N83 11160

SATELLITE SERVICES WORKSHOP
NASA/JSC, 22 - 24 JUNE 1982
SATELLITE DESIGN SESSION

DESIGN OF THE MATERIALS EXPERIMENT CARRIER FOR ON-ORBIT SERVICING

BY

DONALD M. WALTZ AND HANS F. MEISSINGER
TRW
REDONDO BEACH, CALIFORNIA

Contents

DESIGN OF THE MATERIALS EXPERIMENT CARRIER FOR ON-ORBIT SERVICING

Waltz
Field Operations Division
and Technology Group
each, California

Hans F. Meissinger
Mission and Systems Engineering
TRW Space and Technology Group
Redondo Beach, California

1. INTRODUCTION

Materials Experiment Carrier (MEC) is needed to advance materials ng in space toward a fuller, more effective and economical utilization pace environment, starting with a broadened research flight program huttle/Spacelab and thrusting to full scale commercial applications on e Platform.

major facet of the orderly transition from crew tended Shuttle/Spacelab to fully automated operations on MEC/Space Platform missions can be d by planned, periodic on-orbit servicing events that are part of the sion scenario. This will create the opportunity for timely replacement materials processing payload units or payload samples. Design of MEC for it servicing is feasible; the economics of on-orbit servicing looks ing.

n-orbit servicing, like other MEC mission phases requiring repeated Shuttle/ Platform rendezvous and docking, will involve intricate, crew supported, le operations that will gradually evolve into routine activities. This as- of the MEC mission does not require novel technology, per se, but does in- a build up of experience by Shuttle flight crews. Principal concerns ding MEC design and mission planning for on-orbit servicing are: (1) an ness of the inherent complexity of the orbital operations, (2) a practical design approach that emphasizes simplicity and reliability, and (3) implemen- on of interface design solutions that eliminates safety risks involved in payload manipulation by Shuttle crewmen.

This paper discusses the MEC system and its mission from the viewpoing of orbit servicing. Information is provided on MEC system requirements, design tures for on-orbit servicing, on-orbit servicing operations and rationale and ative servicing costs.

All of the information presented herein is taken from a study TRW performed for the NASA/Marshall Space Flight Center. This study Materials Experiment Carrier Concepts Definition Study was performed from October 1979 through December 1981. (Contract No. NAS8-33688). Mr. Kenneth R. Taylor of Program Development at MSFC was the NASA COR for this study.

2. ROLE OF MEC

The U.S. National Aeronautics and Space Administration is currently sponsoring a Materials Processing in Space (MPS) program that involves both ground and space-based research and will require frequent and cost-effective access to the space environment to accomplish its goals. Initially research-oriented, the program will be aimed eventually at space utilization for commercial ventures.

Several first-generation research and commercial payloads are under design and development. They will be carried by the space Shuttle/Spacelab on earth orbital flights starting in the mid 1980's. These missions will focus on acquisition of materials behavior research data, the potential enhancement of earth-based technology, and initial processing experimentation for specialized high-value materials.

The early short-duration and power-limited Shuttle/Spacelab missions will accomplish important MPS research and development. Projected MPS needs in terms of numbers of samples, processing time, and power required to support sustained, systematic space processing activities however, will soon exceed Shuttle capabilities.

The Materials Experiment Carrier (MEC) will provide these augmented capabilities to materials processing in space in the post 1986 era. The MEC vehicle, carrying multiple, advanced MPS payloads will fly attached to the Space Platform. It will be launched and later retrieved by the Shuttle Orbiter, and it will be reflown repeatedly after refurbishment on the ground. Revisits of MEC by the Shuttle for servicing on orbit are also envisioned to enhance mission effectiveness and reduce operational costs.

Compared with MPS/Slacelab, MEC offers:

- Greatly extended mission durations (90 days and longer) for processing a significant number of material samples at affordable costs
- Greater processing power (10 kW and higher)
- A sustained undisturbed micro-gravity environment (with a goal of 10^{-6}g and better)
- An evolutionary step to the goal of commercial space processing

3. ON-ORBIT SERVICING DEFINITION

In the MEC study, on-orbit servicing was defined as the:

(1) Replacement of a materials processing payload or

(2) Changeout of only the sample magazine or storage compartment within payloads or

(3) Replacement of a malfunctioning major subsystem or component or

(4) Some combination of the above

That is, on-orbit servicing operations pertain to exchange of entire payloads, processed samples, or subsystems. Servicing, in this study, did not consider orbital troubleshooting, repair, routine maintenance or calibration of instrumentation or processing equipment.

4. MEC SYSTEM REQUIREMENTS

MEC is a payload of the Space Platform. It always flies attached to the platform. MEC system requirements are given in Figure 1. The principal requirements are keyed to:

1. The projected growth of the Space Platform (SP) from an initial moderately sized vehicle providing up to 12.5 kW power to payloads into a later, full capacity version which will delivery nominally up to 25 kW.
2. An anticipated SP initial operational capability (IOC) in 1987 or 1988.
3. The projected schedule of two Space Platform revisits per year by the Shuttle Orbiter for purposes of SP payload changeout.

DESIGN

1. MEC WILL EVOLVE FROM INITIAL CAPABILITY (9 TO 11 KW NOMINAL, 18 KW PEAK) TO FULL ("ALL-UP") CAPABILITY (25 KW NOMINAL, 40 KW PEAK) PACED BY SP GROWTH AND MPS PAYLOADS EVOLUTION
2. PAYLOADS FOR INITIAL MEC MISSIONS WILL INCLUDE
   - ADVANCED SOLIDIFICATION EXPERIMENT SYSTEM (SES) 3-5 KW
   - UP TO 7 PAYLOAD FACILITIES, ADAPTED FROM ADVANCED MEA(1) 3-5 KW EACH
   - ELECTROPHORESIS OPERATIONS IN SPACE (EOS) 3-5 KW
3. LIMITED SP POWER CAPACITY AND ACCOMMODATION OF OTHER USERS REQUIRES TIME-SHARED MEC PAYLOAD OPERATION
4. PAYLOADS WILL OPERATE AUTONOMOUSLY, MONITORED AND CONTROLLED BY MEC CENTRAL CDMS
5. ACCESS TO PAYLOADS FOR ON-ORBIT SERVICING (P/L OR SAMPLE CHANGEOUT) WILL BE REQUIRED ONLY ON ALL-UP MEC
6. MEC DESIGN AND OPERATION CONSTRAINED BY STS AND ASTRONAUT SAFETY REQUIREMENTS

MISSION

1. MEC/SP MISSIONS CHARACTERIZED BY
   - LONG STAY TIME IN ORBIT (180 DAYS AND LONGER)
   - HIGH POWER LEVEL TO PAYLOADS (UP TO 25 KW NOMINAL)
   - SUSTAINED, UNDISTURBED MICRO-ENVIRONMENT ($\leq 10^{-5}$g)(2)
2. SIX MONTH BASELINE MISSION DURATION CONFORMS WITH PROJECTED TWICE-A-YEAR SP REVISITS BY SHUTTLE
3. MEC IS UNCONSTRAINED AS TO ORBIT ALTITUDE AND INCLINATION, ORIENTATION AND BERTHING PORT ASSIGNMENT
4. ONLY CRITICAL MEC PROCESSES AND PROCESS PHASES REQUIRE INTERACTIVE CONTROL BY POCC, IN NEAR-REAL-TIME, VIA TDRSS/SP FORWARD AND RETURN RELAY LINKS.
5. TELEOPERATOR MANEUVERING SYSTEM (TMS) MAY BE USED IN MEC DEPLOYMENT, RETRIEVAL AND SERVICING TO REDUCE ORBITER MANEUVER REQUIREMENTS
6. MEC IS A REUSABLE, VERSATILE CARRIER OF MPS PAYLOADS

(1) MEA-MATERIALS EXPERIMENT ASSEMBLY, WILL FLY ORIGINALLY ON SPACE SHUTTLE AS AN ORBITER BAY PAYLOAD
(2) OCCASSIONAL MICRO-g DISTURBANCES OF ABOUT 10^{-3}g ACCEPTABLE TO SOME PAYLOADS

Figure 1. MEC System Requirements

4. A set of: (1) early MEC materials processing payloads, to include up to seven advanced MEA type facilities, a solidification experiment system (SES), and a commercial processing facility, known as Electrophoresis Operations in Space (EOS), and (b) full capability MEC payloads to include the above early payloads plus some mixture of the following candidate MPS facilities:

   (1) Advanced Solidification Experiment System

      A. Isothermal
      B. Directional Solidification

   (2) High Gradient Directional Solidification

   (3) Float Zone

   (4) Acoustic Containerless

   (5) Electromagnetic Containerless

   (6) Electrostatic Containerless

   (7) Solution Crystal Growth

   (8) Vapor Crystal Growth

   (9) Bioprocessing

   (10) Commercial Payloads

Accordingly, the MEC concept addressed the following:

(a) The MEC design will evolve from an initial, limited capacity version, designed for use with the initial 12/5 kW SP into a full capacity "all-up" configuration that can fully utilize the resources of the later, full capacity (25 kW) Space Platform.

