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GAMMA RAY OBSERVATORY ON-ORBIT SERVICING

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ABSTRACT

The feasibility of performing on-orbit servicing of the NASA Goddard Space Flight Center (GSFC) Gamma Ray Observatory (GRO) was initially addressed by TRW during the later portion of the Phase C development contract in 1981/82. The current post CDR GRO design reflects a capability for on-orbit changeout of the two Multimission Modular Spacecraft (MMS) modular power system (MPS) modules and the MMS communications and data handling (CADH) module via EVA. In addition, the design incorporates a capability for on-orbit refueling (OOR). The GRO design also incorporates a capability of EVA override operations for the deployment, restowage, and jettison of the GRO solar array and high-gain antenna appendages, the grapple fixture, and the electrical umbilical interface.

To validate the GRO EVA design compatibility prior to CDR, a series of five separate astronaut-suited test runs were performed in the first quarter of 1985 at the NASA/JSC Weightless Environment Training Facility (WETF) using a high-fidelity full-scale mock-up (FSM) of the GRO.

INTRODUCTION

The studies performed by TRW to determine the feasibility of on-orbit servicing, repair, and refueling were performed under a very specific set of NASA assumptions and ground rules. The GSFC GRO Project Office was (and is) under heavy pressure to maintain program costs and schedule commitments established before the on-orbit servicing discussions were initiated. NASA headquarters initiated the first request to the GSFC GRO Project Office to investigate on-orbit servicing for GRO. No additional funding was provided, however, to support the feasibility studies or the subsequent design and implementation efforts.

The selection of the MMS power and communications modules for incorporation into the original baseline design was recommended by TRW during the later portion of the GRO Phase B concept definition contract. This selection was recommended principally as a program cost savings, i.e., to use an existing, qualified, flight-proven design. The attendant on-orbit replacement capability of these modules was not, at that time, considered to be a significant advantage to the GSFC GRO project. The conceptual design of GRO during the majority of the Phase C design definition phase did not include any provision for astronaut EVA involvement in either a planned or contingency support operational role. As an amendment to the Phase D RFP, TRW was asked to identify design modifications and costs associated with incorporating an on-orbit EVA module changeout capability for the power and communications modules, and an EVA-supported appendage deployment manual operation as a contingency should the automatic deployment system fail to operate. In addition, the amendment to the RFP asked to identify the

design and cost impacts for making GRO retrievable by the orbiter. These initial maintenance EVA override, module replacement, and orbiter retrievability features were incorporated into the Phase D contract Statement of Work to TRW in February of 1983. Commensurate with the start of the Phase D contract, the GSFC GRO Project Office directed TRW to perform a feasibility and concept definition study to establish technical, cost, and schedule impact for incorporating an on-orbit refueling capability for GRO. The study was completed in 90 days, and the GRO Phase D contract was modified in June 1983 to incorporate an on-orbit refueling capability into the baseline GRO design.

GRO DESCRIPTION

A summary of the GRO program milestone is shown in Table 1. Figure 1 is a summary GRO project schedule. The GRO mission objectives are summarized in Table 2 and the overall mission concept is depicted in Figure 2.

Table 1. GRO Program Summary

Sponsor: NASA (Office of Space Science)

Customer: NASA Goddard Space Flight Center

Mission contractor: TRW

Program chronology:

- Mission need statement issued in May 1978
- Phase 1 studies conducted in 1980
- Program approval document issued in February 1981
- Phase C contract from April 1981 through September 1982
- Phase D contract from February 1983 through mission end
- PDR in May 1984
- NASA/JSC WETF testing February to April 1985
- CDR in June 1985
- Launch in May 1988. Inclination 28.5 degrees; mission altitude 350 to 450 km
- Two-year science mission
- STS retrieval return from orbit (1990+)

GRO On-Orbit Serviceability

As previously mentioned, program cost considerations significantly limited detailed investigations and conceptual design efforts to establish

Table 2. Mission Objectives

Study dynamic evolutionary forces in compact objects such as neutron stars and black holes

Search for evidence of nucleosynthesis

Investigate gamma-ray-emitting objects whose nature is not understood

Explore our galaxy in the gamma-ray range, particularly with regard to regions difficult to observe at other wavelengths

Study the nature of other galaxies in the energetic realm of gamma rays

Study cosmological effects through detailed examination of the diffuse radiation and the search for primordial black hole emission

additional on-orbit servicing capabilities, e.g., component/module or subsystem changeout. The GRO design proposed for the Phase D development contract incorporated extensive use of qualified, flight-proven hardware that was in many instances not readily modifiable to an ORU configuration. A subsystem component reliability analysis was performed on the GRO attitude control and determination (ACAD) subsystem to establish data on mean time before failure rates and determine what components, if any, should be considered as candidates for on-orbit replacement. Considering the 2-year nominal mission lifetime, this analysis showed that no single component within the ACAD subsystem should be designed for on-orbit replacement, and the overall ACAD subsystem reliability numbers supported the same conclusion. At the start of the Phase D contract, the two MMS power modules and the MMS CADH modules were baselined as the only GRO on-orbit replaceable components/subsystems.

