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EVA EQUIPMENT FOR SATELLITE SERVICE

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ABSTRACT

Requirements are projected for performing orbital satellite service. Emphasis is on defining the role of Extravehicular Activity (EVA) required to support this future space activity. Specific EVA service techniques and equipment are conceived, building on initial baseline service capability supported by the Shuttle Orbiter, Remote Manipulator System, Extravehicular Mobility Unit, and Manned Maneuvering Unit. New EVA concepts discussed are compatible with current and near-term satellites, projected evolution of the Space Transportation System, and anticipated future space construction requirements.

 INTRODUCTION

The Space Transportation System (STS) is a developing national resource that will open a new era of space exploration, utilization and research. New STS capability will provide a cost effective means for payload delivery to and retrieval from earth orbit. In addition, STS will provide a manueverable space habitat from which new spectrum of important manned space research and work activity can be supported. In view of the world's growing dependence on the use of space, particularly the use of satellites for communications, monitoring weather and earth resources, navigation, surveillance and astronomy, plans are being made to dedicate a substantial portion of future STS activity to deployment, service, and retrieval of earth orbiting satellites. This STS satellite related space activity is the subject of this paper.

When STS becomes operational, it will offer a baseline work capability in space capitalizing on astronaut dexterity and adaptive decision-making capabilities. In STS activity associated with satellite payloads the role of astronauts in performing Extravehicular Activity (EVA) is expected to be fundamental to practical achievement of mission objectives. As future NASA planning increases STS capabilities to support a wider range of space activity, a trend of increasing EVA use is foreseen.

In this paper, requirements are projected for a near-term satellite service capability and for an evolved mature service capability, needed for satellites designed for increased orbital serviceability. Emphasis is placed on defining the role of EVA in orbital satellite service. New EVA service techniques and support equipment are discussed which will expand service capability.

SATELLITE SERVICE

Satellite service is a generic term for STS orbital operations associated with satellite payloads. Satellite operations can be partitioned into three categories of orbital work activity:

Deployment - Operations involving delivery of Shuttle Orbiter satellite payloads to earth orbit, including reboost of satellites back to prescribed operational orbits.

Service - Operations associated with resupply, refurbishment, and repair of satellites. Examples include inspection, photography, lens cleaning, film or module replacement, propellant refueling, leak detection and repair, and antenna replacement.

Retrieval - Operations associated with returning free-flying space objects to the Shuttle Orbiter, stabilization of spinning or tumbling space objects, and satellite-to-Orbiter docking. Objects to be retrieved include debris and satellites, recovered either for return-to-earth or service at the Orbiter.

Currently operational satellites are not designed for orbital service because in-flight satellite servicing has not been available. Satellite system design philosophy to date has been to dictate stringent requirements for high reliability to satisfy long mission life requirements. When STS becomes operational, many satellites in low earth orbit (LEO) will be revisitable. This revisit capability will offer the satellite designer new latitude for systems design. It is recognized, however, that orbital satellite serviceability will incur certain design, fabrication, and operational costs, a penalty which must be traded against potential savings realized via relaxed systems reliability and extended satellite program life. Already, the Space Telescope and Long Duration Exposure Facility, representing next-generation
TABLE 1. DESIGN REQUIREMENTS FOR SATELLITE SERVICEABILITY

- Mechanical Loads
- Safe Surfaces & Edges
- Accessible Maintenance Areas
- Replaceable Subsystem Modules
  Payload Instrumentation
  Attitude Control & Propulsion
  Power
  Data Processing & Telemetry
- Fluid Subsystems
  Refuelling
  Safety Venting
  Fluid Isolation
  Fail-Safe Pressure Vessels
- Diagnosis & Checkout Capability
- Standard Interfaces
  Safety Interlocks
  Diagnostic & Checkout Connector
  Disconnects, Fittings & Fasteners
  RMS & FSS Adapters
  Crewmember Restraints & Handholds

Satellites, are designed for orbital service. With future development of reusable Space-Tugs and Tele-
operators for transferring satellites between LEO and geosynchronous earth orbit (GEO), virtually all earth
orbiting satellites will become candidates for LEO
service.

To exploit Orbiter revisit capability, service
 provision has to be designed into the satellite. Projected satellite serviceability design considera-
tions are summarized in Table 1. For example, satel-
ite structure and appendages must be capable of
withstanding force, torque, and impact loads incurred
during normal deployment, service, and retrieval
activities. Satellite configuration should provide
easy crew access to maintenance areas and be designed
to minimize risk of damage to the Shuttle Orbiter
and Extravehicular Mobility Unit (EMU), the astronaut
space suit system. Replaceable subsystem modules
should be easy to remove and install, employing
standard disconnects, fittings, and fasteners.
Anticipated work sites on satellites should include
mounts for crewman rigid work restraints. Remote
Manipulator System (RMS) docking adapters should be
included on satellites. Subsystems should include
safety interlocks for deactivation during service,
and should be of fail-safe design to protect crew-
members against injury. Capability for computer
diagnosis and checkout of subsystems should to be
provided in the satellite design.