(b) The estimated time frame for missions of the initial MEC is in the late 1980's, those of the all-up MEC is 1990 and beyond.

(c) MEC mission durations, even initially, will be 180 days, as dictated by the projected SP revisits by the Shuttle. Missions of the all-up MEC may be extended to last for several revisit cycles i.e., 12 months or 18 months if necessary to meet program objectives, depending on MPS payloads and their orbital stay time requirements.

(d) MEC on-orbit servicing for payload or sample exchange is not contemplated for the initial, 180-day missions as there will be no Shuttle revisits at shorter time intervals. However, servicing may be required in support of all-up MEC operations if missions extend to 12 months or longer durations.

(e) In the projected MEC evolution from an initial to an all-up tion, design commonality and possible use of applicable exis hardware should be emphasized.

Thus, the Advanced Materials Experiment Assembly, MEA-C, cur being designed by NASA/MSFC for Shuttle-based missions prec MEC or the standard Spacelab Pallet, are leading candidates viding the support structure or support subsystems to be us initial MEC design concept. They might possibly also be us building blocks in the evolution of the all-up MEC.

Payloads carried in all-up MEC missions shall have design and i characteristics that are consistent with, and facilitate on-orbit s Servicing operations will include exchange either of entire payload only of sample magazines within payloads, and possibly the replacem functioning payload subsystems.

Servicing operations will require payload and component handli by the Shuttle Remote Manipulator System (RMS) or manually, by a c addition, convenient and safe access to internal equipment shall b via access hatches of sufficiently large size.

5. MEC CONFIGURATIONS

The role of the SP in the evolving MPS program is shown in Fi the Shuttle can accommodate low power, short duration MPS R&D, fa specimen size, sample size, and higher melting points pose the ne as well as MPS carrier systems that are compatible with both the flight modes.

Currently, the MPS program is developing automated payloads Shuttle cargo bay and manned payloads to fly both in the Shuttle in the Spacelab module. This automated work is expected to lead of a customized MPS payload carrier for automated MPS payloads. Materials Experiment Carrier. Concepts for this carrier have be that will minimize Shuttle user charges, which is most important users. Figure 2 depicts the selected MEC concept which can begi carrier and grow in modular steps to accommodate MPS payloads o has seven compartments so that several different processes can parallel, or several different products produced in parallel. would optimize the facility utility and the time on orbit.

ORIGINAL PAGE IS
OF POOR QUALITY

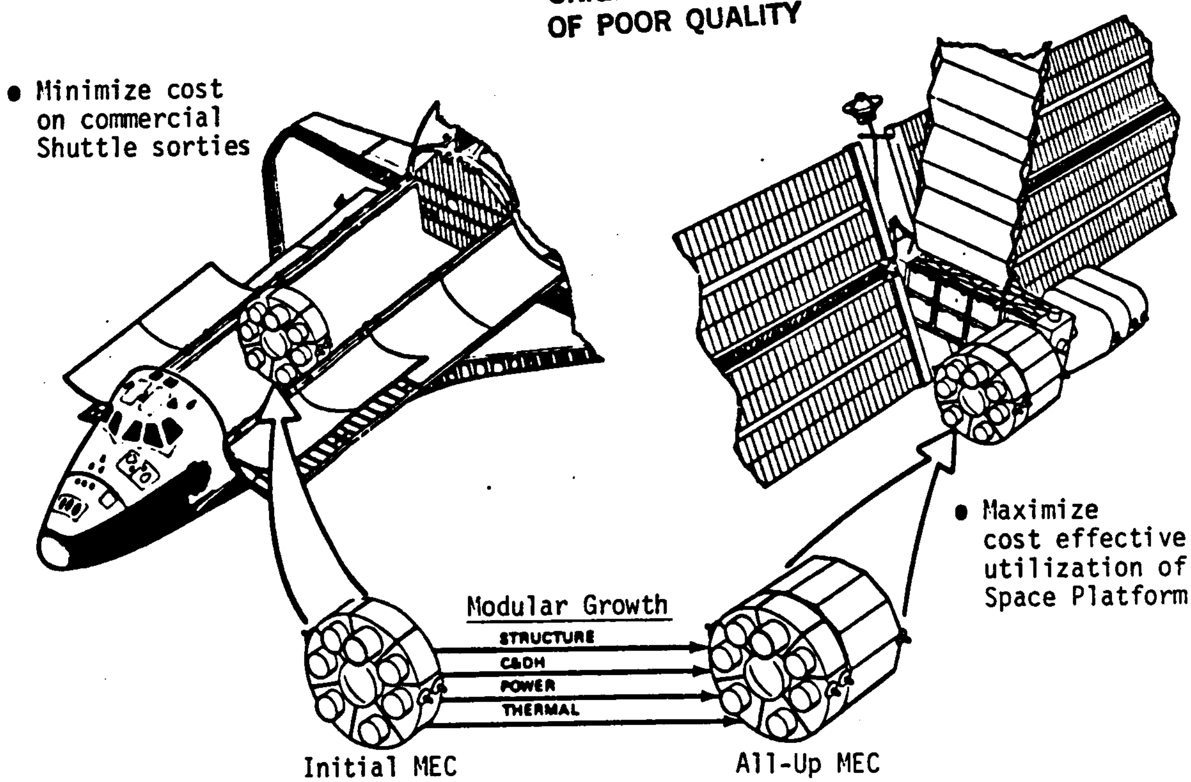


Figure 2. MEC Growth and Utility*

6. MEC DESIGN FOR ON-ORBIT SERVICING

The selected initial MEC concept is based on adaptation of the Advanced MEA spoked disc support structure and subsystem design. The payloads are attached axially through access doors or openings in one bulkhead. This permits larger payload units to be accommodated than by radial insertion.

An alternative design is based on adaptation of the standard Spacelab pallet.

Growth to the all-up MEC configuration is achieved through addition of a four-compartment, side-loaded, drum-shaped add-on module that is attached to the disc-shaped MEC core module. Subsystems located in the core module are retained with extension of capability, as required to support the added payloads.

*Figure 2 is from a paper titled A Focus for Space Industrialization by W.R. Marshall, W.T. Carey, and K.R. Taylor of NASA/MSFC. It was presented at the 19th Space Congress, Cocoa Beach, Florida, 29 April 1982

ORIGINAL PAGE IS
OF POOR QUALITY

In the case of the pallet based MEC design, growth to the all-up version could be achieved by addition of a second pallet in tandem with the first.

INITIAL MEC

Figure 3 shows the initial MEC configuration with EOS attached. Figure 4 shows an exploded view of MEC and EOS in the alignment used for berthing to the Space Platform aft payload port (+x port). This illustration also shows two other payload ports (+z and -y ports) to which the MEC/EOS might be attached, assuming that four such ports are available on the Space Platform. Six MEA-C type cylindrical payloads of equal size are shown protruding from the peripheral compartments of the MEC disc structure, while SES occupies the center compartment. One peripheral compartment, i.e., that located adjacent to the EOS berthing adapter, is used to house the MEC subsystems.

