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Charles R. Ellsworth  
*Program Development, George C. Marshall Flight Center*

Leon B. Allen  
*Program Development, George C. Marshall Flight Center*

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MODULAR SPACE STATIONS

Leon B. Allen and Charles R. Ellsworth
Program Development
George C. Marshall Flight Center
Marshall Space Flight Center, Alabama

ABSTRACT
The NASA Space Station Program has recently undergone substantial changes, brought about by the future availability of the Space Shuttle as an earth-to-orbit transportation system. The assembly of a Modular Space Station in earth orbit from elements delivered by the Space Shuttle is feasible and can be accomplished in the late 1970's or early 1980's. Low transportation costs, return of modular elements for either refurbishment or update, and incremental growth are major advantages of the modular approach. Initially, a modest three- to six-man Station can be assembled in orbit and, over a period of years, evolve to a larger more sophisticated facility by adding modules and updating subsystems as technology advances.

INTRODUCTION
Recent emphasis on the development of the Space Shuttle, combined with the suspension of Saturn V launch vehicle production, has prompted a re-evaluation of elements of the NASA Integrated Plan and, in particular, the Manned Earth Orbital Program. The Modular Space Station (MSS) is a result of this re-evaluation and is configured to take advantage of the low earth-to-orbit transportation costs associated with the Space Shuttle.

The Modular Space Station is composed of 14-foot diameter modules which are individually carried into orbit within the Shuttle Orbiter payload compartment and assembled in orbit. Four program alternatives have been studied (see Figure 1). From a programmatic point of view, the all-Modular, six-man Station with early incremental manning and future growth capability is the most attractive alternative; therefore, this report will be devoted to that concept.

An initial step in the concept definition was to establish general requirements and constraints. The most significant of these (the so-called configuration drivers) are as follows:

1. The fully operational cluster will accommodate a six-man crew.
2. The individual modules to be launched internally within the Orbiter will have a design target weight of 20,000 pounds with maximum external dimensions at launch of 14-foot diameter and 58-foot length.
3. The Station will operate only in the zero-g mode.
4. A minimum power of 15 kWe generated by solar arrays will be provided at the load bus.
5. Shuttle launch frequency will not exceed one launch per month.
6. Logistics supply flights were assumed at 90-day intervals.
7. The Station shall be capable of independent operation with a full crew of six for periods up to 120 days following each supply mission (i.e., 90-day normal supply plus 30-day contingency).
8. Experiments and their accommodations and support requirements will be selected from the NASA Blue Book.
9. The Shuttle Orbiter will provide the necessary maneuvers required for module docking and buildup operations.

In addition to the above guidelines and constraints, the selected configuration also reflects considerations for docking and replacing active modules during the buildup and lifetime of the Station.

EXPERIMENTS
The constraints of a six-man operational capability and a 15-kW electrical power requirement for the fully operational Station necessitated an initial experiment program commensurate with these capabilities. To accomplish this, each scientific and technical discipline of the NASA Blue Book \(^1\) was reviewed and the support requirements in each area were identified. The objective was to define an experiment program consistent with the six-man Space Station capabilities while maintaining basic experiment objectives.

In some cases the NASA Blue Book experiments were deleted from the Station with a recommendation that the
experiments be accomplished by some other method. In
other instances, experiments were combined where
similar or identical equipment was used, thus resulting
in support requirements, weight and dollar savings.
Only those experiments that were judged to hold promise
of near-term economic return or to provide the technol­
gy base for more ambitious future experiments were
retained. A reduction of 30 to 50 percent in the identi­
ified experiment support requirements for the total NASA
Blue Book Program was achieved by these recommended
actions. A typical flight plan of the selected experi­
ments is shown in Figure 2.

CONFIGURATION SIZING AND SELECTION

Prior to the design of the individual modules, it was
necessary to determine the preliminary size of the Sta­
tion and the individual modules, including the number of
floors, length of each module, and the allowable sub­
system weights. Determination of the final size is an
iterative trade between the allowable subsystem and
structural weights and the functional and operational
requirements of each individual module. The first step
in the sizing was to determine the structural weight
versus length of a typical module. A preliminary esti­
mate of the module structural weight versus length with
the resulting allowable weight for the subsystems is
shown in Figure 3.

Subsystems packaging densities vary with each sub­
system; however, assuming an average packing density
of 2.26 lb/ft³, which was found to be typical of past
Space Station studies, and a launch weight limit of
20,000 pounds results in a module length of approxi­
mately 38 feet. This module would consist of approxi­
mately 7,500 pounds of structure (which includes the
sidewalls, floors, and bulkheads) and 12,500 pounds of
subsystems and/or experiments.