TABLE 2. MATURE SATELLITE SERVICE CAPABILITY TASKS

| Service Tasks                      | Propulsion | Power | Solar Cells | Conditioning | Data Processing | Command & Control | Signal Conditioning | Telemetry | Instruments | Passive Cooling | Active Cooling | Passive Sensors | Biomedical | Structure |
|-----------------------------------|------------|-------|-------------|--------------|----------------|-------------------|--------------------|-------------------|------------|--------------|----------------|----------------|-----------------|-----------|-----------|
| Manual & Hand-Tool Operations     |            |       |             |              |                |                   |                    |                   |            |              |                |                |                 |           |           |
| Remove & install panels, covers & shields |           |       |             |              |                |                   |                    |                   |            |              |                |                |                 |           |           |
| Inspect & photograph             |            |       |             |              |                |                   |                    |                   |            |              |                |                |                 |           |           |
| Clean & refurbish surfaces       |            |       |             |              |                |                   |                    |                   |            |              |                |                |                 |           |           |
| Remove & install samples or modular components |           |       |             |              |                |                   |                    |                   |            |              |                |                |                 |           |           |
| Disconnect & connect electrical connectors |           |       |             |              |                |                   |                    |                   |            |              |                |                |                 |           |           |
| Disconnect & connect fluid interfaces |           |       |             |              |                |                   |                    |                   |            |              |                |                |                 |           |           |
| Repair electrical harness & connectors |           |       |             |              |                |                   |                    |                   |            |              |                |                |                 |           |           |
| Repair leaking fluid lines & fittings |           |       |             |              |                |                   |                    |                   |            |              |                |                |                 |           |           |
| Repair structural damage         |            |       |             |              |                |                   |                    |                   |            |              |                |                |                 |           |           |
| Assemble & install appendages    |            |       |             |              |                |                   |                    |                   |            |              |                |                |                 |           |           |
| Specialized Service Equipment Operations |           |       |             |              |                |                   |                    |                   |            |              |                |                |                 |           |           |
| Diagnose, checkout & calibrate   |            |       |             |              |                |                   |                    |                   |            |              |                |                |                 |           |           |
| Measure fluid quantities         |            |       |             |              |                |                   |                    |                   |            |              |                |                |                 |           |           |
| Detect fluid leakage             |            |       |             |              |                |                   |                    |                   |            |              |                |                |                 |           |           |
| Purge & refill fluid subsystems  |            |       |             |              |                |                   |                    |                   |            |              |                |                |                 |           |           |

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Maintenance is expected to be restricted to module replacement and limited repair of non-modular items owing to limitations on EVA astronaut ability to perform intricate manual tasks. In addition, a premium will be placed on maintenance time which, in only a fraction of normal seven-day Shuttle mission time, will be available for work activity. Table 2 lists service tasks for satellite subsystems and major components that appear practical to perform in-orbit. This satellite characterization and service task identification was derived by studying a sample population of current and near-term satellites. In defining the service tasks of Table 2, the following were assumed:

1. Satellite serviceability provision exists,
2. Satellite has been retrieved and restrained at the Orbiter or is orbiting with stable dynamics,
3. EVA astronaut has propulsion capability to reach remote satellites and transport equipment/supplies, and
4. EVA astronaut rigid restraint provision is available on the satellite.
   
Individual tasks of Table 2 suggest that varying degrees of astronaut dexterity, skill, strength and judgement will be required to perform on-orbit tasks such as electrical connector disconnects, adaptation of existing 1-g tools and equipment is envisioned. For performing more intricate tasks, 0-g, vacuum space environment will dictate development of specialized tools and equipment. The ability to perform all orbital service tasks presented in Table 2 represents a well developed, mature satellite service capability.

NEAR-TERM SATELLITE SERVICE CAPABILITY

Initial STS operation will provide a baseline capability for performing a range of satellite servicing tasks. Baseline equipment includes the Shuttle Orbiter, Remote Manipulator System (RMS), Extravehicular Mobility Unit (EMU), and the Manned Maneuvering Unit (MMU). The EMU and MMU will be used to conduct EVA. Use of EVA in prior manned space flight programs such as Skylab provides clear indication of the value of EVA in accomplishing mission tasks requiring mobility, dexterity, and adaptive decision making. EVA today is an established operational capability and is reflected in NASA planning which calls for use of EVA in orbital satellite servicing.

