PROJECT SKYLINK

SKYLAB AND SOYUZ IN AN AMERICAN – SOVIET JOINT VENTURE IN SPACE

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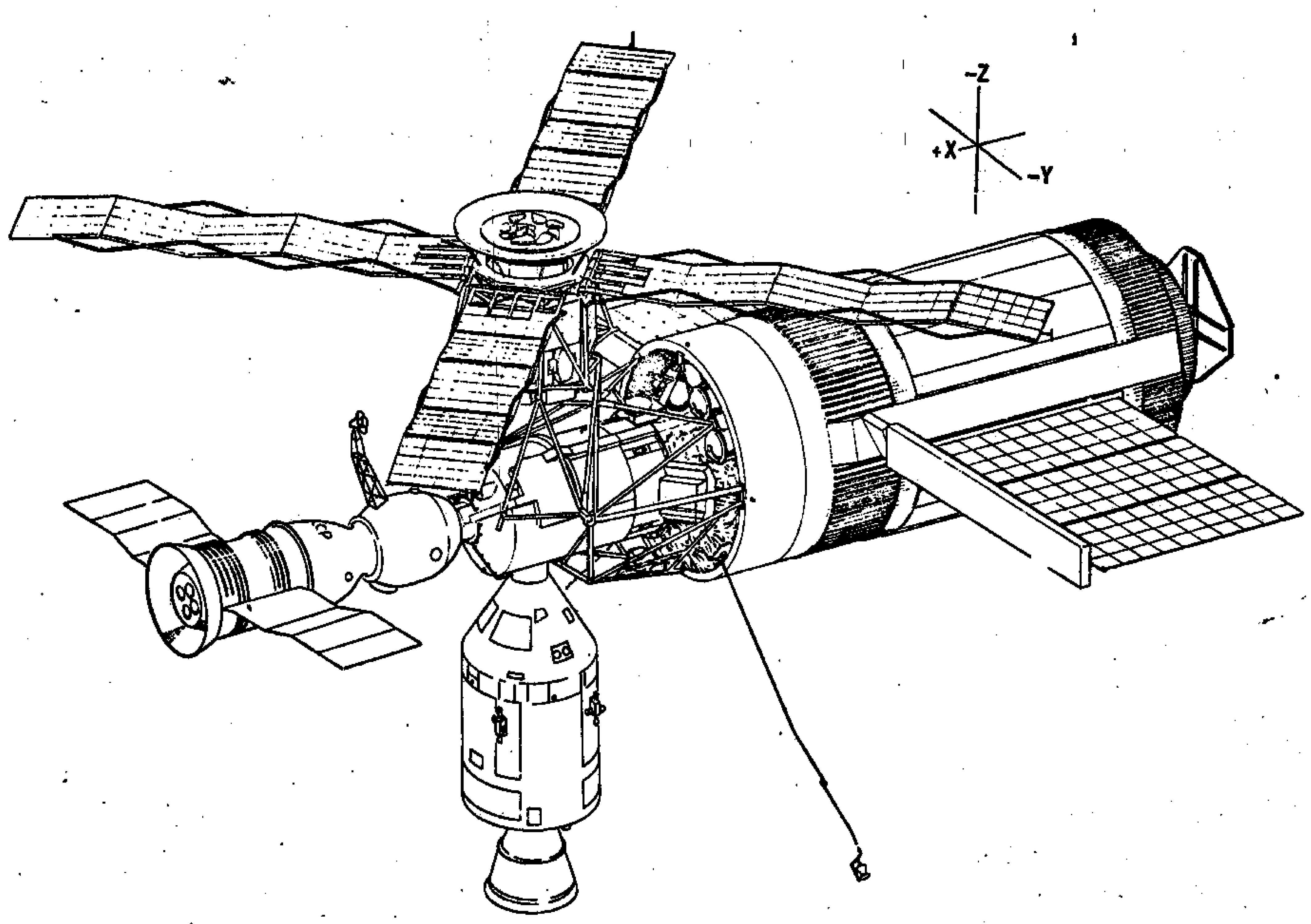

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I. INTRODUCTION

The opportunity for American-Soviet cooperation in space could well begin with the launching of the Skylab missions in 1973. The many gains to be realized from, and the problems involved with, a proposed link-up or co-orbit of an American Skylab and a Soviet Soyuz will be covered in this study.

There are many possible mission profiles, but of major interest will be the following mission options:

1) the docking of a Skylab and a Soyuz
2) the coorbiting of a Skylab and a Soyuz

Some of the advantages of a docked Skylab-Soyuz would be:

- no Soyuz propellant usage during long term visits (30 days
- easier crew rescue during emergency

Some of the advantages of a coorbiting Skylab-Soyuz would be:

- little hardware modification or additions required
- short term (7 day) visits would be more economical

SKYLAB

Scheduled to begin a series of flights in 1973, the Skylab Program will provide answers to questions dealing with the development of large, permanent space stations, including:

1) How will the human body react to weightlessness in flights of almost two months duration?
2) What types of work can man perform during these extended periods?
3) What services can a space station provide?

The Skylab Program orbital cluster consists of a Saturn Workshop (SWS) with an Apollo command and service module (CSM) docked to it (figure 1). The SWS is composed of an S-IVB stage modified into an Orbital Workshop (OWS), an airlock module (AM), a multiple docking adapter (MDA), a Saturn V instrument unit, an Apollo telescope mount (ATM), and an ATM deployment assembly.

The SWS assembly is launched by a two-stage Saturn V.

SOYUZ

The multiman Soyuz spacecraft is, in effect, a miniature manned space laboratory. These vehicles, which are highly maneuverable for rendezvous with other spacecraft, were stated to be "of major importance for setting up research stations in orbit, consisting of several autonomous elements delivered into orbit".

Work tasks of these vehicles are, officially, the following:

1) all-around study of the earth and its atmosphere with the object of solving problems in radio-physics, geophysics, and space navigation

2) study of problems involved in using the near-earth environment (high-vacuum, weightlessness, and radiation) for scientific and practical purposes

3) study of the sun, stars, planets and their moons.

The Soyuz vehicles are capable of docking together nose-to-nose using a male and female docking mechanism.

The craft includes three major modules: orbital module, recovery module, and propulsion module. These are depicted in figure 2.