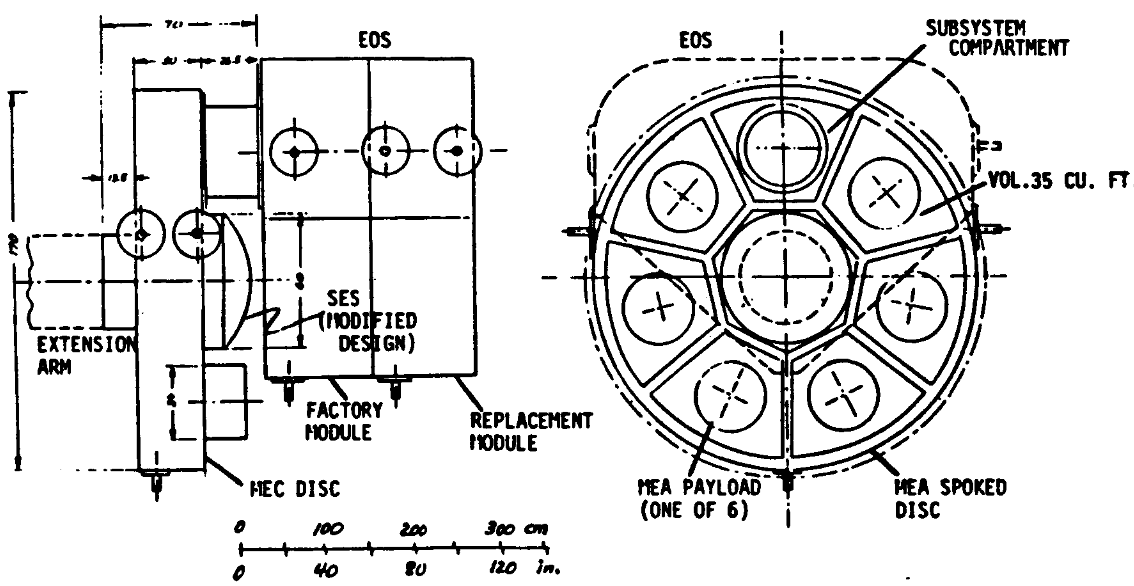


Figure 3. Initial MEC Configuration, Including EOS

ORIGINAL PAGE IS
OF POOR QUALITY

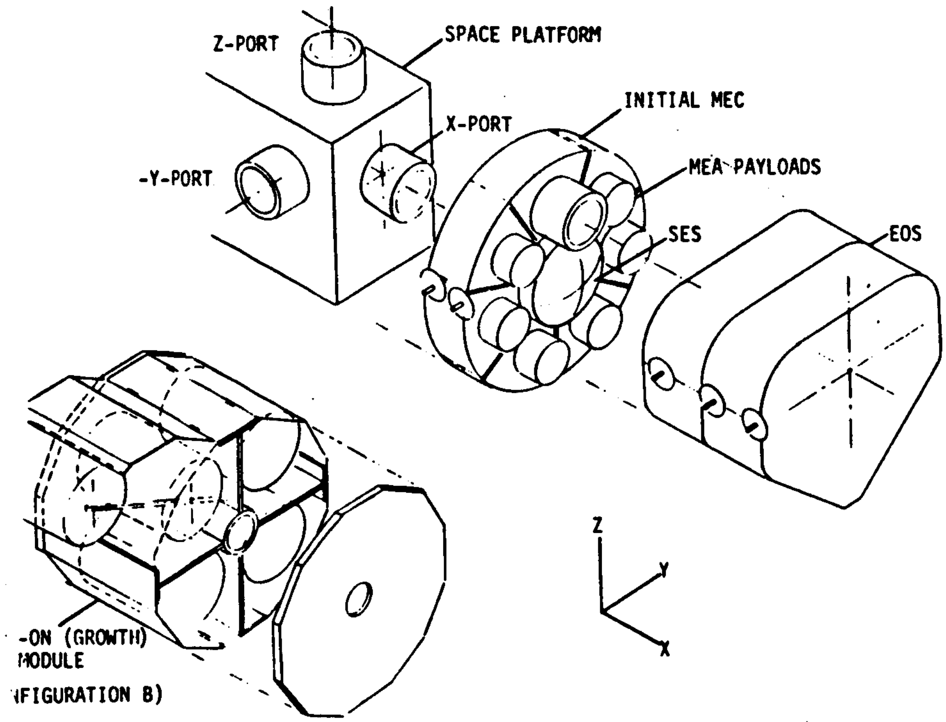


Figure 4. Initial MEC (Spoked Disc) Configuration and Add-On Growth Module

ION OF INITIAL TO ALL-UP MEC

Evolution to all-up MEC will require primarily an increase in payload nodation capacity. The preferred approach is to add a growth module to initial MEC which, by preserving its basic subsystems and payload accommo- on capability, then becomes the "core" module of the all-up MEC.

Secondly, the development of payloads servicing capability from the cial MEC (which does not have to provide this capability) will be required. impact of this requirement on the design and arrangement of the core and wth modules can be summarized as follows:

1. By utilizing the initial MEC as core module a part of the payloads accommodated in the all-up MEC will be of limited size, comparable to MEA facilities. Such payloads will probably be of exploratory design, requiring only short mission durations.

2. MEC missions durations will initially be 6 months, but will ultimately evolve to 12 months or more. At least the exploratory type of payloads may have to be exchanged at 6-month intervals. Consequently, the core module will require conversion to serviceability.

3. Core module conversion will be feasible if the initial design makes appropriate provisions for payload attachment/removal on orbit.

4. Axial payload attachment was previously shown to be advantageous on the initial MEC. With this design feature retained in the core module, it will be necessary to arrange the core module at the aft end of the all-up MEC. The growth module, placed between the SP berthing port and the core module, will therefore require side access to its payload compartments.

5. With this arrangement and the MEC subsystems still housed in the core module, it will be necessary to carry power and signal cables and coolant lines through the growth module into the core module resulting in a small weight penalty.

ALL-UP MEC CONFIGURATION

Retention of the initial MEC as core module for the all-up MEC reflects in subsystem placement and in access provisions for the core module payloads for on-orbit servicing. On-orbit serviceability of payloads in the all-up MEC permits long mission durations for some of the payloads, e.g., those carried by the add-on module, without requiring the same orbital stay time for others.

As shown in the configuration drawing, Figure 5, the four-payload growth module is attached at the forward bulkhead of the six-payload core module. As in the initial MEC configuration, EOS is again attached to an off-center berthing adatper placed adjacent to the trapezoidal compartment of the core model that houses the MEC subsystems. With the growth of subsystem capacity and size required to support the all-up MEC system, a second trapezoidal compartment will be dedicated to housing subsystems and other support equipment, e.g., a waste retention tank. Hence, the reduction of core module payload capacity by one unit.

A utility tunnel, shown in the center of growth module cross section, on the right, is used to connect power and signal conduits and coolant lines from the SP berthing adapter to the MEC subsystem compartments, and vice versa.

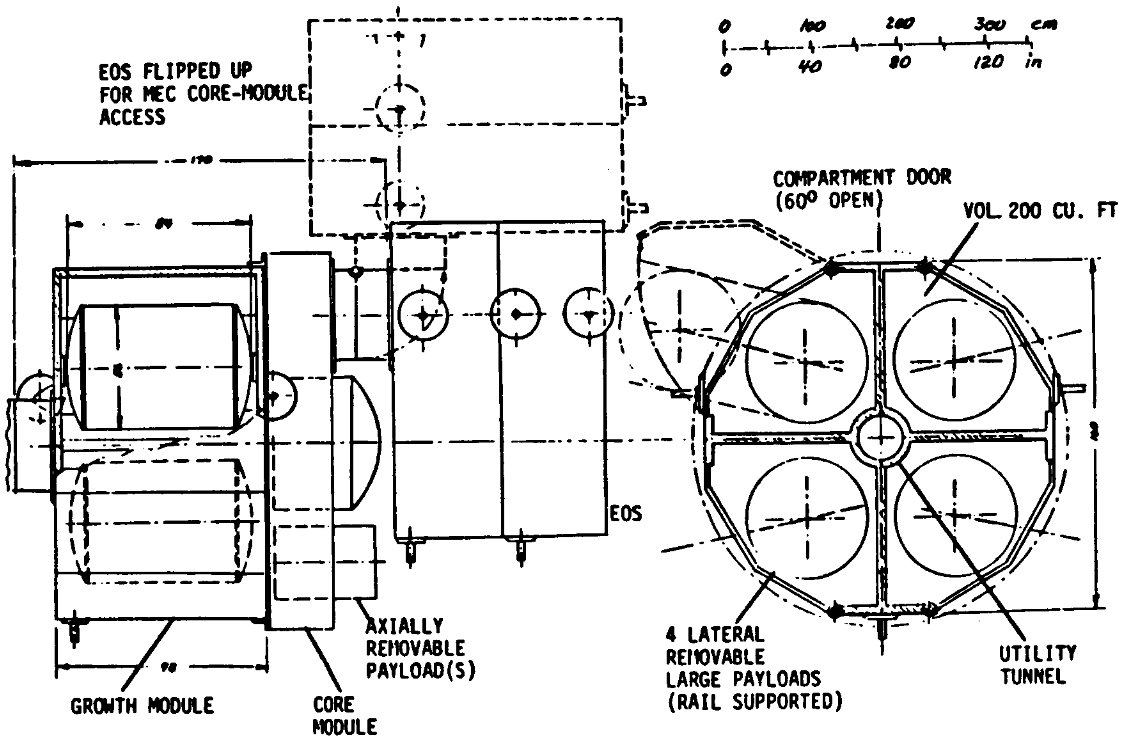


Figure 5. All-Up MEC Configuration, Including EOS

Some extra length of power cable (7 ft), signal cables and fluidlines (14 ft) is unavoidable with the selected design approach, which caters to the servicing access objective for payloads carried by the core module

Another design feature keyed to this objective is the provision for moving the EOS assembly out of the way to allow access to core module payloads. As shown in the MEC side view drawing, this is accomplished by a hinge in the EOS berthing adapter. Design details of this feature still require further definition. The preliminary concept shown here assumes that the retention mechanism in the active half of the adapter carried by MEC will be released prior to flip-up, with flexible cables and fluid lines having enough slack to permit the desired hinge rotation. This would avoid having to disengage the electrical and fluid connectors at the MEC/EOS interface. Several alternative designs have been investigated that similarly do not require modification of the passive adapter half carried by EOS, i.e., the extra cost of interface modification needed to provide core module servicing access would be absorbed by the MEC design rather than by EOS. A simpler, though operationally less attractive, option would involve EOS removal to a temporary parking location by the Shuttle remote manipulator whenever MEC core module access is required.

Note that the EOS swing-out concept illustrated here is made feasible by the off-center location of the berthing adapter.

Figure 6 shows an isometric view of the all-up MEC with a full payload complement. The drum-shaped, twelve-sided growth module is shown with one of the four payload compartment doors opened. Lateral access to the payloads is illustrated, with one payload canister extended on guide rails for servicing or removal. Payload changeout will require handling by the RMS with EVA crew assistance. RMS grapple fixtures required for MEC deployment or stowage and for payload changeout will be inserted manually by the crewman into receptacles provided for this purpose.