Following is a projection of near-term satellite service capability for supporting deployment, service, and retrieval operations. Near-term capability incorporates several new equipment concepts which would provide rigid crewmember work restraint, two-handed work capability, power tool capability, and improved EVA crewmember dexterity, dexterity and vision. In the following discussions satellite service equipment when first introduced has been underlined for ease of reference.

Deployment - Normal deployment of Shuttle Orbiter satellite payloads is expected to be automated, with crew activity confined to the Orbiter cabin. The satellite to be deployed would first be elevated in the Orbiter payload bay by either the Flight Support System (FSS) platform, now under development, or the Remote Manipulator System (RMS). Satellite antennas and solar panels would then be deployed via remote control. Satellite systems would be checked out prior to satellite release from the FSS platform, with release effected by a spring actuator mechanism. The FSS platform may include provision to impart spin to spin-stabilized satellites. Following release, thruster activation would propel the satellite to the prescribed operational orbit.

Contingencies could alter the normal deployment sequence. For example, a satellite solar panel could fail to self-deploy, requiring use of the RMS for panel release. EVA would serve as an additional contingency backup. EVA might also be required to support inspection, evaluation of anomalies, and repair activities prior to or following release of the satellite. Fig. 1 depicts an EVA astronaut engaged in a deployment contingency operation. The astronaut is anchored by foot restraints attached to the NASA-concept Manned Remote Work Station (MRWS) platform mounted to the end of the RMS. MRWS is being considered as a near-term capability improvement for STS. The satellite is shown supported on the FSS platform, which was installed in the Orbiter payload bay before the satellite during pre-flight operations. The EVA astronaut is equipped with an Extravehicular Mobility Unit (EMU) which provides environmental protection and life support.

In the future, EVA may become a normal mode for supporting certain deployment operations. Using Simple Hand Tools, EVA could be used to assemble satellite solar arrays or antennas that are too large or complex for self-deployment. Final assembly operations in-orbit would allow greater flexibility in satellite configuration than previously possible using conventional space delivery systems, which rely on satellite appendage self-deployment.

Service - Shuttle/Spacelab missions are planned to fly with a baseline EVA capability supported by the Manned Maneuvering Unit (MMU). Fig. 2 depicts an EMU-MMU equipped astronaut on an inspection sortie to a satellite in the near vicinity of the Orbiter. The purpose of such EVA could be to visually assess condition of satellites or perform limited service such as experiment module retrieval or film pack replacement.

The current MMU design uses a nitrogen cold gas which provides astronaut propulsion. Two MMU's will be stowed and recharged after use on the FSS, with the performance of the forward module is the Orbiter payload bay. The MMU equipped crewmember dons the MMU by backing into it. The MMU is not to be worn if EVA is limited to activities in
the payload bay. While the MMU will normally be manually controlled, an automatic stationkeeping mode is included which can null out small external forces exerted on the astronaut by automatic firing of thrusters. Finally, a lightweight tether may be required for free-flying EVA astronauts as a contingency precaution.

Figure 2. SATELLITE INSPECTION SORTIE

The existing Shuttle EMU consists of a life support system (LSS) and a modular space suit assembly (SSA). Two EMU's will be stowed and recharged after use in the Orbiter airlock. The LSS and SSA modules are designed for replacement on earth, where the SSA is fitted to a particular crewmember prior to flight. Salient characteristics of the EMU are:

- 7 hour EVA capability
- 3 hour prebreathe required
- manual helmet visor
- manual LSS temperature control
- chest mounted data display
- SSA construction using separate bladder and restraint with tucked fabric joints
- integral, fixed thickness hazards protection overgarment
- heat sink using expendable H2O
- CO2 removal using expendable LiOH cartridge

Initial STS flights will carry assorted EVA hand tools for dealing with Orbiter contingencies such as a stuck payload bay door or damaged thermal tiles. Since the crewmember will be restrained by a flexible tether, EVA will generally be restricted to one-handed tasks with the other hand required for crewmember support. An important step to expand baseline service capability will be to provide a two-handed EVA capability for work on satellites and payloads. Fig. 1 illustrates one astronaut restraint means for performing work tasks in the payload bay area supported by the RMS. Other anticipated service tasks will require a more universal astronaut work restraint system, one that can be employed on any satellite or space structure. Fig. 3 indicates one such concept where the restraint system consists of a Portable Folding Work Platform to which the crewmember is anchored by way of "astrogrid" foot cleats developed for the Skylab Program. The platform-satellite interface consists of one or more attachment fasteners, either installed at known payload service work sites prior to launch or bonded on orbit. An Adhesive Bonding Tool, shown in Fig. 3, is envisioned which would provide required heat, pressure, and cooling for adhesive bonding of two elements in space environment. Requisite service hand tools and supplies could be carried and re-strained in a convenient Tool Caddy mounted in front of the crewmember to the existing Mini-Work System interface. The EVA crewmember, restrained as indicated in Figs. 1 and 3, could easily perform two-handed payload service tasks, such as lens/sensor cleaning and module replacement.