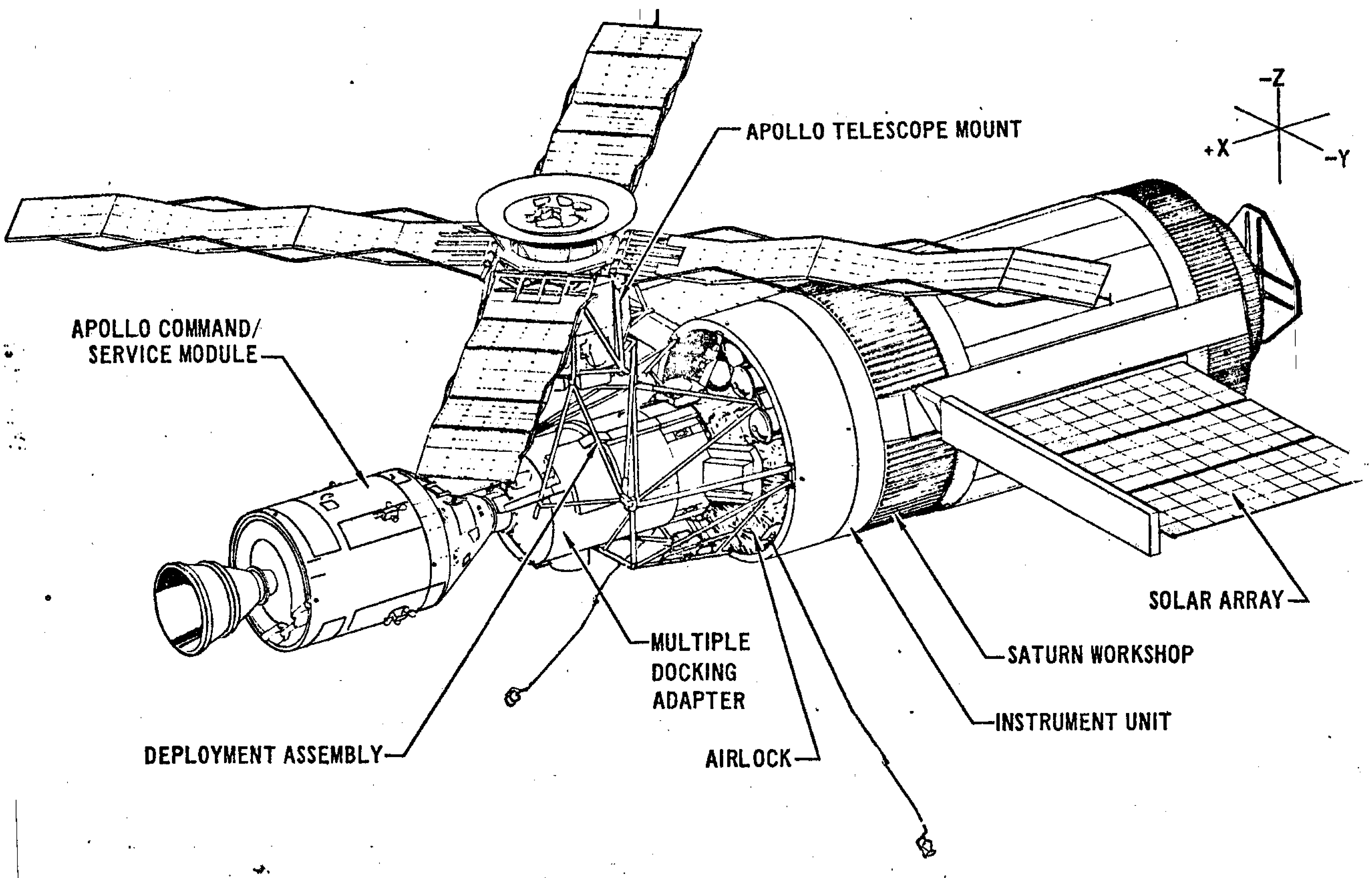


FIGURE 1 SKYLAB ORBITAL CLUSTER

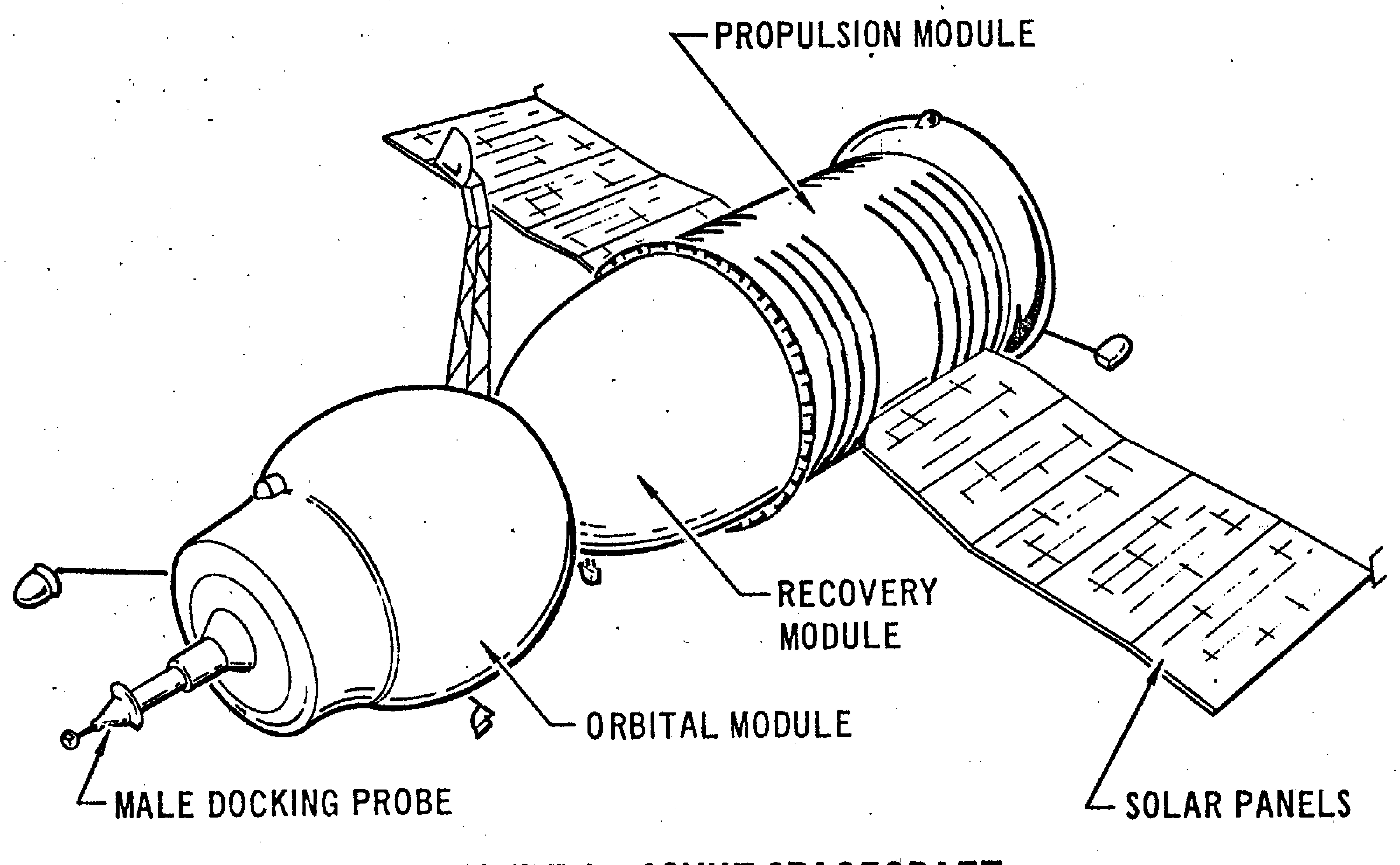


FIGURE 2 SOYUZ SPACECRAFT

The orbital module consists of a scientific laboratory and rest compartment. In it the cosmonaut can perform scientific experiments, carry out physical exercise, and eat and sleep. The control and communication apparatus, a portable television camera, movie camera, and other scientific equipment are included. The section has four portholes used for scientific observation and photography.

The recovery module, used for reentry and for docking control, contains the equipment for navigation and orbital maneuvers.

The propulsion module includes propellant storage for both the deorbit engines and orbital maneuvering system. The solar panels are also deployed from this section.

SKYLAB-SOYUZ

The docked configuration of the Skylab-Soyuz is shown in figure 3. Pictured is option 1. Option 2 would appear similar to option 1, the only difference being the Soyuz occupying a station-keep position about 500 feet from the Skylab. The Soyuz long axis probably would be oriented parallel to the Skylab long axis; it remains on the ATM side of the cluster to avoid possible contact with Skylab radial antenna booms.