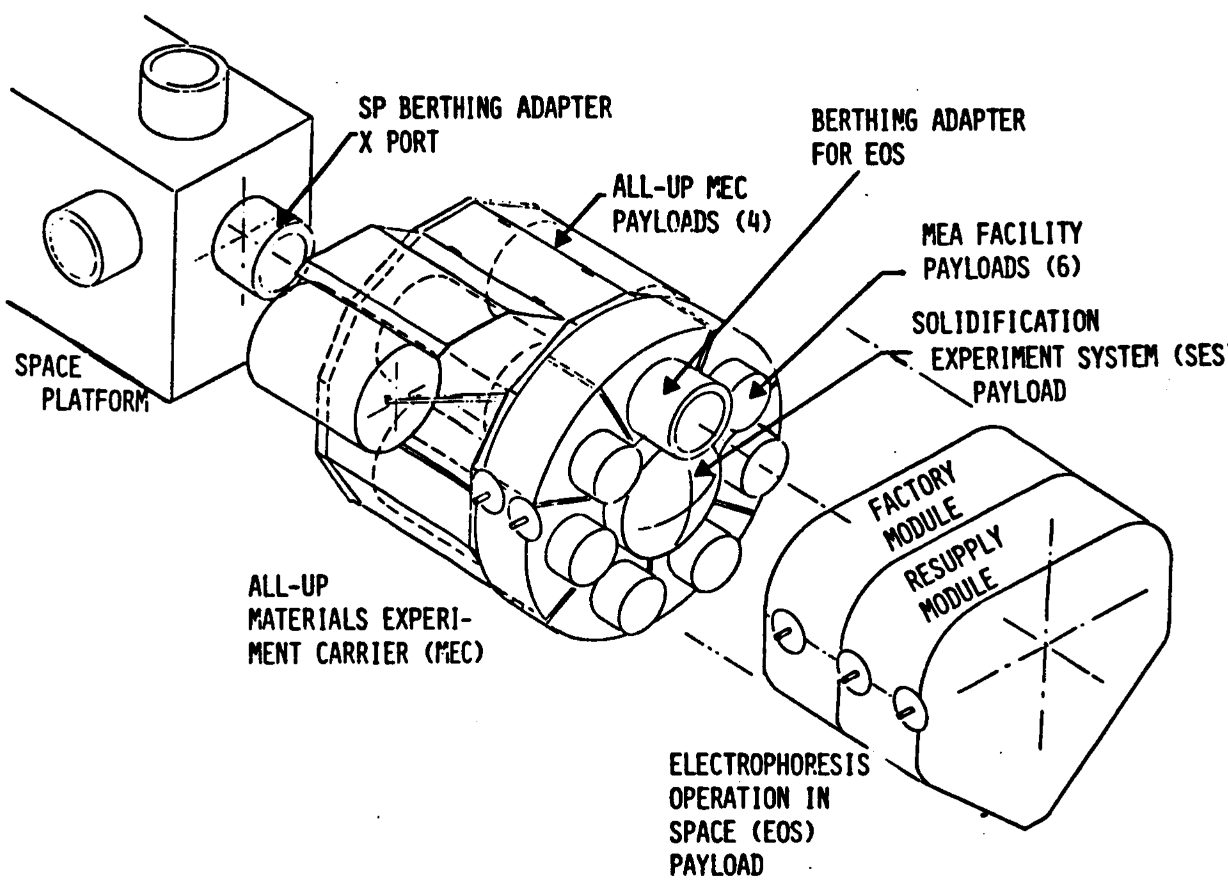


Figure 6. All-Up MEC Configuration With Payloads

ORIGINAL PAGE IS
OF POOR QUALITY

ORIGINAL PAGE IS
OF POOR QUALITY

SELECTED MEC CONCEPT SUMMARY

Principal features, dimensions and weight estimates of the selected design concepts for the initial and all-up MEC are summarized in Figure 7. The spread of estimated weights ranges from 8000 to 10,100 lb for the initial MEC and from 14,970 to 26,310 for the all-up MEC, including 20% for weight contingencies. The large weight variation in the latter case is due to the 1,000 to 3,000 lb weight range for each of the four major payload units carried in the growth module, based on results of the payload survey conducted in the MEC study.

ITEM	INITIAL MEC		ALL-UP MEC	
HOST VEHICLE	INITIAL SPACE PLATFORM (12.5 KW)		GROWTH SPACE PLATFORM (25 KW)	
CONFIGURATION	MEA SPOKED DISC, MODIFIED 14 FT DIAMETER, 30 IN. NET LENGTH (70 IN. GROSS LENGTH, INCL. ADAPTERS)(1)		INITIAL MEC (CORE MODULE) IN TANDEM WITH GROWTH MODULE (MEC B) 14 FT DIAMETER 130 IN. NET LENGTH (170 IN. GROSS LENGTH, INCL. ADAPTERS) (1)	
PAYLOADS	SES, 6 ADVANCED MEA FACILITIES, EOS (ATTACHED IN TANDEM)		SES, 5 TO 6 SMALL PAYLOADS (IN CORE MODULE), 4 LARGE PAYLOADS (GROWTH MODULE), EOS (ATTACHED IN TANDEM)	
SUBSYSTEMS	POWER DISTRIBUTION AND CONTROL, THERMAL CONTROL,(2) CDMS, CONTAMINANT CONTROL/RELEASE, STRUCTURE AND MECHANISMS			
EST. WEIGHT (LB)				
STRUCTURE	1330(3)		2850(3)	
SUBSYSTEMS	800		960	
PAYLOADS(4)	4,480 MIN	6,290 MAX	8,840 MIN	18,300 MAX
CONTINGENCY (20%)	1,390	1,680	2,320	4,200
TOTAL	8,000 MIN	10,100 MAX	14,970 MIN	26,310 MAX

(1) ADD 40 IN. FOR SP AND EOS ADAPTERS (DOES NOT INCLUDE 44-IN. EXTENSION ARM)
(2) ALL-UP MEC MAY INCLUDE AUXILIARY RADIATOR
(3) INCL. 160 LB FOR 2 ADAPTERS
(4) NOT INCLUDING 10,000 LB FOR EOS

Figure 7. Selected MEC Concept Summary

7. ON-ORBIT SERVICING

On-orbit servicing will be required in all-up MEC missions to increase mission cost effectiveness, by

- Extending mission duration and thus increasing mission output, i.e., the number of samples processed per mission,
- Reducing the number of MEC launches and retrievals required per year, thereby greatly reducing transportation costs,
- Achieving imporved payload/mission matching, and more effective Space Platform utilization by MEC, e.g., through replacement of payload units that complete their mission objectives ahead of others

Servicing is not projected on initial MEC missions (a) to simplify the design and thus save initial MEC development cost, and (b) because Shuttle revisits to the Space Platform are projected to occur only twice per year. An orbital stay time of 180 days, conforming with this schedule, is considered sufficiently long for any initial MEC mission so that on-orbit servicing would not even be useful. Most of the considerations discussed in this section therefore will apply to the all-up MEC only.

MEC payloads will have design interface characteristics that are consistent with, and facilitate on-orbit servicing. Servicing operations will include exchange either of entire payload units or only of sample magazines within payloads. Figure 8 compares objectives and design implications of payload changeout vs. sample changeout.

OBJECTIVES

Payload Changeout	Sample Changeout
• Matching of payload productivities • Orbital accommodation of new or additional payloads at favorable times	• Early sample return for analysis on ground • Limited sample shelf-life in orbit: biologicals

MEC/PAYLOAD DESIGN IMPACT

Payload Changeout	Sample Changeout
• Autonomy of payloads • Simple payload attachment, interfaces • Ease of on-orbit access and handling • Interchangeability • Ruggedness to withstand handling	• Accessible/removable storage magazines • Unobstructed access into enclosures • Protective sample enclosure required • Crew hazard avoidance in access, handling

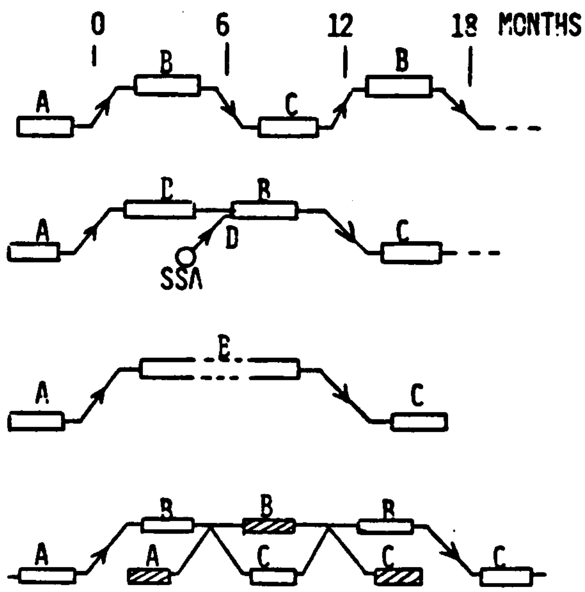
Figure 8. Objectives and Design Implications of Payload and Sample Changeout On-Orbit

ORIGINAL PAGE IS
OF POOR QUALITY

MISSION SCENARIOS WITH AND WITHOUT SERVICING

Four principal scenarios are illustrated in Figure 9. The first, third and fourth of these do not permit or require on-orbit servicing, the second envisions servicing to aid in extending on-orbit operation beyond the projected six-month interval between successive Orbiter visits of the Space Platform. A different mission concept without on-orbit servicing, illustrated in scenario four, foresees alternate launches of two MEC vehicles. One vehicle is refurbished on the ground while the other is in orbit.