Next, it was necessary to establish the functional and
operational requirements of each module at each stage
of Station assembly. At each stage of assembly there
must be provisions for attitude control, power, commu­
nications, thermal control, guidance and navigation, and
checkout capability. In addition, if a checkout and
assembly crew is to go aboard for a short period (up to
days) during each stage of the Station buildup, there
must be adequate safety provisions and living facilities
with a shirtsleeve environment. After establishing
these requirements, it was necessary to trade off the
required function of each module based on the experi­
ment and crew size and the allowable area/volume for
all of the functions against the total weight limitation of
20,000 pounds. Several iterations were necessary to
arrive at the final number of modules and the functions
assigned to each. As a result of the study, it was deter­
mined that five modules were required to form the basic
assembly of the six-man Space Station with an additional
Crew Cargo Module to transfer the crew to and from the
Station. Also, two Attached and one Free-Flying
Experiment Modules were to be accommodated for a
total requirement of nine modules.

Figure 4 shows the general functional requirements
assigned to each of the basic core modules of the select­
ed MSS configuration. Typically, each of the modules
is equivalent to five operational decks or floor areas.

After selection of the size and number of modules
required for the Station, it was necessary to establish
the configuration arrangement. There are numerous
methods and variations of assembling a Modular Space
Station. Shown in Figure 5 are four typical orbital
arrangements of the nine, Shuttle-delivered, cylindrical
modules that compose the full six-man MSS orbital con­
fuguration. In the Offset Cruciform configuration,
modules are aligned along two orthogonal axes with the
Central Docking Module aligned along the third axis.
The four basic core modules in the Nested configura­tion
are parallel to the Central Docking Module with the
transient modules (Crew Cargo, Free-Flyers, etc.)
docked perpendicular to the Docking Module. In the
Stacked Triamese and Stacked Cruciform configurations,
modules are aligned along the Docking Module center­
line and along 120-degree and 90-degree centerlines,
respectively.

Selection of the orbital configuration must be based on
many factors. Some lend themselves to quantitative
analysis; whereas, others are highly subjective in
nature, such as assembly complexity or growth to a
larger facility. Certain criteria are considered more
important than others in the selection of the final con­
fugurations. Figure 6 lists some of the criteria which
must be considered in the selection of the final
configuration.

Characteristics which led to the selection of the Stacked
Triamese for further configuration developments, as
compared to the other candidates, are as follows: The
arrangement achieves near-symmetrical inertial mass
distribution for minimum gravity gradient disturbance
for the six-man Station and retains this characteristic
with growth to a larger 12-man Station. The 120-degree
alignment of the modules presents the best arrangement
for docking to, and replacement of, modules and also
has good heat rejection characteristics for the solar
orientation shown. Thermal interactions between mod­
ules is reduced, and thermal shadowing of modules by
the solar array is avoided.

SELECTED CONFIGURATION DESCRIPTION

The Stacked Triamese, shown in Figure 7, is a config­
uration which best fulfills the established requirements
of a six-man Modular Space Station. It consists of five
basic integral modules with accommodations for docking
Attached Experiment Modules, Free-Flying Experiment Modules, and Crew Cargo Modules.

The basic modules of the Space Station consist of the Power/Alternate Command Post (CP) Module, Docking Module, Primary (CP)/Experiment Module, Crew Support Module, and the Experiment/General Purpose Laboratory (Exp/GPL) Module. Each is located in a specific place in the cluster for a particular reason. For instance, the Crew Support Module, with its larger internal heat load, is located with the end pointing into the sun so that heat can be rejected from the sides more efficiently. The configuration is oriented with respect to the sun, as shown, to avoid thermal shadowing of the modules by the solar arrays. The Crew Cargo and Free-Flying Modules are constrained to the aft and forward docking ports, respectively, for mass distribution considerations.

The full modular assembly includes the two Attached Experiment Modules, one for earth and one for stellar observations. These two modules are located on adjacent 120-degree legs to provide for earth and stellar fields of view for the solar orientation.

Each module has a specific function in the total configuration; however, there are necessary operational duplications and redundancy between the various modules. This redundancy is mainly a result of the safety requirements and the weight limitation of 20,000 pounds per module with secondary impacts resulting from the modular approach which causes natural decentralization of systems and functions. A brief description of each basic module and its primary functions is given in the following paragraphs.

