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Space Station Crew Workload: Station Operations and Customer Accommodations

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ABSTRACT

The crew of the Space Station will divide their time between caring for the station systems and operating and maintaining payloads. Because of the relatively non-stressful flight regime, the long duration program life, and advances in automation and robotics they can devote more work time to payloads than in previous manned programs.

THE GOAL for putting men into space has always been to determine their ability to live there productively and then to do useful work. Past programs, of necessity, have placed great emphasis on getting them there and back again safely with a corresponding impact on the time or ability to perform payload operations. This paper will present the unique aspects of the Space Station that will allow the crew to spend the majority of their work time on payload operations. It will also give limited detail of typical tasks they will be doing.

HISTORY OF CREW OPERATIONS

The first manned programs, Mercury and Gemini, were almost totally engineering feats, developing the techniques for safe launch and entry, automatic controls and manual backups, and tests on-orbit to determine the capabilities of man and machine in a strange environment. Most of the Mercury flights were too short to consider doing any extensive scientific investigations. Gordon Cooper's flight, lasting more than a day, did carry a few simple payloads, and he did do some Earth observation (1). Though the Gemini program included a group of 52 scientific experiments ranging from astronomy to biological studies to communications tests (2), the heart of the Gemini project was to develop techniques for rendezvous and orbital maneuvering that would be necessary in the already announced Apollo program.

It could be argued that Apollo was a science program and, indeed, the data gathered from the six lunar landings was monumental. Apollo was foremost a hardware development program, however. Many finely tuned systems and man-machine interfaces had to be developed to make the lunar landing possible.

In the wake of the Apollo success, the Space Program took a turn from the spectacular to the utilitarian. Skylab would use some of the Apollo hardware as a means of achieving long duration flight in Earth orbit and would be the first program devoted almost entirely to science. Indeed, almost 12,000 man-hours were spent conducting scientific investigations (3). Yet the crew who conducted the investigations in the orbiting laboratory were also the ones that had to guide the spacecraft to and from the laboratory, who repaired the damaged solar panel assembly, who set in place two different sun shades to keep the temperature of the lab at a livable level, who performed numerous maintenance tasks, scheduled and unscheduled. So, though the emphasis was on science, there was still a heavy flavor of flight operations and systems support activity in the crew's day.

With the advent of the Space Transportation System (STS) a decade later, with the Shuttle as the focal point, America's Space Program had come a long way. Space was easier to get to. The scientist could go along with his equipment and a real distinction among crewmembers developed - the mission specialist and the payload specialist. The program was beginning to be customer

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The features of the **Space Station** which permit **crew** members to utilize work time for payload operations are discussed. The user orientation, modular design, nonstressful flight regime, in **space** construction, on board control, automation and robotics, and maintenance and servicing of the **Space Station** are examined. The proposed **crew** size, skills, and functions as **station** operator and mission specialists are described. Mission objectives and **crew** functions, which include performing material processing, life science and astronomy experiments, satellite and payload equipment servicing, systems monitoring and control, maintenance and repair, Orbital Maneuvering Vehicle and Mobile Remote Manipulator System operations, on board planning, housekeeping, and health maintenance and recreation, are studied.
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oriented. At the same time, the crew demonstrated a wide range of abilities in retrieving and repairing faulty equipment that in previous programs would have been abandoned or discarded. Commercially viable space operations were on the verge of reality.

THE SPACE STATION - HOW IT DIFFERS FROM PAST PROGRAMS

There are several basic differences in the station program that will dramatically affect crew operations.

USER ORIENTATION - As already mentioned the United States Space Program has been evolving toward accommodating those users who want to work in space. What makes the Space Station program different is that these user accommodations are being considered right from the conceptualization of the program, before any cutting of metal has begun. How the station is to be used is driving how it is to be built. In the crew area this means building in those features desired by scientist-type astronauts to help them in conducting their experimentation. Data systems and computers will be sized for payload use. In fact, the basic configuration of the station is being driven more by the payloads that will attach to it than the more familiar factors of past designs.