1. INITIAL MEC
   - NO SERVICING
   - RETRIEVE AFTER 6 MONTHS
2. ALL-UP MEC (1 UNIT)
   - SERVICE AFTER 6 MONTHS
3. ALL-UP MEC (1 UNIT)
   - NO SERVICING
   - RETRIEVE AFTER 6 OR 12 MONTHS
4. INITIAL OR ALL-UP MEC (2 UNITS) IN INVENTORY
   - NO SERVICING
   - ALTERNATE LAUNCHES EVERY 6 MONTHS



LEGEND:

A - P/L INTEGRATION
B - ON-ORBIT OPERATIONS
C - REFURB. ON GROUND
D - RENDEZVOUS AND P/L EXCHANGE

NOTE: PROJECTED 6-MONTH STS LAUNCH INTERVAL IS REFLECTED IN EACH OF THESE SCENARIOS. SCENARIO 1 AND 4 KEYED TO 6 MONTH REFURBISHMENT/TURN AROUND TIME ON GROUND. INCREASE TO 8 MONTHS WOULD REDUCE REFLIGHT FREQUENCY.

Figure 9. Mission Scenarios With and Without Servicing

Results of an analysis performed to determine the comparative advantages of missions with or without servicing capability are listed in Figure 10.

ORIGINAL PAGE IS
OF POOR QUALITY

	ADVANTAGES	DISADVANTAGES
Ⓐ NO SERVICE-SINGLE MEC	● SIMPLER DESIGN ● SIMPLER DEPLOYMENT TASK ● NO SERVICE SUPPORT ASSEMBLY ● LESS ASTRONAUT TRAINING	● LESS MISSION AND PAYLOAD DEPLOYMENT FLEXIBILITY THAN Ⓑ AND Ⓒ ● MISSION DURATION GENERALLY CONSTRAINED TO 6 MONTHS, IMPACTS PRODUCTIVITY
Ⓑ NO SERVICE-TWO MEC'S*	● SAME AS ABOVE, PLUS ● OBTAIN MORE PAYLOAD ORBIT TIME THAN IN Ⓐ, I.E., MORE FLIGHT OPPORTUNITIES (CONSISTENT WITH RAPID INCREASE IN NUMBER OF P/L CANDIDATES)	● NEED ADDITIONAL MEC UNIT ● HIGH NUMBER OF LAUNCHES DRIVES UP COST ● NOT AS COST EFFECTIVE UNLESS LARGE P/L FLIGHT DEMAND BACKLOG
Ⓒ SERVICING-SINGLE MEC	● OBTAIN MORE P/L ORBIT TIME THAN Ⓐ WITHOUT FREQUENT MEC RELAUNCH AS IN Ⓑ ● GREATER FLEXIBILITY - P/L MIX - MISSION DURATION - P/L DEPLOYMENT STATUS ● REDUCE COST PER KW-HR	● COST OF SERVICE SUPPORT ASSEMBLY ● EXTRA COST OF CREW TRAINING, EXTENDED SORTIE DURATION ● EXTRA COST OF SERVICEABILITY ● EXTRA COST OF SSA ● EXTRA COST OF GROUND SIMULATOR

*This scenario adversely affected if ground refurbishment/turn around time would be 8 rather than 6 months, resulting in one-year reflight intervals due to projected SP revisit schedule by Shuttle

Figure 10. Servicing Vs. No Servicing (All-Up MEC Only)

RATIONALE FOR ON-ORBIT SERVICING

On-orbit servicing of the all-up MEC permits extension of the mission duration which will be desirable or essential for certain types, e.g., float zone processors, while other payloads that require less time in orbit can be replaced.

Principal factors favoring on-orbit servicing are the need for fewer launches of the large all-up MEC vehicle, saving transportation and ground refurbishment costs, and greater mission flexibility. There are, however, several other factors which tend to limit the potential cost savings, such as: the extra cost of providing MEC with serviceability features; more complex operations during SP/MEC revisits; and the procurement and repeated launch of a separate payload carrier (Service Support Assembly).

Preliminary assessment has shown that the advantages of the on-orbit servicing option outweigh its disadvantages and support the decision to provide MEC with the design features required for serviceability. Further assessment tors and their impact on system design, mission profile definition cost is discussed below.

comparison was performed of two principal mission options, either gle MEC with servicing on orbit (scenario 2 in Figure 9) or two ternate launch opportunities every 6 or possibly 8 months (scenario rmalized cost per year in orbit for scenario 4 will be only slightly that for scenario 2, i.e., about 10 percent. This is due largely of developing and flying a Service Support Assembly in scenario 2 scenario 4. This cost difference alone is not sufficiently large a basis for adopting the servicing mode, scenario 3. The impact of han 6 month ground turn around time on the scenario also should be account. Secondly, an important qualitative difference, not reflect- t figures, is the fact that scenario 4 is limited in orbital stay nission which may not be satisfactory for certain payloads.

a further explanation of this issue, consider the three MEC user popu- haracterized in Figure 11 by their probability distribution vs. desired tay time. In population ① a majority of the users require short stay ound three months. This peak shifts in distribution ② and ③ to four months, respectively. This trend may be assessed as follows:

Payload requirements analyses indicate that distribution ② is representative of potential MEC user population (All-Up MEC).

Orbit stay time = (processing time) x (desired sample number).

Increase in sample number to reduce cost/sample drivers stay time up.

Emphasis on commercial users also drives stay time up (e.g., EOS).

MEC planning should address items 3 and 5, therefore reflect distributions ② or ③ rather than ①.

n these factors and a projected six month revisit interval, MEC stay time ion beyond the six-month interval length with changeout of some payloads ften be advantageous. In this manner one can satisfy users with less ix-months and those with more than six-months desired stay time equally

ORIGINAL PAGE IS
OF POOR QUALITY

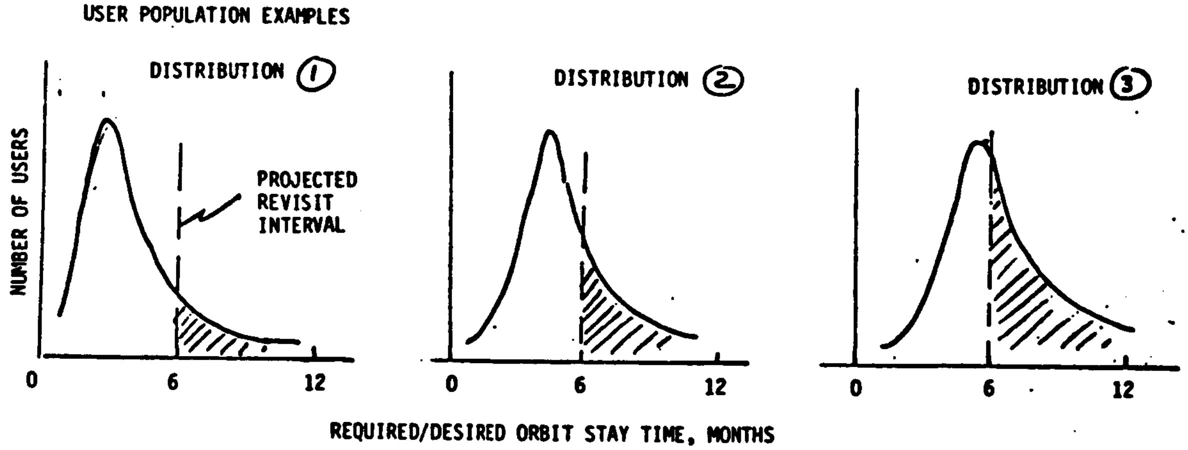


Figure 11. Orbital Stay Time Criteria (All-Up MEC)

IMPACT OF ON-ORBIT SERVICING REQUIREMENT ON CONFIGURATION AND MISSION OPERATIONS

Figure 12 lists design features required for making MEC payloads or sample magazines replaceable on-orbit. These features include not only special provisions for payload access, mounting and demounting, and for mating or demating of electrical and fluid line connectors but also the overall configuration layout. Serviceability also reflects in the arrangement of the EOS payload relative to the MEC core and growth modules, so as to permit unobstructed access to MEC payload compartments. Note that these serviceability design features do not include provisions for on-orbit repair or replacement of failed units, which would further complicate the design.

1. Axial payload attachment in core module (retained in all-up MEC) requires location at growth module aft end.
2. Also requires EOS attachment via hinged adapter.
3. Extra cable and coolant line length from SP to MEC subsystems because of aft end mounting of core module (which contains subsystems).
4. Lateral payload access in growth module dictated by location between SP and core module.
5. Growth module payloads rail-mounted to facilitate on-orbit changeout. (Sample changeout access requires further study).
6. Use of MMS-type/SP-type electrical connectors, quick-disconnects for coolant, guide pins and lead screws for mating/demating of payloads.
7. Provisions in initial MEC payload interfaces to permit conversion to on orbit mating/demating capability (item 6).