The Power/Alternate Command Post Module is basically a three-deck module that, in addition to providing the power for the Station, provides for CMG installation, command and control of the Station, charger/battery/regulator system, hygiene facilities, atmosphere conditioning (a three-man EC/LS), and thermal control systems. The 5,200 square feet of solar arrays provide the 15 kW of electrical power.

The central module of the Station is the Docking Module which is a truncated triangular structure having a total of 11 docking ports. There are three sets of three coplanar docking ports, plus a port on each end. A 5-foot diameter pressurized tunnel, which can be utilized as an air lock, provides the passageway between the radially docked modules. The Docking Module also provides space for unpresurized storage of oxygen, nitrogen, and water consumables.

The Crew Support Module has five decks which provide the private living quarters, hygiene facilities, food management, and recreation/exercise facilities for the six crewmen. Two of the four 3-man EC/LS systems are located on one floor of this module.

The Primary Command Post/Experiment/GPL Module contains the primary command/control and data management center for normal Station operations located on one floor. Another floor contains the dispensary and isolation ward and a three-man EC/LS system, which is part of the backup or redundant EC/LS capability. Two floors are devoted to the BioMed Experiments and the fifth floor is allocated to a General Purpose Laboratory Data Processing and Evaluation facility.

The majority of the GPL facilities, which will occupy approximately three and one-half floors including the Mechanical, Optics and Electrical, and Experiment Test and Isolation Laboratories, are in the Experiments/General Purpose Laboratory Module. The remaining one and one-half floors are allocated to small vertebrates, plants, and invertebrates, and approximately 30 square feet of storage area.

Major characteristics of the cluster configuration are listed below:

- All the modules have an external diameter of 14 feet, an internal diameter of 13.5 feet (except the Docking Module), and do not exceed 58 feet in length.

- Integral experiments have been allocated 410 square feet of floor area and General Purpose Laboratory (GPL) facilities have been allocated 538 square feet. In addition, two of the docking ports will accommodate Attached Experiment Modules (solar, stellar, earth resources, etc.), and one port is provided for Free-Flying Experiment Modules.

- Electrical power is provided by 5,200 square feet of solar array. The fixed array is maintained in a sun orientation to provide 15 kWe of usable power for Station operations and experiments.

- The Environment Control/Life Support system consists of four 3-man systems interconnected to provide 100-percent redundancy.

- Two concepts were examined for habitability area arrangement, the transverse (circular) floor and the horizontal (rectangular) floor. In each concept, the crew quarters floor area was considerably reduced from the 50 square feet per man allowed in previous Space Station studies. This reduction was considered feasible since the Station will operate only in zero-g, and the sleep restraints may be oriented normal to the other crew quarters equipment. In the transverse floor concept, crew quarters area allocation was approximately 29 square feet per man. In the horizontal floor concept, the area allocation was about 32 square feet per man with additional advantages of larger open areas, better facilities arrangement, and more storage area. The obvious disadvantage of the horizontal floor arrangement is the introduction of lateral loads in the mounts at launch for heavy equipment.
Each module has an independent thermal control system, consisting of surface radiators and, when required, because of heat load and heat rejection characteristics of a particular module, a passive thermal capacitor system.

Because of inertial symmetry of the Triamese configuration, only three control moment gyros are required for worst case attitude hold requirements in any orientation.

**CONFIGURATION BUILDUP**

The functional and operational requirements implicit in the ground rules dictated a Space Station buildup that is characterized by two distinct steps. The first step is the initial operational configuration consisting of assembling the five basic modules with all integral experiments aboard and manned by the six-man crew with the Crew Cargo Module attached. The second step, which is the fully operational configuration, is achieved by adding the two Attached Experiment Modules and one or more Free-Flying Experiment Modules.

Five Shuttle launches are required to assemble the initial operational configuration, with a sixth launch necessary to bring up the Crew Cargo Module and the Crew. Therefore, the buildup of the cluster to operational capability requires 5 months due to the constraint of one Shuttle launch per month; however, the modules are designed so that a small assembly crew (two or three men) could be utilized to assist in the buildup and checkout of the assembled modules after each docking operation. These crewmen can remain in orbit up to five days and then must return with the Shuttle. All rendezvous and docking of modules were assumed to be accomplished by the Shuttle. Figure 8 shows the buildup sequence of the six-man MSS.

The initial module placed into orbit contains all the subsystems necessary for unattended operation for one month. This module also has the capability to maintain a fixed attitude to allow the second module to be docked.