PROGRAM LIFE - Apollo had a decade. Skylab was to be three separate missions of long duration. The STS flights are short and bounded. In essence, past programs have been put together knowing they were a step in the ladder, to be replaced by a follow-on program. Space Station is intended to operate for a long time, basically open-ended. This will be reflected in how operations are conducted. The very tightly packed and optimized plan of crew operations found in past flights will not be necessary. There will be flexibility and time for reflection in-flight.

GROWTH - The station is being designed to grow as demanded, in size and in capability. It will allow for improvements in state-of-the-art equipment. New users that appear after the original design is complete can be accommodated by adding on or modifying. This station will not be thrown away in order to build a new and better one; it will evolve into a better one.

NONSTRESSFUL FLIGHT REGIME - In all past programs each mission included the launch and entry, highly stressful periods that taxed the crew and the systems to their maximum. Safety dictated that much of the hardware design, the crew training, the procedures development, the preflight simulations, and the systems verification be concentrated on these two periods which in the real flight comprised a very small portion of the overall mission. And this, as much as anything, limited the effectiveness of the payload operations. The station, however, once assembled will stay there in the very benign conditions of Earth orbit. True, each piece must survive a launch to get there, but then the "shake-rattle-and-roll" will be over.

ASSEMBLY AND CHECKOUT - In all other programs the hardware left the ground in the configuration it was to be used throughout the mission. It was checked out in its assembled state on the ground before launch. Space Station hardware will come together for the first time as a whole in orbit. Crews will assemble it largely by hand while extravehicular (EVA). This will be a very labor-intensive time for the assembly crew and will involve techniques of materials handling and use of tools never tried before. Once the basic station is complete, these assembly operations will still be required to mount payloads to the station structure or to add station structure as part of the growth process.

The interior of the crew modules will also probably be outfitted on-orbit with modular equipment because of the launch weight restrictions of the STS. There will likely be plug in provisions for electrical power, water, and other utilities. This modular concept will give good flexibility in reoutfitting later, in allowing access for maintenance and repair, and in providing for changeout of broken or outdated equipment.

All this on-orbit construction will lead to the kind of integrated systems checkouts normally done at the Kennedy Space Center before launch on previous programs. The crew will be test conductors as they try to verify the equipment and locate problems.

ONBOARD AUTONOMY - All flights to date have relied on a large ground support complex to do many of the things the vehicle was not designed for or to provide services to the crewmen whose time and abilities are limited. A normal flight was not possible without this support; a contingency situation was made worse if the ground support was not there. This ground support is very consumptive of manpower and program dollars. For those reasons a goal of the Space

Station is to approach autonomy with little reliance on the ground. (Total autonomy may be achievable but not cost-effective.) This will mean that the crew will do much of the day-to-day planning of activities, unlike previous crews who had preflight timelines to follow or corrected ones sent up from the control center. They will have sophisticated computer tools to answer questions that are now posed to the ground. Some systems and procedures training will be done in-flight at versatile work stations rather than preflight in expensive simulators. The goal is to shrink the ground support to a practical minimum and put the necessary control onboard.

AUTOMATION AND ROBOTICS - The developments in this area over the last 10 years (since the Shuttle was designed) and the promise of greater things to come during the life of the station dictate that automation and robotics be built into the design to increase crew efficiency and productivity. The precise applications are still being determined. For sure, it means man and machine cooperating in ways beyond what we have done so far in space. Exotic computer applications and software, sophisticated equipment design, and use of emerging technologies are being considered. The overriding station ground rule that all equipment be "user friendly" means that this technology must be harnessed at the crewman's command.

LOGISTICS, MAINTENANCE, AND SERVICING - There was no need to worry resupply in the past like will be done on the station. Stores of equipment replacements, spare parts, and consumables will be required to keep it going over its lifetime. A logistics system will be developed to keep track of supplies, to predict changeout intervals, to schedule the needed articles on the next resupply flight, and to set the ground logistics machinery in motion to get those articles onboard that flight. In this regard, the crew will be "hardware store managers."

They will also have to become good repairmen. It will be impossible and/or impractical to stock replacements for all the thousands of black boxes contained on the station so it will be necessary to get into some of these boxes and restore them to operating condition. Even with the high standards placed on equipment to be flown in space, the large number of parts will dictate that replacement/repair/retest be a significant portion of the crew's time.