Figure 12. Impact of On-Orbit Servicing Requirement on Configuration*

*In all-up MEC only

Servicing operations require payload and component handling either by the Shuttle Remote Manipulator System (RMS) or manually, by a crewman in the EVA mode. The payload units must provide grapple fixtures and/or ahdnles for manipulation by the RMS or crewman. In addition, convenient and safe access to internal equipment must be provided via access hatches of sufficiently large size. Crew servicing also will require access support provisions on payload units and on the MEC proper, such as handholds, handrails and foot rests.

Utilization of the Teleoperator (TMS) to perform remote MEC servicing functions by transferring payloads between the Orbiter and the SP/MEC will be an alternative to Orbiter-based servicing. A principal advantage of this mode is the avoidance of SP/MEC proximity operations and berthing and consequently, any interference this may cause with Orbiter mission objectives other than MEC servicing. Also there would be no need for carrying a SP berthing adapter.

8. MISSION CHARACTERISTICS

MEC will be carried to orbit, attached to the Space Platform and deployed into the free-flying mission phase by the Shuttle Orbiter. At the end of the mission the MEC will be retrieved by the Orbiter and returned to the ground.

During extended missions the Orbiter will revisit the MEC at least once, to perform essential services such as payload exchange, processed sample exchange, or replacement of defective support systems.

MEC mission durations will be up to 180 days and longer. As many as two MEC launches per year may be performed, provided the mission durations and turn-around times between missions are short enough. A total of at least six missions shall be flown by one MEC vehicle.

The projected initial flight date will be 1986, conforming with the IOC of the Space Platform.

Dates for MEC launch, servicing and retrieval must be planned to make use of Shuttle ride sharing opportunities since MEC or the equipment used for MEC servicing will utilize only part of the Shuttle cargo capacity.

MEC-related launch dates and daily launch windows are constrained by the Space Platform rendezvous requirements. Depending on SP orbit inclination there will be one or two daily launch windows.

MEC will not restrict SP orbital characteristics in terms of altitude or inclination except for requiring operating altitudes above the level where the maximum atmospheric drag deceleration would exceed the limit of 10^{-5}g, i.e., typically 160 n.m. (Note: SP will avoid altitudes in this region, in any case, because of large drag makeup maneuver requirements).

SP orbital characteristics preferred by MEC are those that provide (a) maximum average power and (b) convenient access by the Shuttle for deployment, servicing and retrieval. In order to get the best Shuttle cargo weight performance and to minimize transportation cost for MEC launch, retrieval and servicing, low altitude, low inclination SP orbits will be preferred. Also, since MEC depends on ride-sharing with other Shuttle payloads a greater number of launch opportunities would be available under these conditions.

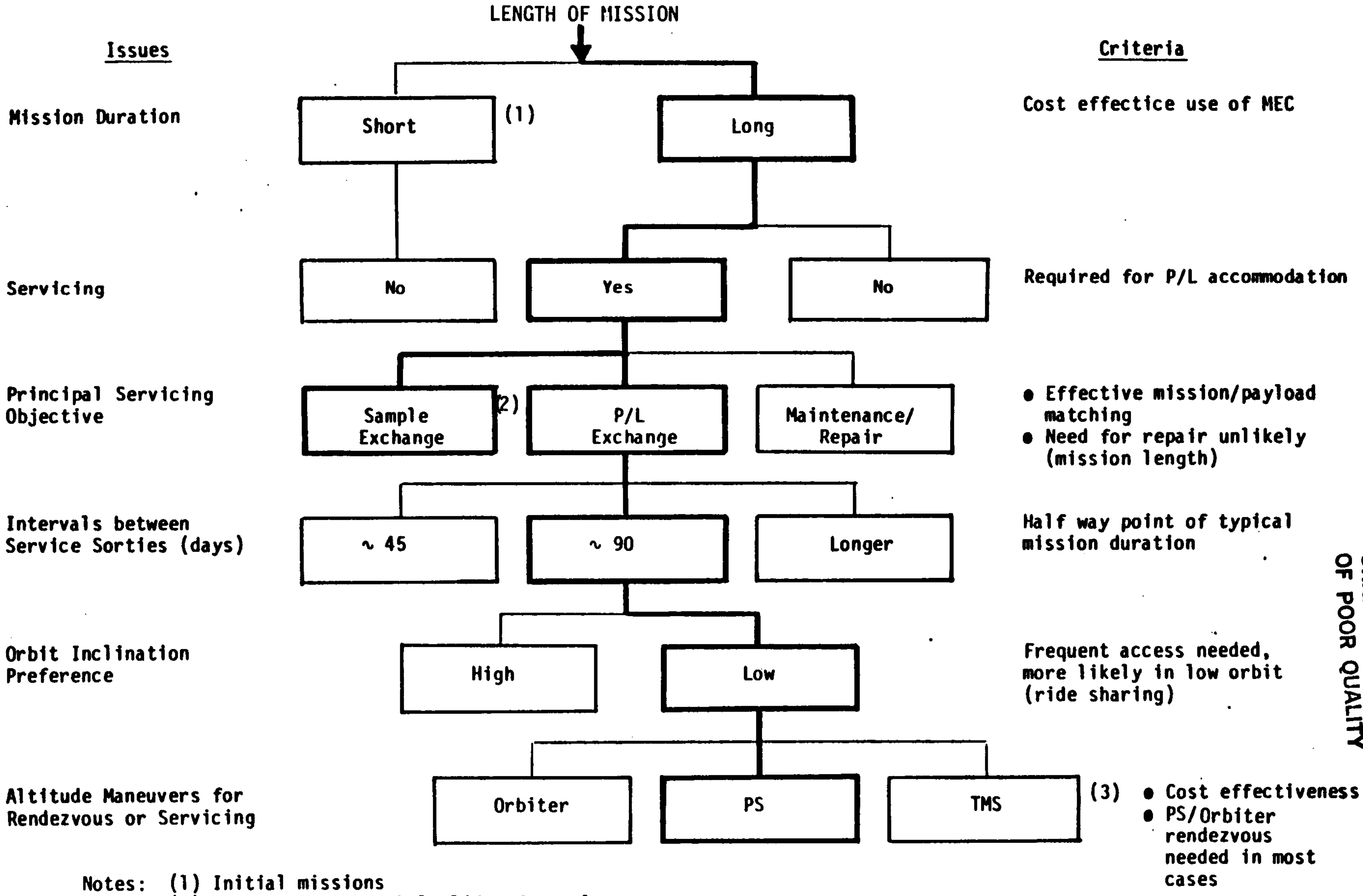
Mission analysis and trades led to the definition of preferred mission characteristics. Figure 13 summarizes results of this analysis, showing a logic flow which indicates the alternatives considered and the rationale applied at each step of the selection process.

The same MEC vehicle is to be used repeatedly. After retrieval for orbit it must be refurbished on the ground and/or refitted with a new payload complement and prepared for relaunch. The estimated turn-around time between missions will be 6 to 8 months.

Generally, the mission shall include on-orbit servicing which involves a changeout of MEC payloads or samples.