The second module placed into orbit is the Central Docking Module. The third module orbited is the Primary Command Post/Experiment-General Purpose Laboratory. This provides the dual command post capability and redundant EC/LSS systems required prior to operational manning. Incremental manning could be accomplished at this stage of the buildup. The fourth module launched is the Crew Systems Module, with the fifth and final basic core module being the Experiment/General Purpose Laboratory containing various physical science laboratories and selected experiments.

The sixth launch is the Crew/Cargo Module which delivers the crew, provides cargo storage, and serves as a "lifeboat." The seventh and eighth modules are the Attached Experiment Modules that contain selected experiments; the ninth module is a Free-Flying Experiment Module. The last module arrival may occur after several changes of the crew (each requiring a Crew Cargo Module launch).

Growth to the 12-man Station can be accomplished by adding another docking module and other appropriate modules, including a second power source.

**INCREMENTAL MANNING**

The selected Modular Space Station was configured and designed based on the assumption that the basic station would be completely assembled prior to manning with the operational crew; however, an analysis was conducted to determine the impacts of operationally manning the station with two or three men early in the buildup sequence. To accomplish this it was necessary to satisfy the basic ground rules of having two pressure compartments for safety considerations and that the EC/LSS be fully redundant when initially manned. This means, for example, that the Station assembly must have a four-man EC/LSS to accommodate a crew of two, and so on.

When examining the modular buildup for incremental manning, the assembly was found to be either EC/LSS or crew-systems limited during the early phases. Using the modules previously described, Station manning could not occur until the fourth launch, at the earliest. By adding crew quarters to the Primary Command Post Module, the assembly could be manned on the third launch; and by adding crew quarters and an airlock to either the Power Module or the Primary Command Post Module and an airlock to the Crew Systems Module, the assembly could be manned as early as the second launch. The Station assembly was at no time power limited.

Additional modifications to the modules would be required to include operational experiment facilities for early incremental manning.

**WEIGHT ESTIMATES**

The detailed weight estimates for each of the functional modules by major systems are presented in Table 1. The design weight limit for each module was 20,000 pounds with the crew system module being the only module to exceed the weight restriction. The basic five-module core Station weight was approximately 93,000 pounds with the full buildup configuration weighing approximately 174,000 pounds when the Attached and Free-Flying Experiment Modules were added.
Table 1. Detailed Weight Estimates

<table>
<thead>
<tr>
<th>Module Subsystem</th>
<th>Power Alt./CP</th>
<th>Docking</th>
<th>Prime CP/Exp. GPL</th>
<th>Crew System</th>
<th>Exp and GPL</th>
<th>Basic Space Station</th>
</tr>
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<tr>
<td>Structure</td>
<td>4,300</td>
<td>5,000</td>
<td>6,450</td>
<td>6,450</td>
<td>6,450</td>
<td>28,650</td>
</tr>
<tr>
<td>Airlock</td>
<td>240</td>
<td>600</td>
<td>240</td>
<td>240</td>
<td>240</td>
<td>4,600</td>
</tr>
<tr>
<td>Docking</td>
<td>1,325</td>
<td>1,325</td>
<td>2,440</td>
<td>400</td>
<td>400</td>
<td>19,059</td>
</tr>
<tr>
<td>Electrical Power</td>
<td>7,400</td>
<td>2,640</td>
<td>1,400</td>
<td>1,000</td>
<td>500</td>
<td>5,090</td>
</tr>
<tr>
<td>Thermal Cont</td>
<td>400</td>
<td>400</td>
<td>2,350</td>
<td>5,000</td>
<td>5,000</td>
<td>12,090</td>
</tr>
<tr>
<td>Wtr./Waste Mgt.</td>
<td>1,000</td>
<td>1,000</td>
<td>2,500</td>
<td>6,000</td>
<td>6,000</td>
<td>8,004</td>
</tr>
<tr>
<td>Crew System</td>
<td>300</td>
<td>6,119*</td>
<td>500</td>
<td>500</td>
<td>500</td>
<td>1,600</td>
</tr>
<tr>
<td>Atmosphere</td>
<td>6,450</td>
<td>2,500</td>
<td>550</td>
<td>550</td>
<td>550</td>
<td>1,590</td>
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<tr>
<td>Water/Tankage</td>
<td>100</td>
<td>1,500</td>
<td>1,490</td>
<td>6,650</td>
<td>6,650</td>
<td>8,330</td>
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<tr>
<td>Food Supply</td>
<td>100</td>
<td>1,490</td>
<td>525</td>
<td>3,575</td>
<td>3,575</td>
<td>4,615</td>
</tr>
<tr>
<td>RCS Sys/Prop</td>
<td>815</td>
<td>615</td>
<td>690</td>
<td>915</td>
<td>915</td>
<td>17,995</td>
</tr>
<tr>
<td>G&amp;C</td>
<td>-</td>
<td>2,500</td>
<td>2,500</td>
<td>2,500</td>
<td>2,500</td>
<td>9,960</td>
</tr>
<tr>
<td>Data Mgt/Comm</td>
<td>1,500</td>
<td>2,500</td>
<td>5,830</td>
<td>8,330</td>
<td>8,330</td>
<td>17,995</td>
</tr>
<tr>
<td>Network and Dis.</td>
<td>815</td>
<td>615</td>
<td>690</td>
<td>915</td>
<td>915</td>
<td>20,110</td>
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<tr>
<td>Exp and GPL</td>
<td>-</td>
<td>5,830</td>
<td>16,350</td>
<td>16,350</td>
<td>16,350</td>
<td>93,494</td>
</tr>
</tbody>
</table>