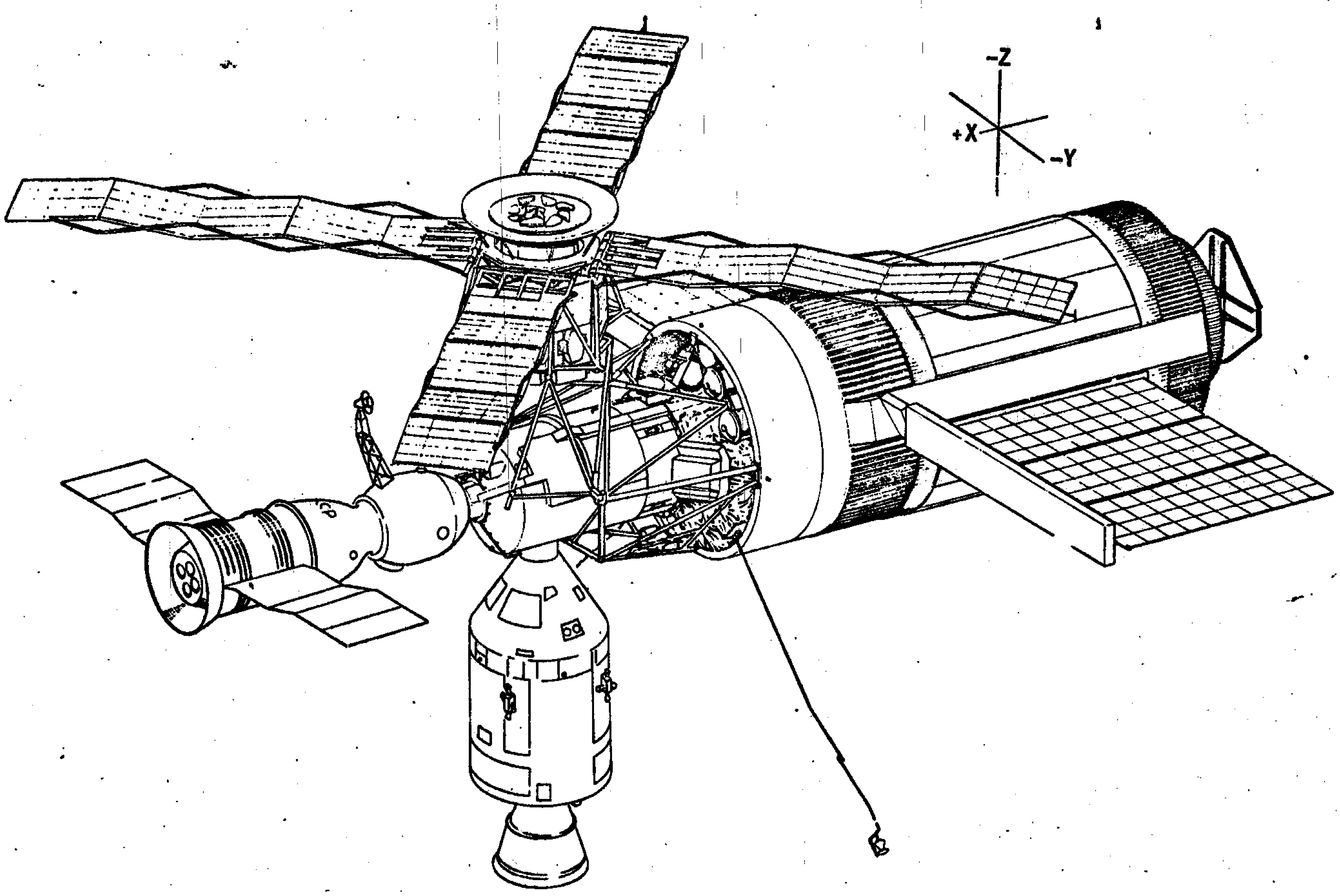


FIGURE 3 SKYLAB – SOYUZ ORBITAL CLUSTER

II. TECHNICAL ASPECTS

A. CMG ATTITUDE CONTROL

The present Skylab cluster uses the ATM control moment gyroscope (CMG) system for attitude control. Under present plans, the CMG would be "dumped" of their stored momentum during the night portion of the orbit by a sequence of maneuvers. It is assumed the Skylab-Soyuz docked configuration would do the same.

This portion of the study deals with the simulation of a docked Skylab-Soyuz in earth orbit, the resultant gravity gradient torques, and the ability of the present Skylab CMG system alone to control the proposed joint cluster. Additional torques caused by aerodynamic drag and crew motion are not considered.

First, an inertia method will be used to determine vehicle controllability. This quick method was derived by Kennel (1968). The magnitude of a figure of merit μ is used where

$$\mu = \frac{\Delta I_3 - \Delta I_2}{\Delta I_1}$$

where $\Delta I_1 = I_{zz} - I_{yy}$

$$\Delta I_2 = I_{xx} - I_{zz}$$

$$\Delta I_3 = I_{yy} - I_{xx}$$

and I_{xx}, I_{yy}, I_{zz}, = principal moments of inertia. It has been suggested that, for optimum CMG control, $|\mu|$ should be greater than 25.

The values of the principal moments of inertia in kilograms-square meters for three configurations are shown below for comparison. The three configurations (shown in figure 4) are:

1) standard Skylab
2) standard Skylab plus second CSM
3) Soyuz at axial port and CSM at radial port

CONFIGURATION	I_{xx}	I_{yy}	I_{zz}
1	645,600	5,051,000	5,057,000
2	1,409,000	6,649,000	6,083,000
3	1,809,142	6,241,467	5,269,783

As can be seen, for a large μ the values of I_{yy} and I_{zz} should be nearly equal so that $\Delta I_I = I_{zz} - I_{yy}$ is small. The value of μ for configuration 1 is greater than 100 and is satisfactory. However, for configuration 2, the value of μ is -18 and for 3 it is -8. Hence, at least according to this particular analysis, the Skylab-Soyuz docked configuration is critical and may not be safely controllable by the CMG alone.

The following analysis using gravity gradient torques arrives at a similar conclusion.

Gravity gradient torques are made up of both cyclic components on each vehicle axis and a constant bias, or ramp, on the x (longitudinal) axis. For each gravity torque there is a certain value of angular momentum H that the CMG must be able to correct for or "store".

The maximum bias value for a Skylab-Soyuz orbital altitude of 435 kilometers is about 5000 newton-meter-seconds (nms). The cyclic components have a magnitude of about 3000 nms. Each value is per daytime orbit. Adding these vectorially,

$$H_T = \sqrt{3^2 + 5^2} \cdot 1000 \approx 6000 \text{ nsm}$$

one arrives at the total momentum due to gravity.

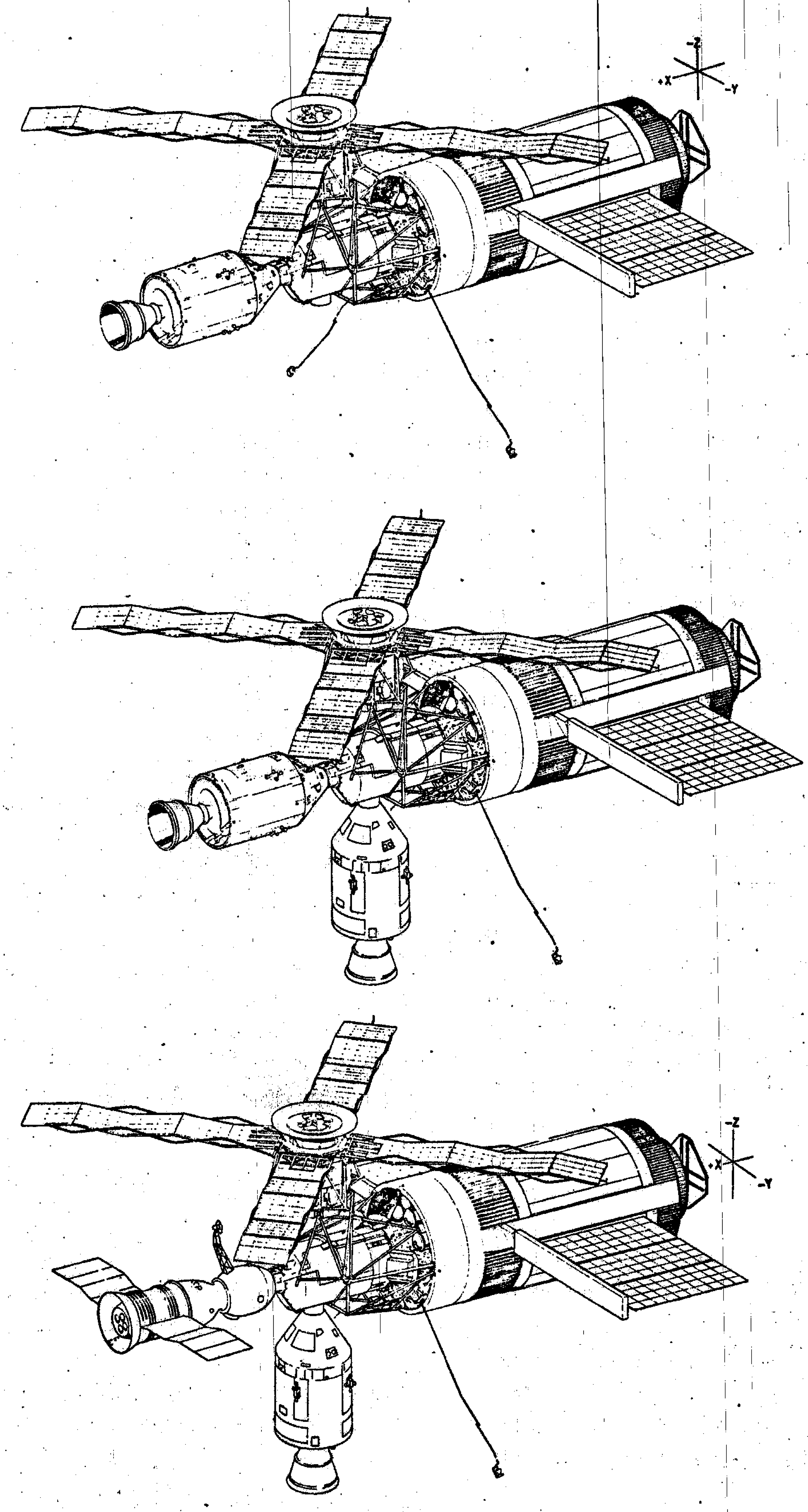


FIGURE 4 THREE DOCKED CONFIGURATIONS

The total momentum storage capability of the three Skylab CMS is equal to 8460 nms. This leaves a margin of 2460 nms, which is felt to be critical and perhaps not a sufficient safety factor to allow CMG control during transients and other torques on the vehicle.