Deployment Mission — Initial Maintenance

The studies performed near the completion of the Phase C contract suggested that an improvement in mission reliability could be achieved if certain mission-critical automatic appendage deployment functions could incorporate an EVA override feature. As part of this effort, a motor-driven appendage release and deployment system was incorporated in place of the original ordnance-activated, spring-release system. Manual EVA wrench-actuated overrides were incorporated into the gear drives of the motor-driven appendage release and deployment mechanisms on the two solar arrays and high-gain antenna booms.

Deployment/Retrieval Mission EVA Evaluation

The anticipated planned and contingency EVA operations for both the GRO deployment and retrieval missions are similar. If a solar array or high-gain antenna appendage mechanism fails to perform satisfactorily, an

astronaut in EVA, using standard wrenches and tethers, can override the electrical drive motor and deploy or restow the affected appendage.

To perform most of the EVA operations that may be required on the GRO deployment mission, the EVA test crew will not have the RMS/manipulator foot restraint (MFR) available; the RMS is being used in conjunction with the GRO grapple fixture to hold the GRO above the open cargo bay. All of the EVA operations associated with solar array or high-gain antenna appendage latch release and deployment must be performed using the portable foot restraint (PFR) units presently in the orbiter inventory. An EVA operational flow is shown in Figure 3.

These EVA override operations using the PFRs were rehearsed as part of the GRO FSM WETF activities. As a result of these tests, a change was incorporated into the flight design of the GRO solar array appendage to provide improved access to the array jettison bolts. In addition, the crew personnel recommended that additional handrails and foot restraint sockets be added to improve EVA accessibility. This hardware has been incorporated into the flight design.

Repair/Refueling Mission EVA Operations

The GRO design incorporates the capability for on-orbit replacement of either of two power modules and/or the communications and data handling (CADH) modules. The mechanical design of these modules is identical to that of the GSFC-developed MMS modules previously flown on the Solar Max and Landsat missions. A sketch of the module is shown in Figure 4. The recent successful STS/Solar Max repair mission validates the on-orbit changeout capability of this package design as well as the support tools and hardware/software used in the operation.

To assure GRO/orbiter refueling interface compatibility, GRO personnel have maintained close communications with the NASA/JSC propulsion branch personnel within the engineering directorate. This task involved the review/critique of the original requirements and SOW documentation for both the on-orbit refueling coupling (payload/orbiter propellant interface) and the OSCRS. The coupling is currently in final development by Fairchild Controls, and the OSCRS program is currently in an 8-month preliminary design study with five contractor teams participating. The current coupling design reflects design improvements that were incorporated as a result of the GRO OOR EVA WETF evaluation testing performed early in 1985 and repeated in June of 1985. The OSCRS RFP/SOW specifically addresses the requirement for compatibility with the GRO propulsion subsystem. JSC is currently planning on the initial OSCRS development and operational readiness by 1990.

Repair/Refueling Mission EVA Evaluation

Of primary concern in the EVA box changeout operations simulated in the WETF testing was the establishment of crew translation routes between the box location on GRO and the box storage location on the FSS A-prime cradle used to berth the GRO during these operations. A mock-up of the on-orbit refueling coupling had been installed on the GRO structure prior to the start of the FSM WETF activities. One of the EVA tests was devoted to

establishing the preferred position for the astronauts during the refueling coupling mate and demate operations. This test was also performed with GRO berthed to the FSS A-prime cradle in the actual mission simulation configuration. Specific astronaut recommendations for EVA design enhancement for support of GRO repair/refueling mission operations included the addition of handrails and portable foot restraint sockets in specific locations and a requirement for an EVA-installed handling fixture for moving the modules between the worksite locations. In addition, an area of interference between the GRO integral berthing adapter structure and the FSS A-prime cradle latch motor case was identified. The GRO structure will be modified to eliminate this interference.

GRO/STS Interfaces

Table 3 provides a summary of the GRO/STS interfaces for each of the three missions. Figure 5 graphically identifies these interfaces.