*Including Tankage

**ELECTRICAL POWER SYSTEM LOAD REQUIREMENT**

A load assessment of the MSS during a typical orbit revealed that the 15-kWe average load was sufficient for the Station. While maintaining the 15-kWe average, it was determined that a 10-percent increase in sunlight loads, with a corresponding decrease in dark-side loads, could be accomplished through load management. This optimizes the EPS by reducing the battery and recharge requirements, and by reducing the array requirements to resupply the energy.

Figure 9 summarizes the EPS power and energy requirements of the six-man station, identifies the system losses involved, and gives a breakdown of the loads required and/or assigned to the various subsystems for a typical orbit of operation.

The load breakdown shown is a preliminary assessment of the load requirement during the lightside and dark-side of the orbit. The total energy required to be delivered by the solar array during the lightside of the orbit is 33,200 Wh of which 16,500 Wh are delivered to the loads, 7,600 Wh are consumed by losses and 9,100 Wh are used to recharge the batteries. During the darkside of the orbit the 9,100 Wh of energy stored in the batteries is used to deliver 7,010 Wh to the loads and 2,090 Wh are consumed by the losses. It is necessary to reduce the experiment operations power from 7,300 W during the lightside to 5,710 W during the darkside due to the overall reduction in power availability.
Figure 10 identifies the power output and size requirements of the solar arrays and illustrates the major subsystem functions and losses involved in providing the 15-kWe average load under a worst case orbital condition of 60/34 sunlight-to-darkness ratio using a solar array battery power system. The average power loss during the day portion of the orbit is denoted by "W day." The loss during the night portion of the orbit is denoted by "W night" with the subsystem losses in percent of power handled also given. Nickel-cadmium batteries of the 100-ampere-hour size were selected to provide darkside power because of their large energy storage capabilities.

**SOLAR ARRAY**

The primary electrical power source is provided by a 5,200-square-foot rollout solar array designed for fixed solar orientation as shown on the lower left side of Figure 11. However, the basic approach does not preclude the possibility of gimballing it with one or more degrees of freedom. The mast is hinged into three sections to limit the stowage height to less than 33 feet. The width of the deployed array must be less than 27 feet to avoid interference with the other Station modules.

The array size initially provides 1.34 times the basic power requirement to account for a 6-percent-per-year degradation allowance. This size is based on the assumption that the array will be replaced at 5-year intervals.

Several alternate solar array types and arrangements were also investigated. Three others considered were (1) the 90-degree Gimbal Array, (2) Side Mount Array, and (3) End Mount Array.

**ATTITUDE CONTROL REQUIREMENTS**

A general analysis of the control requirements for the alternate configurational concept arrangements was performed. The Triamese configuration was selected because it minimized the control requirement while satisfying the operational constraints and overall mission objectives.

A detailed analysis of the control requirements of the Triamese configuration was made during each stage of the buildup and initial operational cycle to determine the size and number of CMG's required and to establish the RCS system size and propellant requirements. Each stage of the buildup was simulated in a solar inertial attitude hold mode. Figure 12 illustrates the maximum cyclic momentum requirements during each phase of the buildup. In all cases, one 2000-ft-lb-s CMG unit per axis was sufficient to counteract the cyclic momentum. Five CMG's were placed on the MSS to provide redundancy. The reaction control system (RCS) was used to provide attitude hold during CMG dumping. The average fuel requirement for the RCS was only 130 pounds per month. One-pound thrusters were adequate to provide the Station attitude hold requirements while the CMG's were dumped. After final configuration buildup, the cyclic control requirements will alternate every three months between configurations 8 and 9 (Figure 12) due to the placement of the Crew Cargo Module on the Cluster.