It is concluded that attitude control of the Skylab-Soyuz using only the CMG system is critical and the Skylab reaction control system may be needed in addition.

B. COMPATIBILITY

The Skylab and Soyuz are quite compatible as general orbital systems. Compatible areas include:

1) Structure - The Skylab was designed to accommodate up to two command/service modules docked to the multiple docking adapter. The load added by a Soyuz vehicle (which is one-half the weight of a CSM) docked to the axial port would not therefore exceed structural limits. The individual configurations of the Skylab cluster and the Soyuz vehicle could remain the same.

2) Orbital inclination - Both the Soyuz and the Skylab are designed for 50° inclinations.

3) Rendezvous and docking procedure - The Soyuz rendezvous procedure is as follows:

a) launch into earth orbit and correction of one of the satellite's trajectories to deflect it into the appropriate range for mutual automatic radar contact and radio engagement
b) active vehicle automatically approaches passive vehicle
c) automatic rendezvous when within 300 to 400 meter closing range
d) mechanical and electrical link-up

There are several modes of operation, including automatic docking (described above), manual rendezvous docking, or station-keeping. All are similar to the Skylab docking scheme, in which the CSM performs the maneuvers and the Skylab is passive.

4) Communications - Agreement would have to be reached concerning voice communication frequencies. Any data links would require compatible data rates and format. It would seem voice communications would suffice for inter-ship data comparisons and exchange, and for updating orbital parameters.

5) Materials - The Soviet use of wood in the Soyuz orbital compartment, if not fireproofed, would not conform to American safety standards. Hence, modification to the Soyuz before American transfer/occupation would be necessary.

C. OPERATIONAL AND HARDWARE IMPACTS

Several changes will be required in the operation of the Skylab to accommodate the Soyuz. These operational changes would impact both mission options 1 and 2.

Key Mission Events (Operational)

The mission events list will have to be modified to include Soyuz docking, habitation, and separation. Table I and figure 5 show the modified mission events timeline and launch sequence. A major change is the deployment of the ATM solar panels after docking of the Soyuz, or after the Soyuz is in its station-keeping position. This change is for safety, to avoid the possibility of the Soyuz contacting in any way the large solar panels during rendezvous (option 2) and docking (option 1).

In addition, crew transfers will be made possible early in the mission. This allows familiarization with each other's systems prior to actual experimentation and daily living. Crew exchange will be by extravehicular crew transfer through the Skylab air-lock module hatch and the Soyuz orbital compartment hatch.

TABLE I
KEY MISSION EVENTS

DAY	FLIGHTS 1, 2, 3
-1	FLIGHT 1 LAUNCH AND ORBITAL ACTIVATION - THE SATURN WORKSHOP (SWS) WILL BE INSERTED INTO THE OPERATIONAL ORBIT AND ACTIVATED FOR CREW ENTRY AND HABITATION. SWS SOLAR PANELS WILL BE DEPLOYED.
1	FLIGHT 2 LAUNCH, RENDEZVOUS, AND STATION KEEPING - THE CSM WILL BE LAUNCHED AND STATION-KEEP WITH THE SWS. FLIGHT 3 LAUNCH, RENDEZVOUS, AND DOCKING - THE SOYUZ WILL BE LAUNCHED AND DOCKED TO THE SWS UNDER OBSERVATION BY THE CSM.
1.5	CSM DOCK WITH SWS - THE CSM IS DOCKED TO THE SWS AND THE CREW ENTERS AND COMPLETES CLUSTER ACTIVATION. ATM SOLAR PANELS DEPLOYED.
2	BEGIN MISSION OPERATIONS. ONE SKYLAB CREW MEMBER TRANSFERS BY EVA TO SOYUZ. ONE SOYUZ CREW MEMBER TRANSFERS BY EVA TO SKYLAB
3 THRU 15	MISSION EXPERIMENTS ADDITIONAL CREW TRANSFERS
16	SKYLAB EVA FOR EXPERIMENTS D021, EXPANDABLE AIRLOCK AND D024, THERMAL CONTROL COATINGS.
17 THRU 25	MISSION EXPERIMENT OPERATIONS.
26	SKYLAB EVA FOR ATM FILM RETRIEVAL.
27 THRU 28	SWS DEACTIVATION OF EXPERIMENTS AND PREPARATION OF SWS FOR 1½-MONTH, NONOPERATIONAL, UNMANNED STORAGE PERIOD.
28	CSM SEPARATION, STATION-KEEPING. SOYUZ SEPARATION, DEORBIT, AND RETURN TO EARTH-EXPERIMENT DATA RETURN. CSM DEORBIT AND RETURN TO EARTH-EXPERIMENT DATA RETURN. COMPLETION OF FIRST JOINT SOVIET AMERICAN VENTURE IN SPACE.

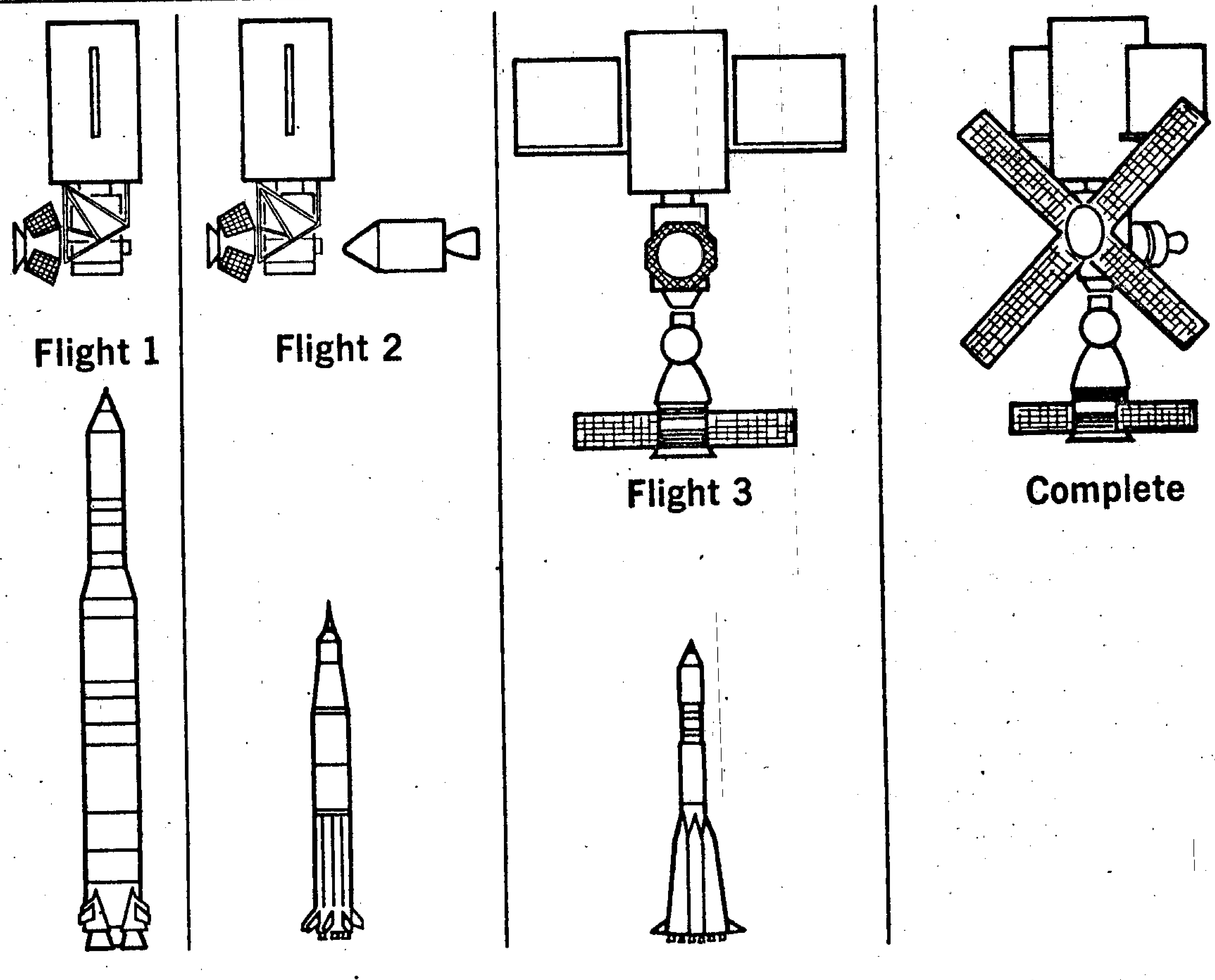


FIGURE 5 MISSION LAUNCH SEQUENCE

D. EXTRAVEHICULAR CREW TRANSFER PROCEDURE (Operational)

Extravehicular crew transfers (ECT) as required by all Skylink missions considered in this paper will involve the most hazardous extravehicular activity (EVA) ever undertaken while in Earth orbit. Whereas there have been previous ECT, they were performed in such a way that the cosmonauts and astronauts could always maneuver along an EVA handrail or handhold. That will not be possible for the entire ECT planned for any Skylink mission option.