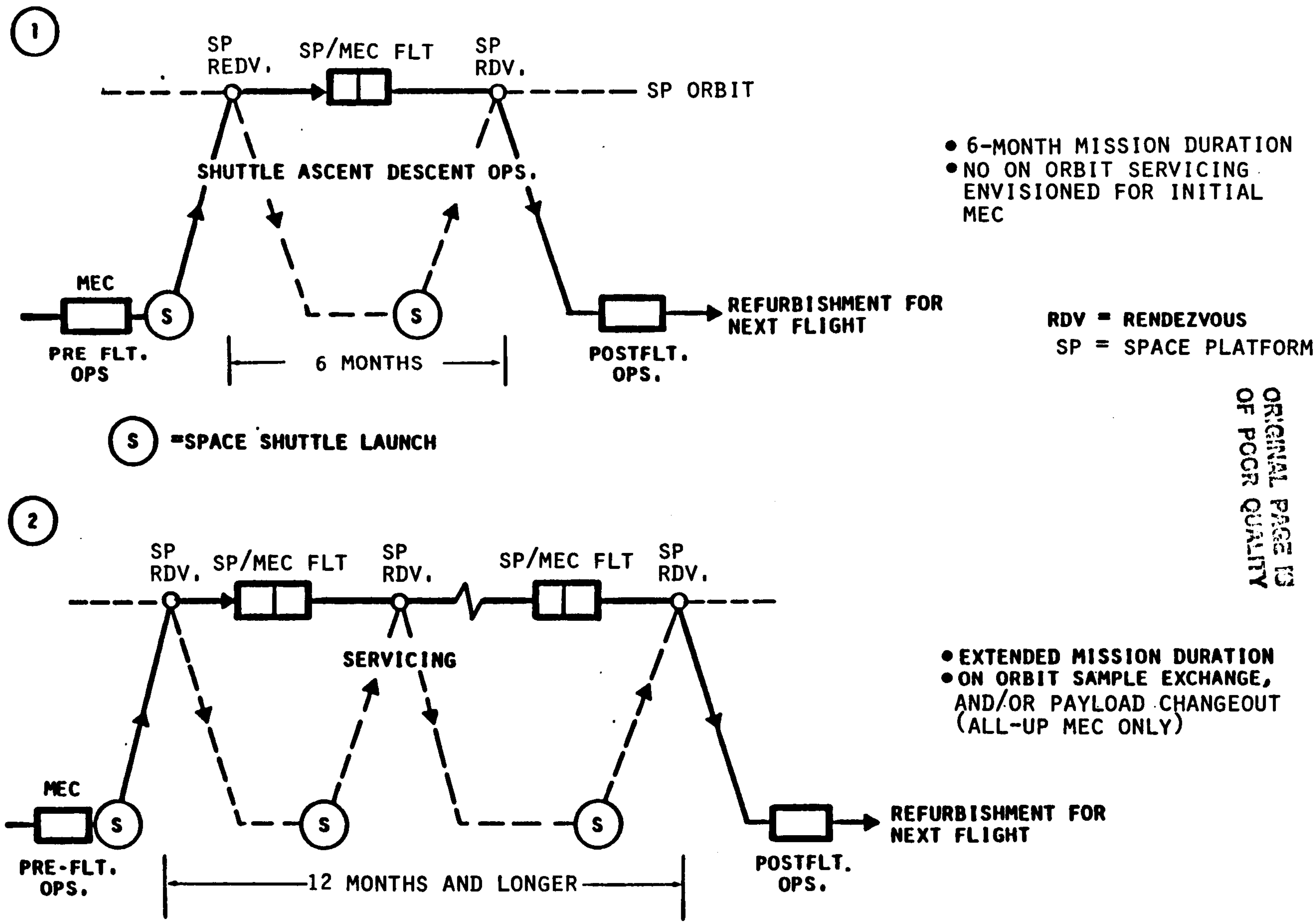
Composition of the MEC payloads, required mission duration and available Shuttle launch opportunities that are compatible with targeting constraints of SP/MEC rendezvous will dictate the timing of revisits for servicing. Mission profiles with or without servicing are shown schematically in Figure 14. Mission phases and sequences are illustrated in Figure 15.

The sequence of on-orbit operations required to deploy the MEC during a Shuttle/Space Platform rendezvous mission is illustrated in Figure 16. After rendezvous, retrieval and berthing of the Space Platform on a structure provided for this purpose in the Orbiter cargo bay, the MEC will be removed from its stowed position and attached to one of the Space Platform payload berthing ports. When attached, the SP/MEC will be checked out as a functioning system before release by the Orbiter to start free-flying operations.



Notes: (1) Initial missions
(2) Needed if short shelf life of samples
(3) Useful alternative, e.g., for payload exchange, to minimize Orbiter and PS mission impact

Figure 13. Mission Profile Selection Logic



ORIGINAL PAGE IS OF POOR QUALITY

Figure 14. MEC Mission Profiles Without and With On-Orbit Servicing

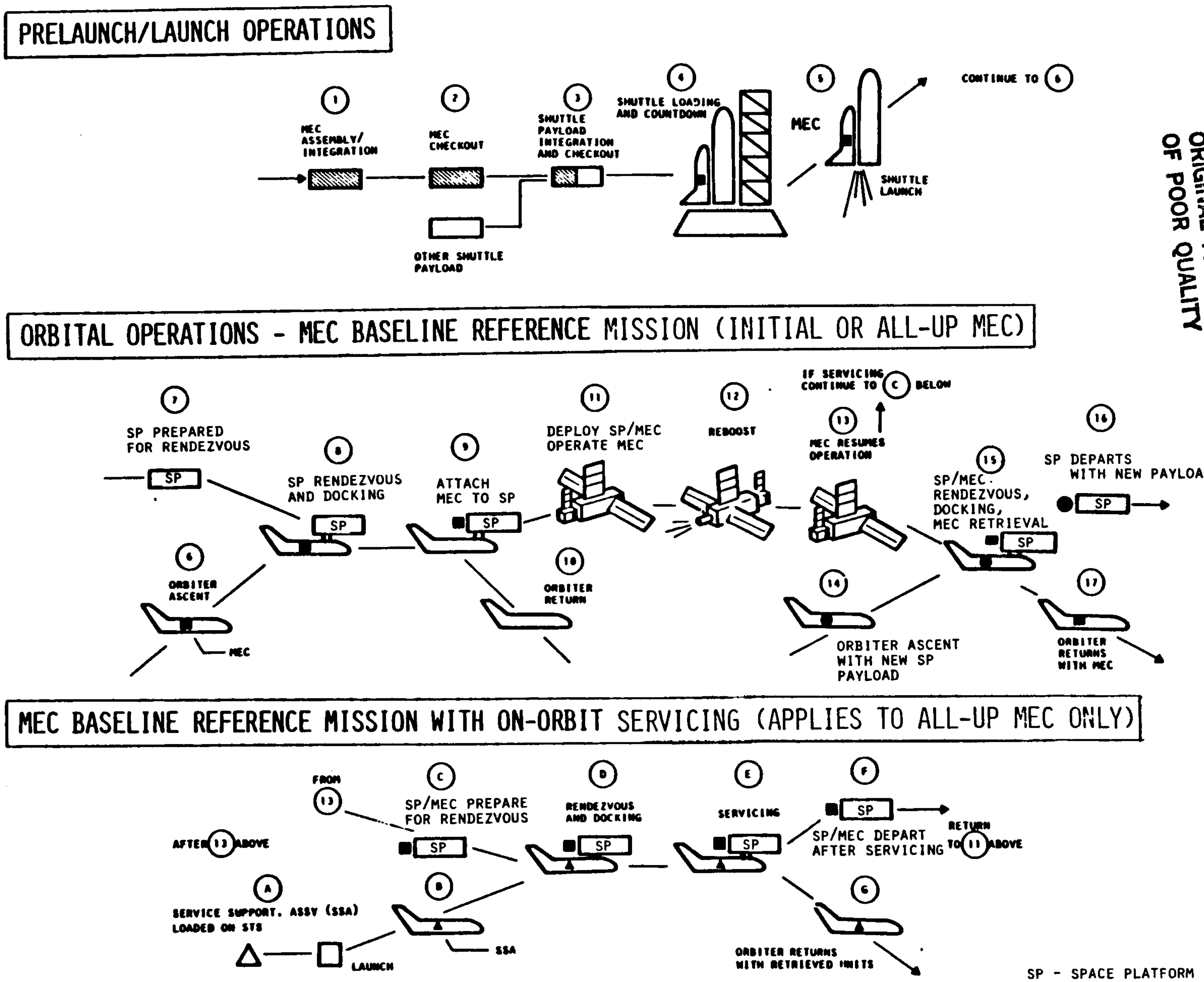


Figure 15. MEC Mission Sequence of Events

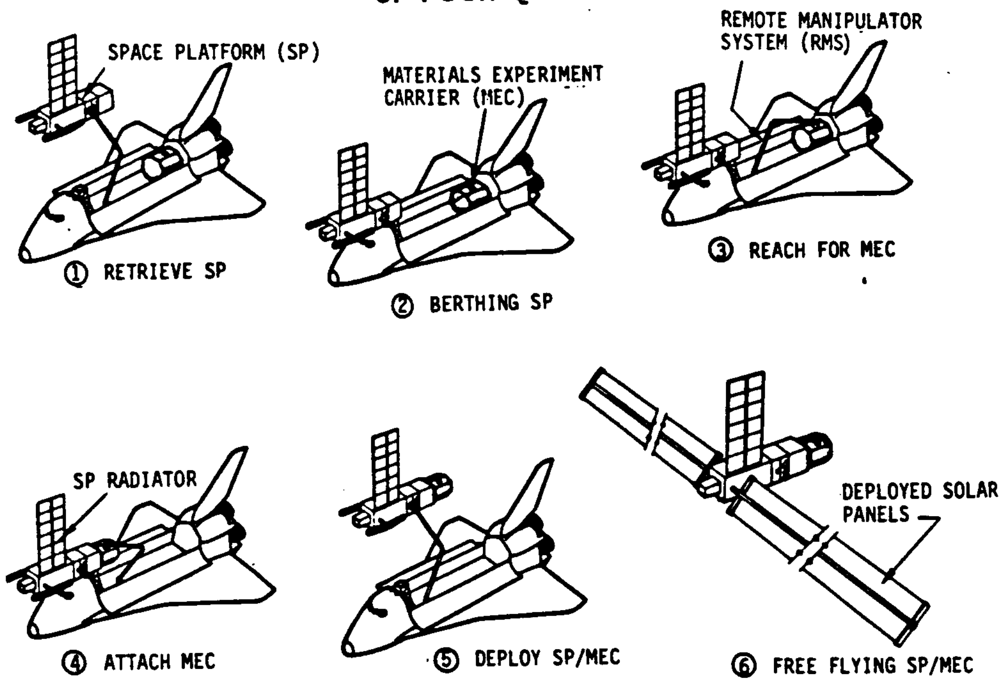


Figure 16. MEC Deployment Sequence

The Shuttle Remote Manipulator (RMS) arm will be the primary support hardware used to capture and berth the SP and to accomplish MEC unstowing, transfer and SP berthing port attachment.