Satellite service tasks will be performed under varying light conditions. Automatic helmet visoring will be required to avoid interrupting tasks to manually readjust visor position. Tasks such as module replacement or handling large panels may require an EVA partner or RMS assistance. These tasks will require a wide angle vision helmet to take advantage of crewmember's head rotation and peripheral vision capabilities. Fig. 3 shows an Automatic Visor Wide Angle Helmet concept which employs four photocell actuated, liquid crystal panels which adjust light transmission selectively. Panels would darken automatically on the sunlit side and lighten in shadow.

As satellite service work tasks requirements become more complex and time consuming, the need for rugged, comfortable, high tactility, high dexterity work gloves increases. Fig. 3 also depicts an improved Rugged High Tactility Glove concept which employs rugged, single wall modular construction for custom fit and in-orbit maintainability. The glove features an exterior surface consisting of short elastomer pins which improve tactility and provide mechanical hazards protection and thermal insulation.

Figure 3. IMPROVED SERVICE CAPABILITY

To support developing service capability, need is foreseen for a hand held power tool. Fig. 4 shows a Multi-Purpose Power Tool concept which features variable speed, rotary motion with reverse capability, reciprocating motion capability, torque set, all embodied in a power handle, and interchangeable tool heads. Tool head magazines would be included for each type of adapter such as fastener drives, bits, drills and punches. Individual tool bits would be selected automatically and stowed within the magazine. An alternative tool head concept is conceptually illustrated in Fig. 4 where a single tool head features continuous adjustment to accommodate different size nut/bolt fasteners. Tool heads for material removal functions, such as drilling and sawing, would be included and designed to collect self-generated debris. Such a multi-purpose power tool would minimize handling of individual small tools and adapters, and reduce time required for performing structural repair, assembly and construction tasks.
the RMS has a maximum tracking velocity of 2 ft/sec

Orbiter payload bay using the RMS under remote control. Collection of orbital debris is not expected
effect RMS docking. Present planning calls for
of required mission time. Development of specialized
equipment for practical debris retrieval and stowage
maximum extended length of only 50 feet. Chief among
quired to effect satellite retrieval. In addition,
berthing satellites to the FSS platform in the
Retrieval - Near-term STS mission planning calls for
limited satellite retrieval and requires flying
active satellites close to the Orbiter and/or maneuvering the Orbiter close enough to the satellite to
effect RMS docking. Present planning calls for
berthing satellites to the FSS platform in the
Orbiter payload bay using the RMS under remote control. Collection of orbital debris is not expected
as part of near-term STS retrieval activity, because debris may be spinning or tumbling, difficult to
snare with the RMS, and costly to retrieve in terms of required mission time. Development of specialized
equipment for practical debris retrieval and stowage for return-to-earth appears necessary.

Intricate Orbiter flight maneuvers may be re
quired to effect satellite retrieval. In addition,
the RMS has a maximum tracking velocity of 2 ft/sec
in any direction, has limited damping capability, can
be backdriven by forces exceeding 23 lbs, and has a
maximum extended length of only 50 feet. Chief among retrieval concerns are:
- Satellite/Orbiter/RMS collision
- Orbiter thruster induced satellite translation
- Satellite dynamics
- Satellite-Orbiter relative motion
- Mission time and propellant required

EVA could prove useful in alleviating some of these retrieval concerns. For example, an EVA astronaut equipped with an MMU could position satellites within reach of the RMS arm, null satellite motions, assist in final snaring of the satellite with the RMS and guide satellites onto the FSS platform.

Additional new service equipment concepts intended to expand near-term capability will now be presented. Resulting new capability is defined as mature in the sense that all service tasks defined in Table 2 could be performed. These concepts, formulated to satisfy specific service requirements, are not optimized as presented.

Satellite Service EMU - To support both mature orbital satellite service and future space construction work capabilities, a number of changes to the EMU comprised of the space suit assembly (SSA), life support system (LSS), and computer capability will be required as indicated in Fig. 5. The improved glove and automatic visor features shown were discussed previously as part of near-term service capability.