Following is the procedure for the ECT as presently envisioned. The Soyuz would keep station with the Skylab about 50 feet below the radial docking port. Two American astronauts would go EVA at this point, one equipped with a portable lifesupport system/ astronaut maneuvering unit, (PLS/AMU), the other with a portable lifesupport system/hand-held maneuvering unit (PLS/HHMU). The astronaut with the AMU would be there to help in case any trouble developed during the transfer, while the astronaut with the HHMU would be the American exchange astronaut. Simultaneously, two soviet crewmen would exit the Soyuz, both equipped with a Soviet PLSS and HHMU. The incompatibility of the atmospheres of each vehicle would not allow integration of life support systems or spacesuit umbilical connections during transfer; thus, it appears individual backpacks will be a necessity.

One cosmonaut would be the Soviet exchange cosmonaut; the other would be there to assist the American exchange astronaut if he should need help. The exchange cosmonaut would attach a nylon safety tether to himself and use the HHMU to maneuver to the MDA to grasp the EVA handrail. He would disconnect his safety tether and attach it to the American who was to make the transfer to the Soyuz. The American exchange astronaut would then use the HHMU to jet over to the Soyuz orbital compartment, where he would grab an EVA handrail. After both astronauts have been safely transferred, all four astronauts would enter their vehicles. The Soyuz would then maneuver to a station keeping distance of 500 feet from the Skylab. This distance would be held constant until experimental requirements or termination of the mission required a change of station-keeping distance. At termination of the mission, the Soyuz would maneuver back to its transfer position and the ECT procedure would be repeated.

The HHMU mentioned above would be similar to the American Gemini unit, except that it would contain a larger supply of gas and would be refillable. Experience indicates that a maneuvering unit of this type gives the astronaut enough translational and attitude control that there should be no problems in crossing the space between the two vehicles and in acquiring the EVA handrails. If simulators should indicate otherwise, then ECT targets could be provided on both vehicles. This might entail a sheath of nylon webbing conforming to the shape of, and held several inches from, the MDA and Soyuz orbital compartment.

EVA Assist Rail (Operational and Hardware)

In order for the crew transfers to be carried out with minimum time and effort, a long handrail may be required in getting from the airlock to the Soyuz and vice versa. The rail would travel from the airlock module Gemini hatch to the forward end of the MDA. The rail could be attached in sections to the airlock and MDA prior to launch, thereby obviating the necessity for astronaut installation after launch and orbit.

The hardware modifications below would

be required primarily for mission option 1.

Docking Collars and MDA Modification (Hardware)

The Skylab multiple docking adapter (MDA) has two docking ports - one on the longitudinal axis and the other radially from the long axis. These parts are shown in figure 1.

A major modification of the MDA would be required to allow Soyuz docking. The overall impact of such a modification, however, appears to be slight.

The Soyuz docking mechanism consists of two portions. The male half, which is about nine feet long, contains the docking port probe. It is inserted into the female half, after which mechanical and electrical linkages are completed by the cosmonauts. The female portion would have to be installed on the MDA (probably on the axial port since its incorporation on the radial port would not allow the present Saturn V fairing to be used).

One problem facing a Soyuz-Skylab link-up is that there is little free room between the ATM and the MDA port V (axial port) in the launch configuration. Two modification schemes are possible:

1) Shorten the female docking cylinder and place part of the latching mechanism inside the MDA. The existing port V on the MDA would then have to allow the male docking probe to pass through the latch to the mechanisms in either the shortened female cylinder, or the MDA, or both. This scheme would not require extensive modification of the MDA exterior, but would necessitate extensive integration of the Soyuz docking mechanism into the MDA.

2) The MDA would be shortened by the removal of port V and part of the cylindrical portion of the MDA. This would allow one essentially to import an unmodified Soyuz female docking collar and attach it to the rigid ring already present in the MDA structure. Problems with the incorporation of the Soyuz mechanism inside the MDA would then be eliminated.

Mission option 2 would not require this modification.

Equipment Reintegration (Hardware)

In both cases described above, the equipment located in the forward end of the MDA would have to be relocated. A cost break-down of the general MDA modifications required is shown in part III of this study.

Mission option 2 would not require reintegration.

CSM Docking Port on MDA (Hardware)

Port III (radial port), where the CSM will dock, is presently a "dead" port. That is, the required electrical and mechanical equipment for CSM docking is not present. Essentially, the equipment located at port V could be relocated at port III. The approximate financial impact is shown in Part III of the study.

Mission option 2 would not require this relocation.

Management and Integration (Operational and Hardware)

The overall management of a cooperative project between two foreign countries can be quite expensive and time-consuming, as demonstrated by the European Launch Development Organization (ELDO). For instance, the facilities for the central management team and their clerical, accounting, and business expenses add up to a sum which is difficult to determine. Telephone calls and personal visits between the United States and the Soviet Union, shipping charges for

Soyuz equipment (assuming the US will integrate all of the Soyuz equipment at Cape Kennedy), and mutually agreeable checkout procedures will have to be arranged.

Hopefully, the management techniques learned from the Apollo and Soyuz programs can be used to facilitate rapid program initiation and completion.

Hardware Impacts of other Possible Missions

There are two other possibilities for American-Soviet Skylab missions. They are:

a) One Soviet is offered a position on a Skylab mission as the third crewman.
b) Two Americans and two Soviets could occupy the Skylab, instead of the normal three man American crew.

Mission A

This mission offers the least number of hardware impacts. The primary impacts would be those associated with crew training and in-flight crew compatibility problems. It would be desirable to have a Soviet cosmonaut who is fluent in English, and American astronauts who can speak Russian. This mission would be highly desirable as a means of getting long term habitation data for both nations without hardware changes or additions.

Soviet reciprocation could take the form of an American astronaut being offered a position onboard a Soviet space station.

Mission B

In this mission the CSM and Soyuz would be used as shuttle vehicles to bring the crewman to the station, after which the vehicles would return to earth. Thus, the Soyuz would not have to be docked to the MDA. In this mission, transfer of the Soviet crewman is accomplished by having the Soyuz temporarily station keep a few feet from the Skylab and then having the Soviet crewmen perform an ECT to the Skylab.

After completion of the transfer, the Soyuz could maneuver away from the Skylab, complete an independent mission, and return to earth. When the Skylab mission is completed, the Sov[illegible] cosmonauts could be picked up by a second Soyuz, or they could return to earth with the Americans in a four man Apollo. If the latter is the case, then perhaps it could be arranged to have one or two Americans transfer to the Soyuz for earth return.

Technical problems associated with this mission include:

- increasing the capacity of the airlock environmental control system to accommodate four men
- increasing the consumables to accommodate four men
- adding the EVA transfer target
- providing a four man Apollo
- adding rendezvous aids for the Soyuz onboard Skylab

E. ORBITAL REQUIREMENTS

For Project Skylink the orbit of the Skylab needs to fulfill three prime requirements:

1) Its orbital altitude and inclination should be such that both American and Soviet space vehicles can rendezvous with it.
2) Its inclination should be high enough (45° or more) so that large areas of the earth's surface can be observed by earth resources sensors.
3) Its altitude should be high enough so that the Skylab will be in a stable orbit for the duration of the mission.

