periods without ground contact. Likewise, half of each lunar orbit placed all the responsibility on board the spacecraft.

The repair of spacecraft really did not get underway until Apollo and came into full swing during Skylab. There were no plans or provisions for repair of equipment in Apollo, so any workaround had to be accomplished with whatever stowage item might fit the need. Probably the most complex repair was that performed on Apollo 13 to improvise use of a command and service module lithium hydroxide cartridge in the lunar module environmental control system. This involved use of a stiff cardboard cover from a checklist, plastic wrapping material, and a large amount of gray tape. The list of repairs performed by Skylab crews is too extensive to discuss, but abbreviated listings of system repairs and experiment repairs are provided in Tables 4 and 5, respectively. In summary, crew repairs and workarounds saved the entire Skylab Program.

V. Extravehicular Activity

Extravehicular activity was introduced on the Gemini IV mission and rapidly advanced from a demonstration to a normal way of supporting the scientific experiment user as well as effecting external repairs to the spacecraft. This capability has been adequately described in the preceding paragraphs. An appreciation of the extent of crew use for EVA can be derived from Table 6.

VI. Housekeeping

Housekeeping involves many of the same tasks associated with this terminology on the ground: eating, sleeping, keeping a neat spacecraft, personal hygiene, and waste management. These tasks were introduced in space flight almost in the order listed. The crew had to eat and sleep even on the 1-day Mercury 9 flight, and the cleaning task - or rather keeping track of stowed equipment - grew

Table 4 System repairs and maintenance (3)

System	Abnormal condition	Corrective action
Structure		
Orbital workshop micrometeorite shield (thermal control)	Shield torn off during launch	Skylab parasol and twin pole sunshade deployed, the latter by EVA
Electrical power		
Orbital assembly solar array system	Solar array wing 2 broken off; wing 1 failed to deploy	Wing deployed during EVA
Orbital assembly charger/battery/ regulator module 15	Stuck relay in regulator	Stuck relay freed by EVA crewman striking spacecraft with hammer in vicinity of relay
Attitude control		
Orbital assembly rate-sensing system	Deterioration in performance of rate gyros	Rate gyro "six-pack" installed
Environmental control		
Thermal control system	Leakage of coolant fluid	Fluid replenished
Refrigeration system	Failed primary/secondary loop bypass valves in partial radiator position	Connector J5 disconnected
Apollo telescope mount control and display panel cooling system	Gas bubbles in cooling fluid	Spare liquid/gas separator installed
Airlock module primary coolant loop	Contamination caused temperature control valve to stick in cold position	Valve resumed operation during troubleshooting
Life support		
Orbital workshop hatch check valves	Check valves leaked	Check valve orifices taped
Orbital workshop vent valve	Vent valves remained open after close commands sent	Valves purged and cleaned
1034-kN/m^2 (150 psi) nitrogen pressure regulator	Nitrogen pressure regulator 69 to 104 kN/m^2 (10 to 15 psi) low	Placed on a 5-day duty cycle
Urine receptacle suction line	Rubber washer loose	New washer installed by crew
Communications		
Transmitter	Transmitter C inoperative	Crewman reset circuit breaker on panel 200
Airlock module tape recorder	Tape slipped off capstan	Crew repositioned tape
Television camera	Color wheel not rotating	Crew removed lens and started wheel manually
Teleprinter	Printout difficult to read	Teleprinter head cleaned
Life support		
Molecular sieves A and B partial pressure carbon dioxide	Erratic readings	A and B sensors replaced, O-ring on molecular sieve B partial pressure carbon dioxide inlet end cap replaced
Condensate dump	Dump probe iced up	Dump probe replaced
Waste management compartment water dispenser	Low water flow	Replaced with spare
Waste management compartment squeezer	Leaked around seal	Seal replaced
Airlock module electrical power system		
Fine sensor control panel	Panel 392 failed test	Sensor replaced with spare

Table 4 Concluded

System	Abnormal condition	Corrective action
Communications		
Television input station	Broken connector pin on television input station 642	Replaced with spare
Television monitor	No video	Monitor and cable replaced
Television power cable	Coaxial lead failed in power cable	Power cable replaced
Airlock module tape recorder	Three recorders failed	Replaced with spares
Teleprinter	Paper feed mechanism inoperative	Teleprinter head assembly replaced with spare unit
Speaker-intercom assembly	Switch failures on two units	Assemblies replaced with spares
Video tape recorder	Failed to transmit recorded signals	Electronics and transport units replaced with spares