To preclude devoting too much time to repair, considerable servicing of equipment will be done to extend its useful life. Some of this will be simplified using automatic fault detection and load sharing equipment, others will be straight "grease gun" operations.

CREW DEFINITION AND ALLOCATION OF CREW RESOURCES

CREW SIZE - The number of crewmen at the beginning of the Space Station program or as it grows has not been determined. Early studies (4) assumed 6; larger numbers of 12 or more are being considered now to man the station at initial operational capability (IOC) in the early 1990's. It is desired to put as many onboard as practical to increase the customer support, but ultimately cost will drive crew size.

SKILL TYPES AND LEVELS - The limit on crew size will have a large bearing on the missions or payloads to be flown. The customers have been identifying their requirements of the crew; i.e., what type of skills and to what level must the crewman be trained to operate the instrument. The current Mission Requirements Data Base (MRDB) (5) that contains detailed descriptions of all the identified missions has defined seven basic skill types and three skill levels. These are:

SKILL TYPES	SKILL LEVELS
1. No special skill	1. Task trainable
2. Medical/biological	2. Technician
3. Physical sciences	3. Professional
4. Earth and Ocean Sciences	
5. Engineering	
6. Astronomy	
7. Spacecraft systems	

Each of the possible 21 combinations is meant to be a unique kind of individual. Therefore, a user may want a 2-3 crewman (medical professional) to perform his mission and no other combination would qualify. Unfortunately, a set of missions could be manifested to fly at a given time that would require more skill type-level combinations than there are crewmen. The solution to this problem would be to either (1) remove some payloads from the manifest, (2) accept a different type-level combination crewman than desired, or (3) automate some or all of the functions. With many of the payloads being proposed the automation option is either impossible or cost prohibitive. And many want to take full advantage of the opportunity afforded by the station to have their own operator there. So this crew size and skill mix problem will affect manifesting for some time.

CREW DEFINITION - Of the 12 member crew being proposed, 6 each would form a team and each team would control station operations for a 12 hour shift. Of the six, one would be a station operator responsible for keeping the core station systems running properly to support the conduct of payload operations by the other five. These five would be mission specialists who would perform various payload functions depending on their skill qualifications. The two teams would alternate working 12 hour shifts to support a complete 24 hour per day station operation.

Each station operator will be scheduled for 8 hours of his work shift to do systems management, maintenance, statusing, reconfiguration, and malfunction diagnosis. The remaining 4 hours he will be on-call while he eats lunch, does replanning, participates in training exercises for proficiency, and gets some physical exercise. The mission specialists are scheduled for 9 hours per shift of payload operations and are on-call for the other 3 hours. Allowing for one day per week off duty for each crewman, a total of 540 man-hours per week are schedulable for payload operations.

MISSION DEFINITION

The current MRDB shows 323 distinct missions desiring to be included in the Space Station program. These can be divided into seven basic categories:

1. Commercial applications missions sponsored by the NASA Office of Commercial Programs.

2. Earth observations missions sponsored by the National Oceanic and Atmospheric Administration.

3. Science and applications missions sponsored by the NASA Office of Space Science and Applications.

4. Technology development missions sponsored by the NASA Office of Aeronautics and Space Technology.

5. Canadian missions.

6. European missions.

7. Japanese missions.

Our international partners from Canada, Europe, and Japan also want to supply major pieces of the Space Station complex. The Japanese and Europeans want to build laboratory modules that can plug into the other core modules and do independent research. The Japanese laboratory would be used for a variety of experimental disciplines, from materials science to astronomy to life science. ESA is proposing either a materials laboratory or a medical/biological laboratory. Canada has expressed interest in providing a satellite servicing facility to be attached to the station structure at the appropriate location. The joint agreements with these international groups includes providing for international crew members in the crew complement.

Of these many defined missions, several are in the areas of materials processing and life sciences. The United States will include two laboratory modules in the configuration devoted to these two disciplines (6). In the astronomy and Earth observation disciplines, many instruments will be hung on the outside structure to perform Earth, solar, and celestial observations. Those missions required to operate physically apart from the station can be maneuvered to those locations by use of an Orbital Maneuvering Vehicle (OMV) or Orbit Transfer Vehicle (OTV). The OMV and OTV will be hangared at the station for assembly and checkout with the payload and for servicing of fuel and other consumables and can be remotely operated to return to the station after payload delivery.