Fortunately, the orbit planned for the

nominal American Skylab mission fits these requirements. Therefore, the orbit chosen for the American - Soviet mission is of the following type: circular with an altitude of 235 nautical miles, a period of 93 minutes, and an inclination of 50°. This compares favorably with the nominal Soyuz orbit which is of the following type: elliptical with a 125 by 141 nautical mile altitude, a period of 88 minutes, and an inclination of 51° 41'. Since the orbit chosen for the American - Soviet mission is a duplicate of the orbit that will be used on the Skylab missions now being planned, there will be no need to recompute velocity requirements for the American launches. Rendezvous velocity requirements will be calculated for the Soviet crew flights only.

For the purposes of this study, it is assumed that the Soyuz is initially injected into an orbit having the following characteristics: circular with an altitude of 125 nautical miles, a period of 89 minutes, and an inclination of 51° 40'. Starting from those conditions, we find that the Soyuz must perform three maneuvers if it is to rendezvous with the Skylab. These maneuvers are:

1) inject into a 125 by 235 nautical mile transfer ellipse
2) circularize its orbit at 235 nautical miles
3) perform a plane change maneuver of 1° 40'.

The most expensive of these maneuvers is the plane change. Since the delta vee required for a plane change decreases as orbital altitude increases, it is obvious that these maneuvers should be performed in the order listed.

The delta vee required for each maneuver was calculated using the reference <u>NASA Launch Vehicle Estimating Factors January 1969</u>. In performing the calculations, it was assumed that the Soyuz would have to perform a plane change of 2°. This was done in order to simplify the calculations and to ensure that the initial calculations would have a safety factor.

Based on these assumptions, the delta vees were calculated and are shown in table II. As shown, the toal delta vee required by the Soyuz for a rendezvous with the Skylab will be 1330 feet per second. If we allow a safety margin for midcourse and terminal docking maneuvers, it is found that the Soyuz will require a delta vee capacity of 1400 feet per second in order to effect rendezvous with Skylab. It should be noted, however, that this in-orbit delta vee requirement can be lowered greatly if the Soyuz launch vehicle is capable of injecting the Soyuz into a parking orbit with the same inclination as the Skylab. In that case, the Soyuz in-orbit delta vee requirement would be 450 feet per second. This is not assumed, however.

TABLE II
VELOCITY REQUIREMENTS FOR SOYUZ RENDEZVOUS WITH SKYLAB

Maneuver No.	Delta Vee (ft/s)
1	200
2	250
3	880

<u>Delta Vee Calculations for Soyuz and Launch Vehicle</u>

In order to determine whether or not the Soyuz would be able to perform the orbital maneuvers required, calculations were made concerning the in-orbit delta vee that could be expected from the Soyuz and the second stage of its launch vehicle. The results of that study are presented below.

1) Delta Vee Assist from Launch Vehicle Second Stage

A study of past Soyuz missions shows that the Soyuz launch vehicle (SLV) can inject a Soyuz space vehicle into a higher energy orbit than the 125 nautical mile initial parking orbit currently planned. This leads to the possibility of using the residual delta vee capability in the SLV second stage to perform a part of the Skylab rendezvous maneuvers.

The SLV residual in-orbit delta vee was calculated as follows. Orbital data was first tabulated for various Soyuz missions. Then it was assumed that each flight was initially injected into a 125 nautical mile circular orbit. Finally, the delta vee required to attain the final mission orbit was calculated. This delta vee was then said to be the SLV second stage residual delta vee.

The Soyuz missions studied were those in which the Soyuz weight was assumed to be approximately equal to the weight of the Soyuz that will be used for the joint American-Soviet mission. This information is presented in table III. It shows that the maximum calculated residual delta vee for the SLV second stage is 40 feet per second.

TABLE III
SLV RESIDUAL IN-ORBIT DELTA VEE

SOYUZ FLIGHT NO.	Perigee NM	Apogee NM	SLV Residual (fps)
5	125	143	25
7	125	141	20
9	151	163	40

However, it is felt that this figure is not a maximum and that a figure of about 50 feet per second would be a reasonable estimate. For the rest of this section, it is assumed the SLV second stage could provide 50 feet per second delta vee for performing orbital maneuvers.

2) Soyuz Delta Vee Calculations

Since the SLV second stage can provide 50 feet per second delta vee, the Soyuz must be capable of providing the remaining 1350 feet per second. The following are the initial assumptions for the Soyuz in-orbit weight breakdown:

Soyuz vehicle.....6050 kilograms
Soyuz propellant module.........1500 kilograms
Propellant mass (estimated).... 500 kilograms

No information was available concerning the propellants used by the Soyuz orbital maneuvering system (OMS). Therefore, assumptions were made of the specific impulse of the propellants used in the Soyuz OMS. The result was the graph in figure 6, which plots delta vee as a function of the exhaust velocity, which, in turn, depends on the specific impulse.

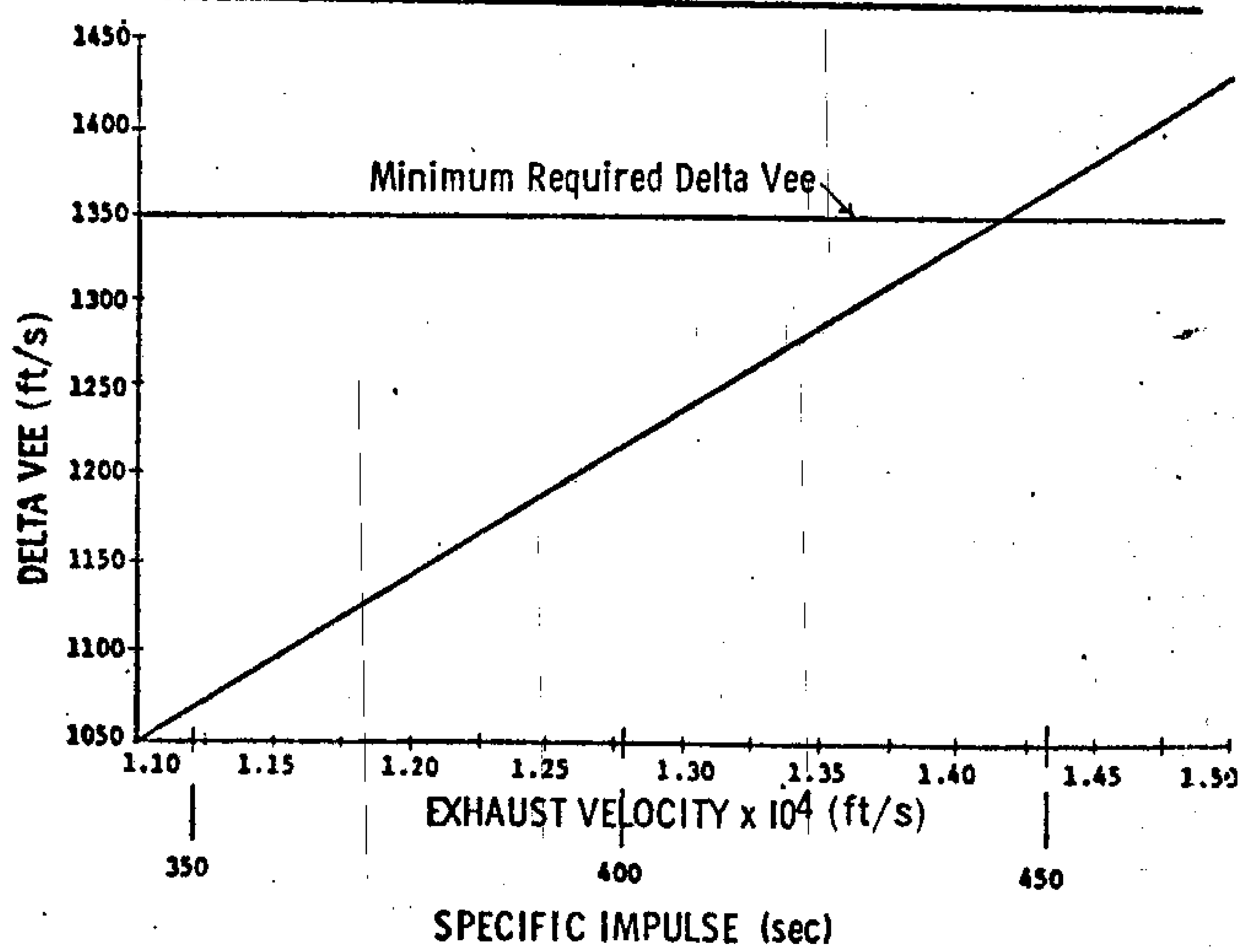
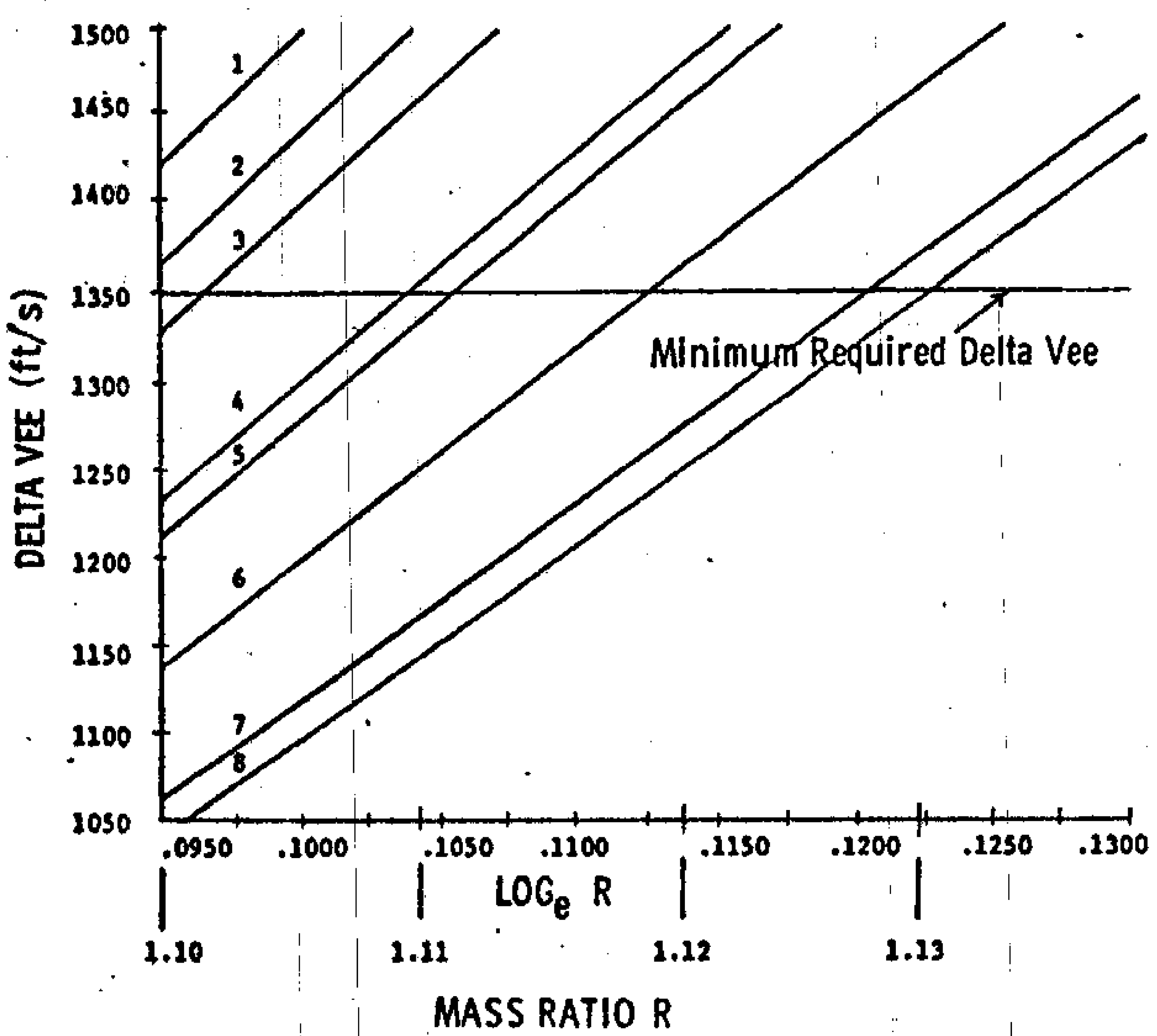