Table 5 Experiment repair and maintenance(3)

Experiment	Abnormal condition	Corrective action
Apollo telescope mount		
White Light Coronagraph (S052)	Contamination on occulting disk	Contamination brushed off disk during EVA
X-Ray Spectrographic Telescope (S054)	Drive mechanism on aperture door failed	Door manually opened by removing release pins during EVA
	Filter wheel jammed between two filter positions	Wheel moved to open position during EVA
Ultraviolet Scanning Poly-Chromator-Spectroheliometer (S055A)	Aperture door ramp latch binding	Door ramp latch removed during EVA
Extreme Ultraviolet Coronal Spectroheliograph (S082A)	Aperture door ramp latches binding	Door pinned open during EVA
Chromospheric Extreme Ultraviolet Spectrograph (S082B)	Exposure timer operating erratically	Replacement timer installed
	Cover on hydrogen-alpha 2 telescope aperture operating intermittently	Cover pinned open during EVA
Image Scope Television Monitor (S082A/B)	Monitor inoperative	New monitor installed
Earth resources experiment package		
Multispectral Scanner (S192)	Improperly seated cooler/detector	Reseated and realined
	Incorrect prelaunch attenuator adjustments	Attenuator adjusted
	Detector did not provide desired resolution	Modified thermal detector installed
Microwave Radiometer/Scatterometer and Altimeter (S193)	Electrical short caused erratic antenna motion	Antenna pinned in 0° pitch position during EVA

Table 5 Concluded

Experiment	Abnormal condition	Corrective action
Biomedical		
Sleep Monitoring (M133)	Cap electrodes dried out	Rejuvenation kits used
Mark I Exerciser	Spring broke	Spring replaced
Specimen Mass Measurement Device (M074)	Electronics module failed on wardroom device	Replaced with module from waste management compartment unit
Corollary		
Nuclear Emulsion (S009)	Detector package motor failed	Motor replaced
Articulated mirror system	Tilt control jammed	Crew freed tilt adjustment gears
	Mirror surface contaminated	New mirror installed
	Mirror position indicator	Mirror positioned by counting control knob turns
Ultraviolet Panorama (S183)	Film plate jammed	Malfunction procedure used for carousel alinement
	Electrical failure in protective circuit	Jumper wires connected
Apollo telescope mount		
Persistence Image Scope	Fuzzy image, poorly defined bright spots, and horizontal bright lines	Contacts cleaned and batteries changed
Earth resources experiment package		
Multispectral Photographic Cameras (S190A)	No film motion at camera station 6	Station 6 magazine replaced
	Dust particles on optics and film emulsion buildup on platens	Cleaned with cleaning kits
Tape recorder	Metal oxide buildup on recording heads	Contamination removed from heads and tape rollers
Biomedical		
Sleep Monitoring (M133)	Improper operation of indicator lights	Cable replaced
	Lack of telemetry data	Two experiment cables replaced
Lower Body Negative Pressure (M092)	Blood pressure measuring cuff failed	Cuff replaced

Table 6 Extravehicular activity

Program	Man-hours (hr:min)	Number of times performed	Number of crewmen
Mercury	None	None	None
Gemini (EVA on five flights)	12:25	9	5
Apollo (EVA on seven flights)	166:56	19	17
Skylab (EVA on all three visits)	81:58	10	9

from a few items in Mercury to more than 40 000 potentially loose items in Skylab. The significance is that all this stowing activity takes time; an average of more than 60 percent of each Skylab working day was spent by the crew in this mundane role.

VII. Crew Role in Space Shuttle

What is the picture for the astronaut in the future? What is his role in Space Shuttle? To begin, the Shuttle configuration poses a more complex control task both during launch and entry/landing. Boost control is effected by a combination of thrust vector control (TVC) between three liquid hydrogen/oxygen engines (SSME) and two strap-on solid rocket boosters. There is a variance in thrust as well as in gimbal rate between the two. Because of the lifting surfaces (wing and vertical tail), control inputs must not exceed sideslip (beta) and angle-of-attack (alpha) limits relative to dynamic pressure. Because this winged lifting-entry spacecraft must land on a runway, the aborts are more complex than for previous spacecraft. On Mercury, Gemini, and Apollo, if the spacecraft separated and landed with the blunt end first, the job was essentially done. An engine throttling task is also imposed for the first time on the Space Shuttle.