**HEAT LOAD AND RADIATOR AREA REQUIRED**

Heat loads for each of the modules have been determined as shown in Figure 13. The Crew support module has the largest heat load (7.7 kW), but has sufficient radiator area to reject the heat because of its orientation in the cluster; however, the CP/GPL-Exp. and GPL/Exp. Modules cannot fully reject their heat loads (4.6 kW and 3.1 kW, respectively) with the available radiator areas shown. These data are based on the maximum orbital heating conditions. A supplementary system using passive thermal capacitors could be used (similar to Skylab A) to handle peak heating conditions.

As shown on Figure 14, Modules 4, 6, and 9, whose ends point toward the sun and can utilize two one-eighth arc length radiator segments, have ample radiator surface area. Modules 3, 5, 7, and 8 have less heat rejection capability, since more of their surface area is exposed to the sun and the radiator segments are subject to earth IR and albedo. These four Modules can utilize only one of the one-eighth arch length segments.

**STRUCTURE**

The minimum wall thickness required was determined to be approximately 0.16 inch. This design condition was based on the requirement that a module be able to be returned to earth with a zero pressure in the module as shown on Figure 15. The internal pressure of the Station is normally 14.7 psia which would require a wall thickness of only 0.06 inch. Allowance for 3 inches on each side for the meteoroid and thermal protection systems resulted in an internal diameter of the modules of 13.5 feet.

The modules have monocoque cylinder walls and conical bulkheads on each end of the cylindrical sections. There is a 5-foot-diameter docking hatch where the modules interface with the Docking Module. The meteoroid protection system is a double bumper type system.

**ALTERNATE FLOOR ARRANGEMENT**

An alternate floor arrangement for the Crew Systems Module utilizing a hybrid longitudinal/transverse floor design is shown in Figure 16. The galley, wardroom,
head, and EC/LS system would occupy the longitudinal floor area which has a floor width of 11.2 feet with a total working surface area of 456 square feet and a ceiling height of 6.5 feet. The crew compartments would occupy the space above the ceiling.

The orientation of the six required crew compartments with respect to the longitudinal working surface is shown in Figure 17. Access to the crew compartment is through a door in the ceiling of the longitudinal floor compartment. It is noted that the ceiling height within each crew compartment is 6.5 feet. The total area of the crew compartment is 32.4 square feet; however, because of the indicated unused areas and the EC/LSS conduits running through the compartment, only 30.0 square feet of the total area is actually used for crew-quarters functions.

It may be interesting to note that if a pop-out panel is provided in the ceiling of each crew compartment for purposes of dual escape, an individual could enter a crew compartment at one end of the module and not emerge until he reached the other end, thus providing an alternate escape route for safety considerations.

The volume below the longitudinal floor would be utilized for such functions as storage, holding tanks, refrigeration units, and EC/LSS conduits.

EC/LS SYSTEM SELECTION

A trade study was made to select the desired degree of water and oxygen recovery. The items considered in the selection of the EC/LS system were the degree of development of the recovery system, system weight, logistics and power requirements.

The extent of water recovery considered varied from no reclamation to a completely closed loop with complete recovery of the water. If no reclamation is used, 16 tanks weighing 1,600 pounds are needed to contain the 18,680 pounds of water required for 90 days. Closure of the loop would be accomplished by addition of reclamation equipment to reclaim condensate, wash, or urine water. An air evaporation assembly could be used to reclaim urine and wash water either separately or together. Condensate or wash water can be reclaimed by multifiltration either separately or together. The system weight for recovery of the water is approximately 500 pounds including the tanks. The logistics requirements for various degrees of water loop closures are shown in Figure 18. If no reclamation is employed, the water requirement amounts to approximately 18,680 pounds every 90 days. Closure of the loop means reclaiming water from the wash, condensate, and urine sources. Reclaimed water from these three sources will reduce the logistics demand to approximately 940 pounds per 90 days. Water from the fecal source is usually dumped overboard. The power requirements for all degrees of closure are relatively small (less than 50 W) except for recovery of the urine by air evaporation which results in peak loads of 620 W. The recovery of the wash water by multifiltration requires only 15 W of power. The selected mode was the partial closure of the loop which can be accomplished by reclaiming the wash and condensate in separate loops and dumping the urine overboard. Eighty-five percent of the water can be reclaimed by this process which reduces the water logistics requirement to 2,890 pounds per 90 days.