FIGURE 6 SOYUZ DELTA VEE vs EXHAUST VELOCITY

To continue the calculations, the specific impulse was held constant and the mass ratio R was varied. The result is the graphs in figure 7, which plot delta vee as a function of $\log_e R$. As the graphs show, there are certain minimum requirements for specific impulse and mass ratio that must be met if the Soyuz is to perform its rendezvous maneuvers. If the specific impulse is 350 seconds then the mass ratio must be 1.127. However, the mass ratio of the Soyuz as derived from the figures given above, is only 1.1. Hence, if the specific impulse of the Soyuz OMS is 443 seconds or lower, modifications will be necessary.



Line No.	Exhaust Velocity (ft/s)	Specific Impulse (sec)
1	15,000	469
2	14,400	450
3	14,000	437
4	13,000	406
5	12,800	400
6	12,000	375
7	11,200	350
8	11,000	343

FIGURE 7 SOYUZ DELTA VEE vs MASS RATIO AND EXHAUST VELOCITY

These modifications could take the form of decreased Soyuz "dry weight" by the removal of excess equipment, such as the docking unit if option 2 is used, increased fuel weight through the use of additional light weight fuel tanks, or some combination of measures. However, if the mass ratio is constant at 1:1, then the minimum specific impulse required will be 443 seconds. Perhaps uprating the OMS by higher specific impulse fuels would be feasible.

The value of 50 feet per second residual delta vee is probably quite conservative. Therefore, it can be concluded that if the plane change can be accomplished by a change in Soyuz launch azimuth, and if the SLV can use its residual in-orbit delta vee for reaching the required altitude, the Soyuz can rendezvous with the Skylab without major modifications.

III. FINANCIAL ASPECTS

The overall financial impact of the addition of a Soyuz spacecraft to the Skylab is shown in table IV. It must be emphasized that the values shown are very rough estimates and are enumerated primarily to show a possible method for determining cost savings.

It should be noted that the degree of impact shown is not a measure of the cost of the said modification. Rather it is a measure of the degree to which the modification effects the entire Skylink design.

Cost Additions

The MDA modification is approximated at a cost of $200,000. This includes the removal of the forward cylinder and attachment of the Soyuz docking collar.

The MDA equipment which would have been in the forward cylinder will have to be redistributed in the MDA by the integration contractor. This has been estimated at $3,000,000.

The CSM docking port III (radial) will

TABLE IV
COST ADDITIONS AND ELIMINATIONS

Hardware Modification	Cost Additions $ Thousands	Degree
MDA Modification	200	Major
MDA Equipment Reintegration	3,000	Medium
CSM-Docking Port Equipment Relocation	200	Minor
EVA Assist Rail	100	Minor
Management and Integration	5,000	Major
Total	8,500	

Experiment Cooperation	Cost Eliminations $ Thousands
Earth Resources	8,000
Science	8,000
Biomedical	8,000
Technology	0
Crew Operations	0
Solar Astronomy	0
Total	24,000
	−8,500
Resultant Savings	$15.5 Million

have to acquire the equipment originally connected to port V (axial). The cost of relocating this equipment has been estimated at $200,000.

The installation of an EVA assist rail involves bolting a type of lightweight tubular railing to the airlock and MDA. Manufacturing and installation costs are estimated at $100,000.

The cost of management and integration, including all the items previously listed, is difficult to determine. An approximate cost of $5 million is used as a very rough estimate.

Cost Eliminations

When the experimental programs of the Skylab and Soyuz are combined, it is quite likely that some areas of duplication will arise. By eliminating one of the duplications, the cost of experiment inclusion onboard one of the vehicles could be avoided, resulting in a certain cost savings.

An approximate cost for the integration of two earth resources sensors, for instance, was estimated at $8 million. If these two sensors could be eliminated on the Skylab, and the Soyuz capability used instead, a cost savings of $8 million results.

This method of rough estimation of savings can also be applied to other areas in which the Soyuz vehicle would take up part of the experimental hardware. There is liable to be varied degrees of duplication in the areas of science and biomedicine, for instance. Again, the elimination of one or two experiments and their allocation to the Soyuz, which would already have that capability within its confines, would result in savings of about $8 million in each case.

In the areas of technology, crew operations, and solar astronomy, each vehicle has an inherent capability which would best be used as a cooperative exchange of usage and data. Elimination of experiments is less feasible here.

Shown in table IV is only the savings to the United States. Reciprocal savings to the Soviet Union would also occur when certain experiments of theirs would be carried out on Skylab, especially in the area of solar astronomy.

A resultant savings, which is largely rough estimation, is listed as $15.5 million.

IV. SCIENTIFIC ASPECTS

There are six major areas of scientific investigation on Skylab:

- solar astronomy
- science
- biomedicine
- technology
- earth resources
- crew operations.