On entry, the Orbiter is inherently unstable laterally to low supersonic speeds and is unstable longitudinally all the way through landing with most center-of-gravity loadings. The control logic initially is a blend of aerodynamic surfaces (elevons) and reaction control system (RCS) motors. Lateral-directional control is complicated by the initial requirement at high angles of attack (>30°) for a reverse elevon logic. Minimum controllability occurs at a Mach number of 5.0, and the rudder is used with all the above to provide the maximum "control muscle." Shortly thereafter, the RCS is no longer required and control is like that for normal aircraft with conventional elevons used for roll control.

The subsonic lift-to-drag (L/D) ratio approximates that of the X-15 experimental rocket aircraft. The resulting deadstick landing approach is as much as 24°, and flare is initiated from just below an altitude of 2000 feet with the landing gear lowered some 20 seconds before touchdown.

These control tasks result in complex control logic for stability and a difficult piloting task. Full automatic control capability is provided, but man's flexibility will require his piloting skills in the development phase. Because of the special case of an air launch from a Boeing 747 aircraft and the relatively short flight time, the initial approach and landing test (ALT) flight will be flown using a manual control steering mode. In the vertical or orbital flight test program, the primary control mode will be automatic, with the possible exception of subsonic flight and landing, as the only automatic landing scheduled during the ALT is a demonstration. However, the crew will be prepared to take over with manual control steering or a direct mode in all mission phases. With the repetitive Shuttle operations for hundreds of flights, the automatic system will mature and become the predominant way of flying Shuttle to and from orbit. The piloting job on orbit remains the same as in Apollo relative to major engine firings and rendezvous/docking.

Conversely, the crew's activities with experiments and payload will be phased in slowly but will continually grow in both magnitude and variety. There are two classes of payloads: delivery/recovery and laboratory/observatory (Fig. 6). Examples of the former would be communication and navigation satellites, and the European Spacelab is a laboratory/observatory variety. Astronauts will perform monitoring and servicing roles to support such payloads as a communication satellite with an attendant upper stage. The Skylab crew work on the ATM experiment approximates the astronaut role with the Spacelab. However, even in this case, the crew will serve as technicians in activating and deactivating the Spacelab and its multitude of experiments. Obviously, new types of payloads will appear during the course of the Shuttle lifetime that will require continually increasing crew participation.

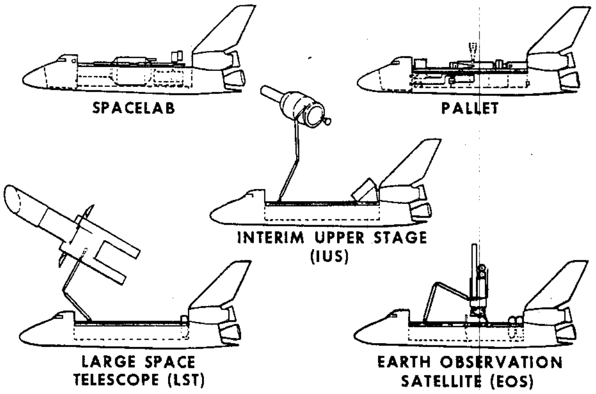

Fig. 6 Space Shuttle payload carriers.

Under "other duties as assigned," the systems management tasks offer the greatest distinction from previous programs. Eventually, the Shuttle will operate autonomously, which necessitates an onboard capability approaching that of the mission control ground complex. For maximum efficiency, it is planned to have split-shift crew operation in support of the Spacelab to maximize data return. The crew cabin is divided into an upper deck work area and a downstairs living area to permit continuous operation, in contrast to the previous "all crew sleep simultaneous" mode of operation, thereby significantly reducing time lost in housekeeping.

VIII. Summary

The astronaut's piloting skills will be used primarily in the early days of Shuttle, reverting to a monitor role with the maturity of automatic systems. The crew role will continue to expand in conjunction with experiments/payloads and overall systems management. Rendezvous/docking, extravehicular activity, and housekeeping tasks will be similar to those outlined from previous programs.

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