PLANNED CREW OPERATIONS

The following list of crew functions will be considered in designing station hardware and crew accommodations. They fit into two categories as previously stated: customer support and station (or facility) operations. They can be further divided into two basic types of activities: intravehicular (IVA) and EVA depending on their location either inside the pressurized modules or outside requiring a pressurized suit.

CUSTOMER SUPPORT, IVA - A design goal of the station is to allow as many of the crew functions as possible to be done in a shirt sleeve environment inside the pressurized modules. The overhead is substantial for doing EVA operations and will impact overall station efficiency and productivity. The currently proposed IVA payload operations fit into three general categories; materials processing, life sciences, and external observations. There will be some miscellaneous payload tasks that do not fit either of these areas.

Materials Processing - The routine operations for materials processing include loading and unloading the samples in various furnaces or other controlled heating devices, monitoring the processes, and operating photo recording equipment to document the process. A materials expert would also be able to observe and even control the process and to directly influence the outcome of the sample. For example, if a crystal were growing with imperfections he could etch it back to a good surface. There are many controllable parameters that influence these processes and the expert can investigate them individually or in combination to establish process control criteria.

Life Sciences Experimentation - The effects of zero gravity on the human body are still largely unknown or poorly understood. Much data on many subjects will be taken over a long period before solid conclusions will be reached. Because crew resources will be a precious commodity on the station and because of the limit on the symptoms that can be imposed, animals will be used for much of this data collection. The crew will provide care for these animals and perform various tests on them. Part of the crew will act as subjects for certain tests. The doctors onboard will conduct the more elaborate tests and will be responsible for the health and well-being of the crew and the animal subjects.

Astronomy, Solar, and Earth Observations - Most of these instruments will be mounted outside the pressurized modules and will be remotely controlled by the crew from a work station inside or by the onboard computers. Most pointing of the instruments will be computer controlled with the crew monitoring their performance and making any backup corrections required. If photographic film is used (as opposed to video) the crew will retrieve and reload that film either by using the Mobile Remote Manipulator System (MRMS) to grab the instrument and then pass it through a scientific airlock to the inside or by going EVA and performing the changeout by hand (as was done on the Skylab Apollo Telescope Mount (ATM) payload). The crew themselves can also perform visual observations to augment these instruments.

CUSTOMER SUPPORT, EVA - The crew will have many jobs to do outside the modules. The MRDB has identified a requirement for several hundred man-hours of EVA during the early life of the station.

Satellite Servicing - A job that has been done three times already on Shuttle flights, retrieval of damaged or nonfunctioning satellites for repair, will be a routine station service. These satellites will be remotely piloted into a hangar-type facility on the station and two or more crewmen working EVA will service them and make any necessary repairs. This servicing/repair operation will include removing and replacing subsystem equipment on the satellite, maybe even rewiring it. The ability to operate complex tools and to do close work has already been demonstrated by man in a pressure suit in zero g. The crew will replenish the satellite fuel and other consumables using techniques already performed on the STS 41-G flight.

Payload Equipment Mounting/Changeout/Servicing - EVA crewmen will erect and/or attach payload hardware all along the station structure. (Some of this gear may be mounted remotely using the MRMS by plugging it into a receptacle designed for that purpose.) This hardware will vary from small passive collectors to very large antenna systems. Once these items are mounted they will also be serviced and replaced as necessary during later EVA's.

STATION OPERATIONS, IVA - There will be many tasks required to keep the station running smoothly and to support the customer operations. These will be the responsibility of the station operator on each shift with help as needed from various mission specialists.

Station Systems Monitoring and Control - In the long term this will be an automated function with only occasional verification by a crewman. Until the station matures, however, an operator will be working to develop and then fine tune these various system controls. It is planned to use a computerized work station with advanced CRT graphics capability to do this control job. There will be multiple work stations throughout the modules. Some will be permanently mounted at convenient locations; others will be portable, to be plugged into the common utilities almost anywhere.