Table 3. GRO/STS Interface Summary

INTERFACES	DEPLOYMENT	REPAIR/ REFUELING	RETRIEVAL
1. STANDARD FIVE-POINT ACTIVE TRUNNION INTERFACE	X		X
2. DEPLOYMENT, BERTHING, AND RESTOW USING RMS/GRAPPLE FIXTURE STANDARD INTERFACE	X	X	X
3. BERTHING TO FSS A PRIME CRADLE VIA GRO INTEGRAL BERTHING ADAPTER		X	
4. ELECTRICAL POWER AND HEATER CONTROL THROUGH AESE	X	X	X
5. STANDARD UMBILICAL RELEASE SYSTEM (SURS) POWER AND SIGNAL INTERFACE	X		X
6. PF1 MDM INTERFACE DURING IN-BAY POWER-OFF OPERATIONS	X	X	X
7. PI/PDI INTERFACE FROM CADH TO TDRSS/MCC/POCC VIA LGA	X	X	X
8. AFT FLIGHT DECK (AFD) STANDARD SWITCH PANEL (SSP) FOR GRO POWER CONTROL AND SAFETY STATUS MONITORING	X	X	X
9. FHST SHUTTER CONTROL FROM SSP	X	X	X
10. AUXILIARY EVA UMBILICAL FOR MONITORING OF CRITICAL OOR PARAMETERS		X	
11. PLANNED AND UNSCHEDULED EVA			
• APPENDAGE DEPLOYMENT/ RESTOW/JETTISON	X		X
• ORU (MPS, CADH) CHANGEOUT		X	
• REFUELING		X	

GRO FOLLOW-ON SERVICING POTENTIAL

When the GRO has completed its scientific mission, it could be used as a spacecraft on which to conduct technology demonstration and crew training to advance on-orbit satellite servicing. With the Space Station as the host vehicle, a series of servicing technology development missions (TDM) is envisioned. The technology considerations, benefits, Space Station requirements summary, and scenario highlights are listed below:

- 1) Technology considerations
 - EVA construction/disassembly
 - On-orbit fluid transfer/storage
 - OMV operations
 - Part replacement
 - Contingency service operations
 - On-orbit system/subsystem test
 - Satellite retrieval
 - Advanced crew support technologies
- 2) Benefits
 - Extension of life of GRO
 - Applicable to repair/refurbishment of many other spacecraft
- 3) Space Station requirements
 - Mechanical and electrical support equipment
 - Crew support equipment
 - Refillable propellant tanks
 - Special crew training
 - Autonomous mission support systems
- 4) Scenario highlights
 - GRO retrieval from 400 km orbit
 - Comprehensive status tests
 - Refurbishment/repair of units
 - Propellant refill

- Comprehensive checkout
- Redeployment into operational orbit.

TDM Description

The objective of the TDM is to demonstrate the capability to service a low earth orbiting satellite, in this case the GRO, at the Space Station. Such servicing will extend the useful life of the spacecraft. GRO was picked as an example.

Because of its great size, special arrangements must be made to service the GRO at the Space Station. It would be desirable to attach the GRO to the servicing shelter cargo rails with the "skin" of the shelter removed. This would permit the use of extended payload retention latch assemblies (PRLA) to allow adequate space for the refueling operation and access to orbital replacement units (ORU).

Sequence of Events

The Orbital Maneuvering Vehicle (OMV) "flies" out to rendezvous with the GRO, attaches to the grapple fixture (located above the trunnion mount), and maneuvers the spacecraft toward the Space Station. To facilitate this operation, the grapple fixture must be oriented toward the GRO center of gravity.

When the GRO is very near to the Space Station, the module manipulator system connects to the OMV grapple fixture. An astronaut in a manned maneuvering unit goes out and mounts a portable grapple fixture to the end of the GRO satellite. A handling and positioning aid (HPA) can be attached to this portable grapple fixture to secure the spacecraft while the OMV is demated from the permanent grapple fixture and stored using the module manipulator system. The combined capabilities of the module manipulator system and HPA can then be used to position the GRO against the PRLAs attached to the cargo rails. Attachment will be made remotely from inside the Space Station.

The next step is changeout of an orbital replacement unit. The type of unit to be replaced will be determined at the time the demonstration is planned, based on requirements to extend the life of the spacecraft. If solar arrays need to be replaced, the entire array, including its drive assembly, will be changed out. If no subsystems require replacement, a standard command and data handling module could be changed out to demonstrate the technique. ORU changeout will be performed by two suited astronauts using portable handholds and foot restraints, wing tab connectors, and the module manipulator system and HPA.

After the changeout, the astronauts will set up a fueling kit and position the fueling (and pressurizing) connector(s) against the fueling port and hold it (them) there with the HPA (and module manipulator system). The astronauts then return to the Space Station and the coupling of the fuel connector is completed remotely. This reduces the risk of space suit contamination, enhancing crew safety.

After refueling, fuel lines are evacuated and uncoupled from the spacecraft. Then the OMV is mated to the spacecraft, the portable grapple fixture is removed, and the GRO is returned to optimum low earth orbit.

Benefits and Applications

This TDM will demonstrate the capability to retrieve a LEO spacecraft, bring it to the Space Station, perform necessary servicing, and return it to the optimum orbit, thereby extending useful satellite life. This capability has applications to virtually all LEO satellites, and will enable more sophisticated servicing operations that can be performed by remote (in situ) operations or by servicing with the STS orbiter.