A promising development approach for the SSA, to meet more demanding work requirements, would use Long-Life Modular Soft Goods employing single wall, laminated construction. This type of construction is puncture, tear, and abrasion-resistant and is compatible with long-life joint design. Smooth, firm inner SSA surfaces would be included to promote improved hygiene maintenance. SSA elements would be replaceable in flight, where comfort and fit could be maintained by substituting modular sizing elements allowing the suit to accommodate crewmember size changes resulting from 0-g spinal elongation.

Significant STS activity is expected in orbits of high inclination in connection with earth observation satellites. Eventual work in GEO is also projected following development of a LEO-GEO Manned Orbital Transfer Vehicle. These orbits will present a significant increase in radiation level over those of other low earth orbits, which an operational EVA capability must protect against. Cumulative radiation exposure will depend on mission-related factors
such as duration, amount of EVA, specific orbital altitude and inclination, and will, therefore, be highly variable. Ability to pre-tailor the amount of EVA Over Garment Hazards Protection to a particular mission would be attractive, providing the EVA crewmember only that amount of protection required, eliminating unnecessary encumbrance. In this concept, radiation protection would be fitted to the SSA during pre-flight operations in which modular overgarment sections would be attached to the soft-goods. This concept for overgarment hazards protection includes use of tough, puncture and tear-resistant materials of low atomic weight in the outer layers. These outer layers would decelerate radiation electrons to produce soft secondary X-rays, where flexible, high-density inner layers would complete the radiation protection by absorbing the secondary X-rays.

Development of the 25 kW Power System will mark the beginning of orbital space vehicle transition from fuel cell to solar electric power, reducing the amount of water available for EVA expendable water cooling. A practical concept for an LSS No-Vent Regenerable Heat Sink is required to overcome this limitation. A possible heat sink concept incorporates a phase change material (PCM), such as ice, together with a radiator. The PCM material would be sized to handle heat rejection requirements for a portion of a normal EVA sortie, with remaining heat rejection provided by the radiator. The PCM would be regenerated at the Orbiter between EVA's. The radiator could be configured several ways. For example, it could be left at a semi-permanent worksite to support EVA shift work activities while the PCM would handle EVA crewmember cooling during transit between Orbiter and worksite.

For extended duration missions, STS payload weight and volume constraints indicate requirement for LSS Regenerable CO₂ Removal. A potential approach for CO₂ removal makes use of a liquid KOH solution, circulated first through a membrane absorber, to pick up CO₂ from the crewmember vent flow stream. The CO₂-laden solution then passes to a membrane desorber, where the CO₂ is rejected to space vacuum. This concept would eliminate need for expendable L10H canisters and would require no post-EVA service.

An LSS requiring No-Prebreathe is highly desirable for reducing mission consumption of O₂ expendables and simplifying EVA preparation. Approaches under consideration for eliminating prebreath requirement include increasing normal operating suit pressure, reducing Orbiter cabin pressure, or using a time-variant suit pressure which would decompress during EVA down to the present operating pressure of 4 psia.

High level of scheduled EVA work activity is expected to dictate requirement for a nominal 8-Hour EVA Capability. This would require additional stored oxygen, battery capacity, and repackaging of the LSS to accommodate new CO₂ removal, heat sink, oxygen, and battery subsystem changes. The new LSS packaging, including integrated radiator, would require study to determine a practical configuration that would not impair crewmember work mobility, yet support long-term fixed worksite tasks, short-term tasks at temporary worksites, and free-flying tasks.

An expanded EMU caution and warning system computer concept would permit the LSS to be placed under computer control. For example, suit temperature could be preset and automatically maintained. The present chest-mounted display and controls module could be replaced with a Wrist Input Terminal with readout display. This would provide improved work visibility and mobility. LSS valves would be actuated by input from the wrist wrist terminal. Additionally, the EMU computer would be configured to accept input from a magnetic program card for sequencing and visual display of Procedural Steps superseding the need for service manuals, cuff cards, and checklists.

Two additional concepts for support of EVA operations would make use of expanded EMU computer capability. The first, shown in Fig. 5, is a Heads-Up Data Display where data would appear as an image on a frontal portion of the visor or on an LCD display unit integrated with the helmet. Heads-up display would permit the crewmember to read computer data output and service instructions while keeping the task view in view. This display would eliminate necessity for moving the hand during manual work tasks to read data from the wrist unit. Second would be a surface Temperature Sensor, mounted on top of one glove finger, where signals from the sensor would be processed by the computer for display of worksite surface temperatures. This would allow the crewmember to take necessary precautions before touching high temperature surfaces. Remaining new concepts, depicted in Fig. 5 are discussed below.