Maintenance and Repair - Past flights have demonstrated the great value of man-in-the-loop for this kind of function. When a problem occurs the crewman will use sophisticated diagnostic techniques to locate the source and then effect a replacement from his stores or perform the necessary level of repair. An advanced tool kit will be available to him. Onboard video tapes or uplinked TV of repair procedures will be available, also. Very complicated repairs or those requiring use of complex debugging or testing equipment may involve sending up a highly skilled technician on the next resupply flight.

OMV Rendezvous and Proximity Operations - A crewman acting as pilot will assume control of the OMV and its payload at some distance from the station. Remote video from the OMV and a control stick will enable him to fly it. The OMV may bring in a satellite or one of the large platforms containing instruments that is coorbiting with the station. The OMV could move a piece of equipment from one location on the station to another. The pilot will have enough control to maneuver the OMV around various appendages on the station without contact and will be able to hard dock to various ports. When an OMV is launched from the station to retrieve a satellite the onboard pilot could handover the control to a pilot on the ground to make the actual retrieval or could do the whole task himself.

MRMS Operations - This task will be done primarily by an inside crewman though the MRMS may be designed for operation by an EVA crewman. The required visual feedback will come by looking through a window directly at the MRMS or by remote video which will be prime when the device is moved far up the station structure away from the control module or on the back side hidden from direct sight. This operation will be very similar to the current STS Remote Manipulator System (RMS) operation except for the moving base of the MRMS which greatly increases its coverage range. One unique operation will be the removal of hardware from the Shuttle payload bay in which the MRMS and the Shuttle RMS can be used in concert.

Onboard Planning - Rather than use a preflight crew timeline that would quickly be out-of-date or rely on the ground to prepare a new one, the crew will have the proper scheduling tools to produce their own daily schedules. Long range resource planning will be done by the ground and a set of constraints and priorities given to the crew for a week's time or so. They will load these into their computer along with any onboard biases not available to the ground and build interactively their daily timeline.

Refresher Training - Because of the long missions and the need to refresh certain skills that are labor intensive or require fine eye-hand coordination, a crewman will sit at a work station and participate in a training exercise that is identical to what he did preflight. Smart systems will even enhance the training based on results of actual operations. The task of remotely piloting an OMV during proximity operations and docking to the station is one potential training task. Another aspect of onboard training is replaying video tapes of tasks like maintenance and repair of a complicated system. This capability significantly reduces the proficiency level that must be attained in preflight training. Of course, these tapes will not have to be stowed onboard for station operations; uplink video makes that unnecessary.

Housekeeping - The station needs to be cleaned periodically just like any other dwelling place. All crewmen will take their turn at this. Washing dishes and clothes will be a new thing because there isn't room to allow the storing of disposable clothing and utensils. Trash collection and disposal is required. Vacuuming to collect all the little particles of lint and dust is done to keep the air clean and the equipment uncontaminated.

Health Maintenance and Recreation - Because of the limited number of crewmen and the desire not to require extensive and complicated medical services, it is important to keep everyone in as good health as possible. This goes beyond daily care of good diet and adequate restful sleep. Exercise facilities are necessary for maintaining muscle tone and stimulating the cardiovascular system. The crew will use the exercise equipment often and will also monitor their state of health with sophisticated monitoring equipment. For recreation they will have stereo equipment in their personal sleeping quarters as well as television for use with video tapes, commercial satellite broadcasts, and two-way tele-video conversations with the ground. Observing the stars and the Earth will still be a favorite pastime.

SUMMARY

Since manned spaceflight began almost 25 years ago one of the dreams has been to put a scientist into a laboratory-type environment in space to investigate those phenomena found only there. The Space Station will realize that dream. Professionals will work within their fields to develop the database for future exploitation of space. Working right beside them will be those skilled technicians who have been trained to operate the technical tools - the remote manipulators, the pilotless maneuvering vehicles, the automated work stations - that keep the station and their payload equipment running smoothly. The station crew will use a blend of automation and manual operations to perform all their tasks as efficiently as required given their limited number. All this will make the first space science institute a reality.

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