Benefits from the Skylab-Soyuz mission would accrue primarily in the forms of scientific information exchange and cooperation.

Solar Astronomy

This is one of the primary areas of Skylab investigation. The Apollo telescope mount (ATM) will have many solar instruments including an X-ray spectrograph, UV spectroheliometer, X-ray telescope, and UV stellar photosystem.

The Soyuz craft has several instruments for solar study; however, they are not as extensive as those of the ATM. Therefore, this would be an area of investigation the Soyuz need not duplicate. The data gathered would be available to Soviet personnel. Also, the cosmonauts would be able to suggest possible experimental schemes, such as time exposures and filters, perhaps covering an aspect of solar astronomy within the capability of the ATM but not originally planned. The solar experiments onboard the Soyuz could be eliminated, assuming they all could be performed by the ATM. Soyuz weight, volume, and cost savings are indicated.

Science

Both the Skylab and Soyuz carry out experiments in geophysics, stellar astronomy, and upper atmosphere physics. Duplicate experiments or equipment could be eliminated in both vehicles, thereby allowing the Soyuz, for instance, to concentrate on another group of areas. Both vehicles might carry instruments to study the optical degradation of portholes and optical surfaces. Since the Soyuz does have more exposed window area, it could carry primary responsibility for optical degradation of viewing ports.

Biomedical

Both the Skylab and Soyuz have the capability for long duration stays in space. The Soyuz can remain in orbit a maximum of 30 days. Biomedical instruments not involving spacesuit compatibility could be shared by both teams of astronauts. For instance, the Skylab could offer its lower body negative pressure experiment and its exercycle, both of which would be too large for incorporation into the Soyuz. In turn, the Soyuz could offer experience in visual acuity and long-distance eyesight degradation measurement; because of (1) the several large viewing ports in the orbital compartment and (2) formal experiments in these areas. The unique Soviet experiments in vision, including "light index and visual optical" methods of information exchange between two spacecraft, would be a significant Soyuz contribution in this area.

Technology

The expertise gained by the Soyuz vehicles in the welding of metal in conditions of vacuum and weightlessness would benefit somewhat parallel efforts in material processing onboard Skylab. The different materials and techniques could be compared, resulting in the possibility of an expanded experimental program without any additions to either spacecraft.

Earth Resources

Both vehicles have extensive programs in multispectral photography and sensing. The Soyuz primarily would photograph and scan areas of Soviet land mass and snow areas. Skylab infrared instruments and its multispectral scanner would study selected earth sites. Since duplication would not be needed because of output sharing, the functions of two of the four sensors located in the Skylab could be carried out by the Soyuz. As was shown in the section on financial aspects, this could result in a savings of perhaps $8 million in the Skylab program, and a gain of instrumentation usage by Soyuz personnel who have come onboard Skylab.

Crew Operations

Soyuz experience in EVA transfer would be useful to Skylab personnel during vehicle exchange. The sleep, food, and hygiene facilities would be utilized by both crews on both vehicles and could yield data on the improvement of both systems. The astronaut maneuvering unit would be on Skylab to be used by Skylab personnel and observed in use by Soviet crew members. Likewise, the portable life support systems used by the Soyuz personnel could be observed in action by Skylab astronauts. It is doubtful that the equipment could be used by the opposite country's crewmen because of suit incompatibility.

V. POLITICAL ASPECTS

The possibilities of American - Soviet cooperation hinge on the political climate at the time. Agreements between the two countries have included United Nations resolutions covering liability, assistance, and return of space hardware and personnel, agreements not to make political claims to the moon or other planets, and, most recently, the Moscow conference at which American - Soviet cooperation and compatibility were discussed.

The first discussion of an all-out joint venture was initiated when President Kennedy proposed a combined manned lunar landing effort in 1963. At that time, the Soviets did not respond. President Kennedy summed up the general problems to be overcome when he made this statement at a press conference in 1963:

"The kind of cooperative effort which would be required for the Soviet Union and the United States to go to the moon together would require a breaking down of a good many of the barriers of suspicion and distrust and hostility which exist between the Communist world and ourselves. There is no evidence that those barriers will come down."

The idea of American - Soviet cooperation seems to be a special case of the general concept of international cooperation. If one reads the NASA guidelines for general space cooperation, the barriers do not appear formidable, at least from an American point of view:

1) Designation by each participating government of a central civilian agency for the negotiation and supervision of joint efforts.

The USSR Academy of Sciences would fulfill this requirement.

2) Agreement upon specific projects rather than generalized programs.

One main goal of a Skylab-Soyuz station would also be the main goals of both the Skylab and the Soyuz by themselves: experience in long-duration manned habitation in space. Hence, the link-up or coorbiting would result in the combination and strengthening of the specific scientific and practical experiments carried on each vehicle.

3) Acceptance of financial responsibility by each participating country for its own contributions to joint projects.

In the case of the Skylab-Soyuz, the cost of modifications would have to be shared by the cooperating nations. In the case of Skylab-Soyuz station-keeping only, no cost for modifications would result.

4) Projects of mutual scientific interest.

Since the original goals of both Skylab and Soyuz are about the same, the combined project would definitely be of mutual scientific interest, if it would not, in fact, actually enhance the interest. Also, operations in earth orbit would tend to be only for reasons of science and cooperation, since neither side would want military hardware to be seen by the other side. Although the conservative argument might be that the distrust between the two cultures knows no bounds, the ambience of space seems unique enough perhaps to change, or at least to suppress, hateful attitudes.

One barrier, however, might be the unwillingness of either country to appear as "student" while the other is "teacher." At present, both the US and USSR are about equal in earth orbit capability and duration. Although the manhours spent in space is greater for American astronauts, the types of earth orbit missions are not unique. Thus, both sides would stand to gain experience in long duration habitation of an embryonic space station. This is, of course, dependent upon Soviet ventures up to, and including, 1973. If, by that time, they already have a large orbiting space station, it is doubtful they would want to join with Skylab. Perhaps then the Soviets would be willing to visit or coorbit with the Skylab. Mission option 2, involving no hard docking, would then be used. Transfer of crews and scientific findings would occur. It is also possible the Americans could visit the Soviet station and carry out a program similar to the one outlined for Skylab-Soyuz station-keeping.

Management

The use of an independent management organization, perhaps a third party, has been suggested as one management technique. Experience with the ELDO program recommends this approach. It has been found that because of domestic requirements and duties of each member country, little is done soon enough. The use of a third party would, in essence, require the complete turning over of the management aspects to an all-powerful integrating task group. Perhaps the United Nations could play a major role.

On the other hand, the red tape inherent in such a "middleman" concept would perhaps be too cumbersome, especially considering the linguistic and distance problems. Perhaps a direct one-to-one relationship between personnel would be best. In other words, each American official in charge of a major Skylab aspect would have his Soyuz counterpart in the Soviet Union. A direct telephone and television link, possible with communication satellite agreements, would aid project integration.

VI. CONCLUSION

A combined Skylab-Soyuz could be flown with medium (option 1) or little (option 2) hardware impacts on the vehicles. Both vehicles could carry out their portion of the required rendezvous procedures; hence, it is not a question of whether or not it can be done, but whether or not both sides would be willing to do it.

It can also be concluded that a combined Skylab-Soyuz mission would result in the following:

1) a critically stable vehicle while in orbit, if only Skylab CMG are used for vehicle attitude control (applies to option 1 only)
2) increased scientific return
3) improvement of chances for future space cooperation
4) financial savings to both nations

What indications are there that the time is right for such cooperation?

One indication is the Soviet press conference held after the Soyuz-9 flight on July 9, 1970. Dr. Keldysh, president of the USSR Academy of Sciences answered the question: "What are the prospects for Soviet-American cooperation in the establishment and use of orbital stations?" His reply is revealing: "We will consider with maximum attention proposals for cooperation, in particular the proposal by Dr. Paine for the unification of docking devices...."

Another indication of progress was given by the Soviet scientist Professor Leonid Sedov, at a recent congress of the International Astronomical Federation. He said, "A flight to Mars and the creation of large orbital stations, and other tremendous projects in space exploration, will certainly demand the joint efforts of all nations."

The Skylab-Soyuz link would be a first step in the direction of cooperation in the exploration and mindful utilization of outer space. With little to lose and much to gain, both nations should begin seriously discussing the possibilities as soon as possible.

The opinions expressed in this paper are solely those of the authors and in no way reflect the opinions of the National Aeronautics and Space Administration or the McDonnell Douglas Corporation.

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