Deployment - Future EVA deployment operations could involve final assembly and installation in-orbit of satellite superstructures such as antennae, instrumentation booms, and solar arrays. Cost savings might be realized by avoiding the complexities of conventional self-deployment mechanisms which rely on the various appendage elements automatically snap-locking in place in-orbit. Final satellite in-orbit assembly could also take better advantage of Orbiter payload capacity, which will tend to be volume limited rather than weight limited for the case of satellite-shaped payloads. Finally, capability to assemble satellite structures in-orbit from multiple mission Orbiter payloads offers potential for orbiting large scale satellite systems not previously possible.

Service - A mature orbital satellite service capability would permit a variety of service tasks beyond near-term capability, such as fluid system repair and subsystem diagnosis and checkout. Performance of these additional service tasks will require development of specialized service equipment, concepts for which will now be discussed.

Fluid system repairs are expected to involve relatively complex tasks, such as leak detection, replacing seals within fittings, pump replacement, and repair of tubing sections. Future satellites would be expected to include valves for isolating fluids during normal service. However, a Fluid Service Kit might be required for containing fluids within portions of satellite subsystems, permitting opening of line connections during repair operations without uncontrolled loss of fluid. Localized line freezing or run-down fluid removal represent possible approaches to fluid containment. Additionally, the kit could provide means for leak detection to diagnose fluid loss problems and verify integrity of fluid systems following repair. A concept for leak detection involves fluid loop pump-down followed by pressurization of the loop with a diagnostic gas. Diagnostic gas leaking to space vacuum would then be detected through its color or desorption of the leaking fitting.
A Fluid Service Facility, concepted to be located below the FSS platform in the Orbiter payload bay, would provide satellites with electrical power for systems checkout, and support satellite propellant defueling, refueling, and pressurizing. The fluid service facility would be capable of metering fluid quantities transferred to the satellite.

Computerized satellite subsystem diagnosis and checkout is expected for assessing subsystem performance down to the level of replaceable modules and for identifying problems in interconnecting wiring. Signals used for determining subsystem performance could consist of actual satellite subsystem sensor outputs and simulated sensor signals generated by a Diagnostic Computer Kit. The Fluid service facility would be capable of metering fluid quantities transferred to the satellite.

Computerized subsystem diagnosis and checkout is expected for assessing subsystem performance down to the level of replaceable modules and for identifying problems in interconnecting wiring. Signals used for determining subsystem performance could consist of actual satellite subsystem sensor outputs and simulated sensor signals generated by a Diagnostic Computer Kit. Fig. 6 depicts remote satellite service diagnostics in process. The crewmember is shown working with a diagnostic computer kit which has been patched into the subsystem to be tested. The diagnostic kit would consist of a microprocessor, signal generators, analog to digital signal converters and software. The microprocessor would execute software diagnostic routines, programmed for the specific satellite, and stored on magnetic cards to be inserted into the microprocessor. Software routines could also be used for calibration of satellite equipment. Alternatively, the diagnostic computer could be included as part of the satellite system or incorporated into an expanded EMU computer capability.

With relatively simple but Specialized Service Tools other important work tasks could be performed. Deactivating satellite subsystems may be required before performing EVA service or docking satellites to the Orbiter. Potential methods for deactivating satellite subsystems include activating safety interlocks where available, removing antenna or solar panels, baffling thrusters, and venting of pressure vessels. In addition, folding or removing satellite appendages might be required to permit certain satellites to fit into the payload bay. Such activities would probably require EVA because future satellites will probably not be self-folding or self-safetying. EVA may also be required for activities such as defueling satellites, attaching an FSS platform berthing adapter to a satellite where one does not exist, and removing structural debris from a satellite prior to transport into the payload bay.

Satellite Service MMU - Fig. 8 shows a satellite service MMU which will be a prime requirement for performing service tasks shown in Figs. 9-11. The satellite service MMU concept features increased ΔV propulsion capability achieved by using a hot gas propellant such as hydrazine. This is required for maneuvering large payloads, satellite stabilization activities described below, and extending service range. Other MMU features include a propellant Quick Recharge Provision without requiring crewmember donning of the MMU, Fully Folding Arms that permit close approach to worksites and control provision...
permitting the MMU to be flown hands-off by the crewmember under automatic EMU Computer Control. This last feature is discussed in the next section. Finally, the existing MMU center-of-gravity Thruster Trim feature may require modification to accommodate larger payloads carried.