Urine water recovery was rejected because of the effort and expense to develop flight-tested hardware; whereas, the multifiltration process is simple, requires very low power, and is inexpensive. The weight of this assembly to recover wash and condensate water is 230 pounds.

Closure of the oxygen loop requires the addition of Sabatier and electrolysis assemblies. The addition of oxygen recovery equipment (Sabatier + electrolysis) results in 994 pounds of metabolic oxygen reclaimed every 90 days. The addition of the Sabatier and electrolysis assemblies results in considerable increase in power requirements, especially the peak loads for the electrolysis. These assemblies require an average power of 1,283 W. Peak loads amount to 2,383 W for these assemblies. Also, the system cost and maintenance requirements increase significantly with the introduction of the oxygen recovery equipment. The above considerations resulted in the selection of an open-loop oxygen system particularly in view of the potentially low cost re-supply capability.

The summary comparison of the operational and logistical weights and peak power requirements for the open, selected, and closed loop EC/LSS is shown in Figure 19. The open-loop dry assembly weight includes CO₂ removal, trace contaminant, pressure control, water and waste management, suit loop, and Portable Life Support System assemblies. The selected dry assembly weight includes the above assemblies plus oxygen and urine recovery equipment.

The power values reflected on the chart represent the total operational power for each loop. These amount to 1,930 W for the open loop, 1,955 W for the selected loop, and 5,980 W for the closed loop.

CONCLUSIONS

The Modular Space Station is an attractive and versatile method of performing a viable earth orbital science and applications program. The MSS approach offers program flexibility in that the Station can be incrementally assembled and manned, and over a period of years grow into a large Space Station. This approach also provides the capability of returning the modules to earth by the Shuttle for repair or refurbishment.
The Modular approach provides an initial design based on the existing state-of-the-art which, on later module launches, can be updated with technology advancements. Commonality of the Module structure is inherent in this approach.

The Modular approach results in additional functional and operational redundancies, which, although enhancing the Station safety characteristics, results in more complex Module interfaces and increases the systems integration requirements.

Several configuration arrangements are feasible; however, the Triamese configuration minimizes the interrelated problems associated with control, heat, operations, viewing, docking, etc., while satisfying the overall operational constraints and the mission objectives.

ACKNOWLEDGMENT

The information presented in this paper resulted from the cooperative efforts of personnel in Program Development, George C. Marshall Space Flight Center, National Aeronautics and Space Administration.

REFERENCES

(1) Candidate Experiment Program for Manned Space Stations, NASA NHB 7150.1, September 15, 1969.

BIBLIOGRAPHY


ILLUSTRATIONS

Figure 1. Modular Space Station Program Options.
Figure 2. Experiment Flight Plan.
Figure 3. Module Weight vs Length for Preliminary Sizing.
Figure 4. Module Functional Requirements.
Figure 5. Configuration Alternates.
Figure 6. Configuration Evaluation Criteria.
Figure 7. Reference Configuration.
Figure 8. Configuration Buildup Profile.
Figure 9. Power System Load Requirements.
Figure 10. Power System, Energy Balance.
Figure 11. Solar Arrays Selection Concepts.
Figure 12. Cycle Momentum Requirements for Solar Pointing.
Figure 13. Module Heat Load and Radiator Area Required.
Figure 14. Thermal Radiator Locations.
Figure 15. Pressure Wall Thickness.
Figure 16. Crew Systems Module, Longitudinal Hybrid.
Figure 17. Cross Section – Crew Systems Module.
Figure 18. Logistics Requirements for Varying Degrees of Water Loop Closures.
Figure 19. Overall EC/LSS Weight and Power Comparisons.
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**FIGURE 1 MODULAR SPACE STATION PROGRAM OPTIONS**

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**FIGURE 2 EXPERIMENT FLIGHT PLAN**
**Figure 3** Module Weight vs Length for Preliminary Sizing

### Major Functions

**Power/Alt. CP (P)**
- Primary Power Source
- Alternate C/C Center
- CMG's
- RCS
- EC/LSS (3 Men)

**Docking Module (D)**
- Docking Ports
- Tunnel System
- Air Locks (EVA and Modules)
- Unpressurized Storage

**Primary CP/Exp. - GPL**
- Primary C/C Center
- Data Proc. Lab. (120 FT²)
- Biomed. (260 FT²)
- EC/LSS (3 Men)
- Disp./Isolation Ward