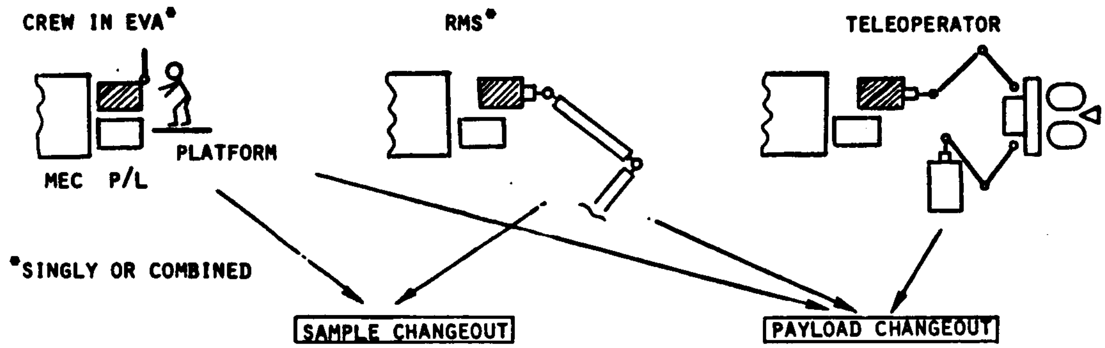
Assistance by crew member extra-vehicular activity may be required as a backup in supporting the remotely controlled RMS operations. Stringent safety requirements must be observed to avoid potential hazards to the Orbiter and crew that are inherent in all phases of this activity.

Sequences similar to those shown in Figure 16 will be employed in MEC retrieval from orbit and on-orbit servicing activities.

Alternative MEC deployment, retrieval and servicing sequences may be supported by the Teleoperator Maneuvering System (TMS). Thus, the TMS may be utilized to aid in achieving Orbiter rendezvous with the SP and in redeployment of the SP or to carry MEC to or from the SP if direct rendezvous/docking of the Orbiter with the SP is to be avoided; or to carry MEC payload units from the Orbiter to the SP/MEC and back to the Orbiter in remote payload changeout (servicing) operations.

9. SERVICING MODES

Figure 17 schematically shows the three servicing modes and summarizes objectives and design impacts. Remote servicing by the TMS reduces SP/Orbiter proximity operations and berthing events, Orbiter or SP maneuvering requirements and interference with, or disruption of Orbiter and SP normal activities.



	SAMPLE CHANGEOUT	PAYLOAD CHANGEOUT
OBJECTIVES	• EARLY SAMPLE RETURN FOR ANALYSIS • LIMITED SAMPLE SHELF-LIFE IN ORBIT: BIOLOGICALS	• MATCHING OF PAYLOAD PRODUCTIVITY • MORE PAYLOADS ACCOMMODATED PER MISSION
MEC/PAYLOAD DESIGN IMPACT	• ACCESSIBLE, EASILY REMOVABLE SAMPLE MAGAZINES • UNOBSTRUCTED ACCESS INTO ENCLOSURES • PROTECTIVE SAMPLE ENCLOSURE • CREW HAZARD AVOIDANCE IN ACCESS HANDLING	• PAYLOAD AUTONOMY • SIMPLE PAYLOAD ATTACHMENT AND INTERFACES • INTEGRATION • RUGGEDNESS TO WITHSTAND REMOTELY CONTROLLED HANDLING

Figure 17. Alternate On-Orbit Servicing Modes

10. SERVICING COST MODEL

A simplified cost model was used to assess the potential savings achievable through servicing. It is assumed that each servicing sortie extends the orbit stay time by the length of the original mission and thus increases the total product obtained in the same ratio, at a fraction of the reference mission cost.

ORIGINAL PAGE IS
OF POOR QUALITY

Figure 18 shows the reduction in "cost per total mission product" vs. the number n of service sorties flown. The cost index of the reference mission is used as normalizing parameter, that is, in the bar graphs shown its value is indicated as 100 percent at n=0. Key parameters in the cost model are the relative cost C of a servicing mission and the relative mission operations cost A per unit time. Servicing is more cost-effective if both of these cost fractions are low.

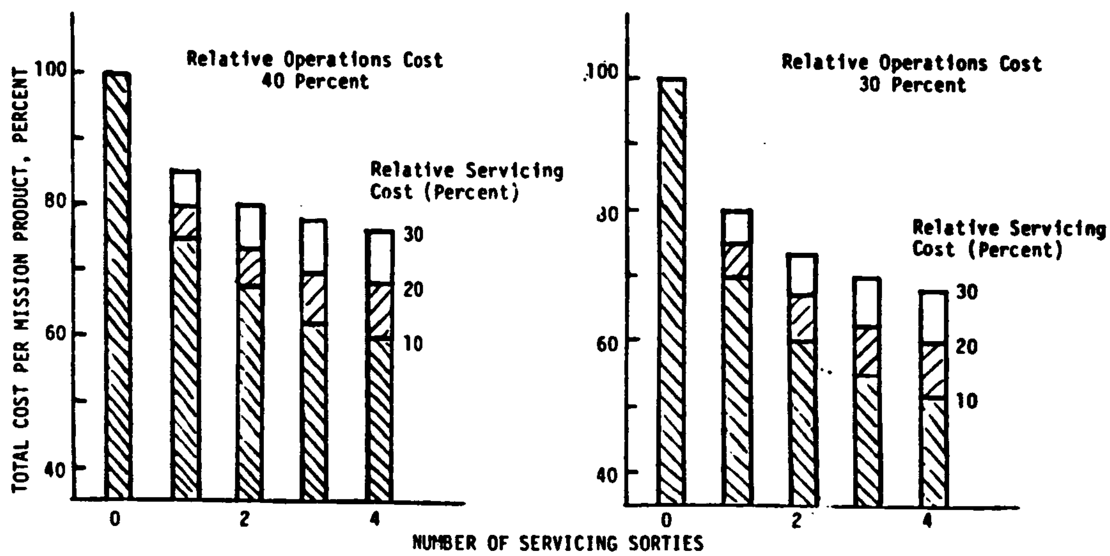


Figure 18. Examples of Cost Reduction Through On-Orbit Servicing

The bar graphs in Figure 18 represent mission operation costs of 30 and 40 percent at a reference mission duration of 100 days. Relative servicing costs of 10, 20 and 30 percent are assumed. For example, for A=30 and C=20 percent and two service sorties the cost index is reduced by 33 percent. Cost reductions of up to 50 percent are projected for n=4 with the largest step resulting from the first service sortie.

11. CONCLUSIONS

On-orbit servicing is a complex subject. Safety, design, mission operational factors, user needs and cost are all involved in the decision in incorporating on-orbit servicing into a space system. This presentation highlighted the issues that were subjected to study during the MSFC sponsored MEC study. Conclusions reached, during the study, are listed below:

1. On-orbit servicing will be required in all-up MEC missions to increase mission cost effectiveness, by
   - Extending mission duration and thus increasing mission output, i.e., the number of samples processed per mission,
   - Reducing the number of MEC launches and retrievals required per year, thereby greatly reducing transportation costs,
   - Achieving improved payload/mission matching, and more effective Space Platform utilization by MEC, e.g., through replacement of payload units that complete their mission objectives ahead of others
2. On-orbit servicing, like other MEC mission phases requiring repeated Shuttle/Space Platform rendezvous and docking, will involve intricate, crew supported, Shuttle operations that will gradually evolve into routine activities. This aspect of the MEC mission does not require novel technology, per se, but does involve a buildup of experience by Shuttle flight crews.
3. Payloads carried in all-up MEC missions shall have design and interface characteristics that are consistent with, and facilitate on-orbit servicing. Servicing operations will include exchange either of entire payload units or only of sample magazines within payloads.
4. Principal factors favoring on-orbit servicing are the need for fewer launches of the large all-up MEC vehicle, saving transportation and ground refurbishment costs, and greater mission flexibility. There are, however, several other factors which tend to limit the potential cost savings, such as: the extra cost of providing MEC with serviceability features; more complex operations during SP/MEC revisits; and the procurement and repeated launch of a separate payload carrier (Service Support Assembly).
5. Composition of the MEC payloads, required mission duration and available launch opportunities that are compatible with targeting constraints of SP/MEC rendezvous will dictate the timing of revisits for servicing.
6. The Shuttle Remote Manipulator (RMS) arm will be the primary support hardware used to capture and berth the SP and to accomplish MEC unstowing, transfer and SP berthing port attachment.

7. Alternative MEC deployment, retrieval and servicing sequences may be supported by the Teleoperator Maneuvering System (TMS). Remote servicing by the TMS reduces SP/Orbiter proximity operations and berthing events, Orbiter or SP maneuvering requirements and interference with, or disruption of Orbiter and SP normal activities.

8. A simplified cost model was used to assess the potential savings achievable through servicing. It is assumed that each servicing sortie extends the orbit stay time by the length of the original mission and thus increases the total product obtained in the same ratio, at a fraction of the reference mission cost.

9. Preliminary assessment has shown that the advantages of the on-orbit servicing option outweigh its disadvantages and support the decision to provide MEC with the design features required for serviceability.