Retrieval - Several new free-flying EVA concepts illustrated in Figs. 9-11 may be useful in satellite and space debris retrieval operations. Determination of range, rate of range closure, and satellite spin/tumble dynamics will be important to the EVA crewmember in approaching space objects safely. A Range-Rate-Spin Detector for use in this determination is shown in Fig. 5, mounted to the EMU helmet. In this concept, a pulsed laser beam is transmitted to a satellite and is partially reflected from the surface. The reflected beam is detected and processed by the EMU computer for display of range-rate-spin information. Timing, intensity and phase characteristics of the reflected laser beam produce information required for EMU computer processing. Alternative detector concepts include use of an optical range finder or Radar principle. Range and range-rate data could also be used to control EVA astronaut rendezvous with space objects to minimize MMU propellant expenditure and transit time. In this concept the EMU computer evaluates range-rate data in real time and generates signals for automatic MMU thruster control to maintain the desired transfer orbit trajectory.

A potentially useful adjunct to EMU computer control of the MMU is a Voice Control feature. The EMU computer using voice synthesis techniques converts astronaut voice commands into MMU thruster control signals. This relieves necessity for using hands for MMU control or changing EVA crewmember position while hands are performing service tasks. Voice data computer entry technology is becoming commercially well developed and would be available to support this space application.

A satellite retrieval concept is depicted in Fig. 9 which could avoid several potential retrieval problems discussed under near-term service capability. A steering thruster, part of a Retrieval Kit concept, is shown being attached to a satellite in Fig. 9A by means of an adjustable attachment tripod. The tripod with connectors on its arms is designed to grasp the specific configuration of satellite being retrieved. In practice, satellites to be retrieved would already include provision for thruster docking. The EVA crewmember on the right is shown attaching connector arms to the satellite while the EVA partner guides and stabilizes the thruster.

The steering thruster incorporates braking and positioning thrusters which provide active steering control at the satellite during retrieval which is effected by reeling the satellite back to the Orbiter. The steering thruster control system can be remotely activated at any time, by the EVA crewmember, as the distance between the satellite and the Orbiter is shortened. Braking thrusters fire forcing the reel line to become taut. Subsequently circumferentially positioned thrusters are automatically selected by the steering thruster control system to null out satellite velocity components other than directed along the taut reel line. Accelerometers are included as part of the control system for detecting velocity components off the steering thruster centerline. A reel line safety disconnect would be included which could be remotely activated by the EVA crewmember. Fig. 9B shows the retrieval in progress with the EVA crewmember having activated the steering thruster which is making a retrieval trajectory adjustment.

Fig. 9C shows the final step in the conceptual EVA satellite retrieval sequence. The steering thruster is being removed from the attachment tripod exposing an RMS grappling pin. EVA would be used for final satellite positioning, to dampen out remaining small satellite motion, and to assist in final snaring of the satellite with the RMS. The steering thruster would then be moved back into the payload bay along a tram line for storage and propellant

Figure 9. SATELLITE RETRIEVAL
replenishment prior to supporting the next retrieval operation. This steering thruster concept might also find application in transporting materials in future, large scale, space construction operations.

Fig. 10 shows a concept utilizing EVA to stabilize a spinning/tumbling satellite. One crewmember is shown casting a bolo-line using a spring-loaded casting gun which is part of a Stabilization Kit. The line moves across the satellite path, is captured, and begins to wrap around the satellite. The second crewmember shown in the lower left has placed the MMU in the automatic stationkeeping mode and dialed in reel drag to effect removal of angular momentum from the satellite. The line continues to pay out until the satellite has been despun to a prescribed level of low energy dynamics. During stabilization the laser range-rate-spin detector provides data, which is processed by the EMU computer, for generating MMU thruster control signals to correct for differential orbital mechanics between the crewmember and satellite. Periodically the crewmember removes reel drag and takes up a new position to compensate for any induced satellite motion. Once the satellite is within a safe envelope of low energy dynamics, the EVA crewmember moves in and makes contact with the satellite. Final satellite stabilization would be achieved by using MMU thrusters with the unit operated in the automatic stationkeeping mode.

Figure 10. SATELLITE STABILIZATION

Concepts are depicted in Fig. 11 for handling what could become a significant future problem in space, namely, space debris. The graphic, while an oversimplification of the space debris problem, illustrates concepts. The EVA crewmember on the left is shown using the MMU for free-flying retrieval of small debris. The debris basket, mounting to the mini-work-system, is part of a Debris Collection Kit, used to stow pieces of debris gathered by hand. The basket employs a brush-bristle top for positive containment of captured debris without creating a hazard for the space suit. Basket pads protect crewmember's legs from contact with debris in the basket. The crewmember on the right is shown collecting debris. A line has been anchored to the satellite and reeled out by the EVA crewmember moving about retrieving debris. Debris is attached to the line, using straps with end clips. The line bearing the debris would subsequently be reeled aboard the Orbiter where stowage and tie-down provisions would be available to restrain debris for return-to-earth.