**Crew Systems (CS)**
- Crew Quarters (6 Men)
- EC/LSS (6 Men)
- Galley/ward room
- Hygiene/Waste Mgt.

**Experiments/General**
- Mech. Lab (195 FT²)
- Test and Isol. Lab. (63 FT²)
- Optics and Elec. Lab. (180 FT²)
- FPE 5.6, 5.8, 5.10, 5.25, 5.26 (150 FT²)

**Crew/Cargo (CC)**
- Crew/Cargo (6 Men)
- EC/LSS (6 Men)
- Cargo Storage
- Lifeboat
- Crew Rotation
- Warehouse/Pantry

**Figure 4** Module Functional Requirements

1-21
FIGURE 5 CONFIGURATION ALTERNATES

STABILITY AND CONTROL
- ORIENTATION AND MANEUVERS
- MASS DISTRIBUTION
- PROPULSION SYSTEM/CONSUMPTION
- DYNAMIC STABILITY

ASSEMBLY COMPLEXITY
- MECHANISMS/INTERFACES/
- STRUCTURES
- OPERATIONS — DOCKING, ETC.
- BUILDUP SEQUENCE

HABITABILITY
- CREW ACCOMMODATION
- SAFETY
- METEORITE/Thermal (RADIATION PROTECTION)
- ORIENTATION
- TRAFFIC PATTERNS

OPERATIONAL SIMPLICITY
- REPLACEMENT
- APPROACH PATTERN — REND/Docking
- CARGO TRANSFER (INTERNAL)
- ARTIFICIAL—g EXPERIMENT

SYSTEM INTEGRATION
- EPS ACCOMMODATION
- EXPERIMENT ACCOMMODATION
- EXTERNAL SURFACE UTILIZATION ANTENNAS/RADIATORS/
- DOCKING PORTS
- INTERFACES — BOTH FUNCTIONAL AND PHYSICAL

GROWTH TO LARGER FACILITY
- RESPONSIVENESS TO PROGRAM CHANGES
- MODULE ADD-ON COMPLEXITY
- ABILITY TO ACCOMMODATE FUTURE
- USERS' REQUIREMENTS

FIGURE 6 CONFIGURATION EVALUATION CRITERIA
FIGURE 7  TRIAMESE CONFIGURATION

FIGURE 8. CONFIGURATION BUILDUP PROFILE

LAUNCH SEQ. MODULE
1 - POWER/ALT CP
2 - DOCKING
3 - PRIMARY CP/EXP-GPL
4 - CREW SYSTEMS
5 - EXPER./GPL
6 - CREW CARGO
7 - ATTACHED
8 - ATTACHED
9 - FREE FLYING CREW CARGO (90-DAY RESUPPLY CYCLE 5-DAY OVERLAP)
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*INCLUDING TANKAGE
FIGURE 9  POWER SYSTEM LOAD REQUIREMENTS
Figure 10  Power System, Energy Balance
FIGURE 11 SOLAR ARRAYS SELECTION CONCEPTS
FIGURE 12 CYCLE MOMENTUM REQUIREMENTS FOR SOLAR POINTING

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FIGURE 13 MODULE HEAT LOAD AND RADIATOR AREA REQUIRED
FIGURE 14 THERMAL RADIATOR LOCATIONS

FIGURE 15 PRESSURE WELL THICKNESS

F.S. = 1.4
*BASED ON 13.5-FT DIAMETER MONOCOQUE CYLINDER
FIGURE 16  CREW SYSTEMS MODULE, LONGITUDINAL HYBRID
CREW COMPARTMENT
TOTAL AREA = 32.4 FT.$^2$
FREE FLOOR SPACE = 13.0 FT.$^2$

DIA. = 13.5 FT.
LONGITUDINAL FLOOR

STORAGE #2
VERTICAL SLEEP RESTRAINT
STORAGE #3
STORAGE #4
FREE FLOOR SPACE
ENTERTAINMENT UNIT

FIGURE 17 CROSS SECTION - CREW SYSTEMS MODULE
FIGURE 18 LOGISTICS REQUIREMENTS FOR VARYING DEGREES OF WATER LOOP CLOSURES

FIGURE 19 OVERALL EC/LSS WEIGHT AND POWER COMPARISONS