Figure 11. DEBRIS COLLECTION

SATELLITE SERVICE CAPABILITY EVOLUTION

Development of an improved capability EMU and MMU along with other specialized satellite service equipment will be required to support a mature satellite service capability. A summary is given in Table 3 of new equipment concepts presented in this paper together with baseline service equipment that will be available when STS becomes operational. As equipment is added in the right-hand column, service capability evolves as indicated by the left-hand column. It is recognized that design studies will be required to define optimal new equipment concepts required to support the mature satellite service capability represented in Table 3.

No attempt is made to place a time scale on projected evolution of satellite service capability. This is because there are many unknowns at this time such as STS user demand for improved service capability, funding available for service equipment.

TABLE 3. SATELLITE SERVICE CAPABILITY EVOLUTION

<table>
<thead>
<tr>
<th>Service Capability</th>
<th>Support Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deployment</td>
<td>Shuttle Orbiter</td>
</tr>
<tr>
<td>RMS Retrieval</td>
<td>FSS</td>
</tr>
<tr>
<td>Limited Payload Support</td>
<td>RMS</td>
</tr>
<tr>
<td>Inspection &amp; Photography</td>
<td>EMU</td>
</tr>
<tr>
<td>Simple Service Tasks</td>
<td>Tether</td>
</tr>
<tr>
<td>Limited Remote Inspection</td>
<td>Simple Hand Tools</td>
</tr>
<tr>
<td>Advanced MMU</td>
<td>MMU</td>
</tr>
<tr>
<td>Eliminate Prebreathe</td>
<td>MRWS</td>
</tr>
<tr>
<td>Two-Handed Service Tasks</td>
<td>Rigid Crewmember Restraint</td>
</tr>
<tr>
<td>More Complex Service Tasks</td>
<td>Improved EMU</td>
</tr>
<tr>
<td>Assembly Operations</td>
<td>- Automatic Visor</td>
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<tr>
<td></td>
<td>- High Tactility Glove</td>
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<tr>
<td>Safetying Operations</td>
<td>Hand Held Power Tool</td>
</tr>
<tr>
<td>Systems Diagnosis &amp; Checkout</td>
<td>Specialized Service Tools</td>
</tr>
<tr>
<td>Fluid Service Tasks</td>
<td>Diagnostic Computer Kit</td>
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<tr>
<td>Electrical Service Tasks</td>
<td>Fluid Service Facility</td>
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<tr>
<td>Remote Service</td>
<td>Fluid Service Kit</td>
</tr>
<tr>
<td>Structural Repair</td>
<td>Satellite Service EMU</td>
</tr>
<tr>
<td>Satellite Retrieval</td>
<td>Satellite Service MMU</td>
</tr>
<tr>
<td>Satellite Stabilization</td>
<td>Remote Service Kit</td>
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<tr>
<td>Debris Collection</td>
<td>Retrieval Kit</td>
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<tr>
<td></td>
<td>Stabilization Kit</td>
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<tr>
<td></td>
<td>Debris Collection Kit</td>
</tr>
</tbody>
</table>
development, and orbital service problems encountered. What appears certain is that NASA, in planning STS, has provided a useful baseline orbital satellite service capability which can be evolved to what has been described as a mature satellite service capability.

CONCLUSIONS

Space Transportation System (STS) will soon provide easy access to earth orbit with reusability offering cost saving advantage over use of non-reusable space delivery systems. STS will provide delivery and retrieval of orbital payloads and a maneuverable work base from which a new spectrum of manned space activity can be supported. In the near-term Shuttle mission activity will include space research utilizing the Spacelab facility and orbital satellite service operations associated with satellite payloads. Initial baseline satellite service capability will be supported by STS equipment comprised of the Shuttle Orbiter, Remote Manipulator System, Extravehicular Mobility Unit, and Manned Maneuvering Unit. EVA is expected to play a fundamental role in accomplishing satellite service space work required to meet Shuttle mission objectives.

It has been projected that the number of satellites designed for orbital servicing will substantially increase over the next two decades, owing to space program cost savings realized by extending satellite mission life, via Shuttle service missions. In turn, this trend will dictate requirements for improved satellite service capability, with growing dependence placed on the use of EVA. Development of new equipment to support evolving satellite service capability will follow.

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