The increased capability enabled by satellite servicing at the Space Station provides the following benefits.

- 1) The spacecraft can be disassembled for access to connectors, sensors, and other equipment (the service platform provides room for storage and tie-down during servicing operations).
- 2) Large, complex components, such as solar arrays, can be replaced or refurbished and tested prior to spacecraft redeployment.
- 3) Spacecraft optical, thermal, and solar array surfaces can be cleaned or refurbished.
- 4) Large, fragile spacecraft (those assembled, tested, and inserted into orbit from the Space Station) can be serviced with reduced risk of damage.

In addition to the increased servicing capability, the following benefits can be realized.

- 1) The spacecraft capability can be upgraded by retrofit to provide, for example, more power from increased solar array area and/or more battery capacity, more accurate stationkeeping with improved sensors, and more reaction control capacity from added fuel capacity.
- 2) The spacecraft mission can be altered by replacing existing experiments or functions with others.
- 3) The spacecraft orbit can be changed with appropriate sensor changes and reinsertion into the new desired orbit via the OMV.

Special Considerations

This TDM is baselined using the GRO as the service object. While the GRO is being designed for limited on-orbit servicing via the STS orbiter, several special considerations are applicable for Space Station servicing:

- 1) The grapple fixture (used to remove the GRO from the orbiter payload bay) must be oriented toward the center of gravity of the spacecraft to permit retrieval and reboost by the OMV.
- 2) The GRO design must include provision for attaching a second (portable) grapple fixture for handling at the Space Station.
- 3) The GRO refueling equipment to be used by the orbiter must be compatible with Space Station capabilities.

CONCLUSION

The excellent overall results of the test program using the GRO FSM at the NASA/JSC WETF has validated the capability of the current GRO baseline design to support on-orbit servicing from the orbiter. This capability includes both planned EVA operations and contingency EVA override operations that significantly enhance the probability of mission success.

The utilization of the GRO in developing Space Station operating technologies appears to be an attractive option after the GRO scientific mission is completed.

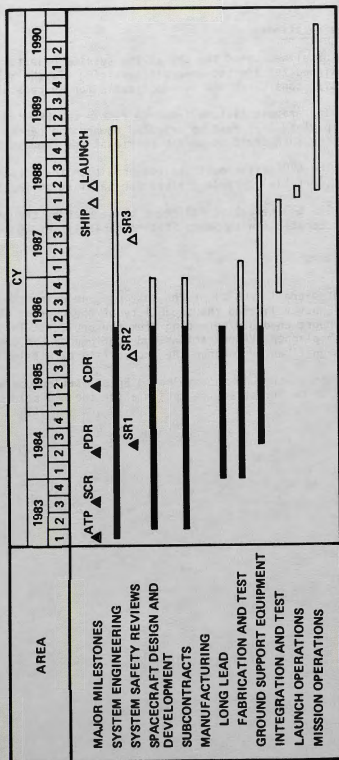


Figure 1. GRO Project Schedule

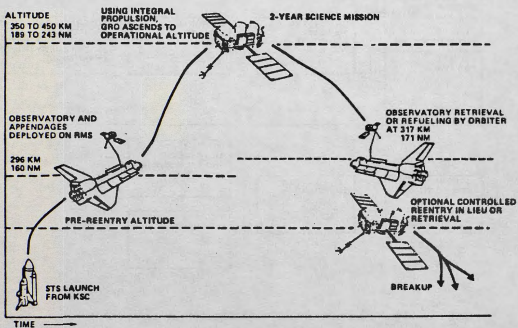


Figure 2. GRO Mission Concept

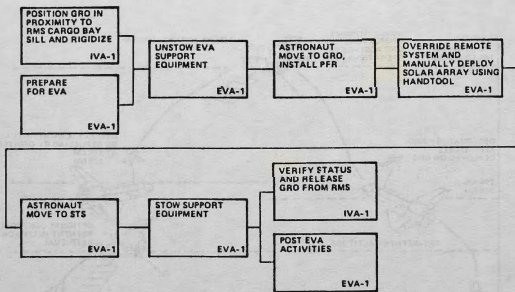


Figure 3. GRO Deployment Mission EVA Flowchart

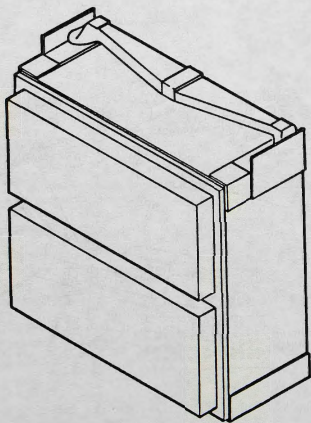


Figure 4. MMS MPS and CADH Module Configuration

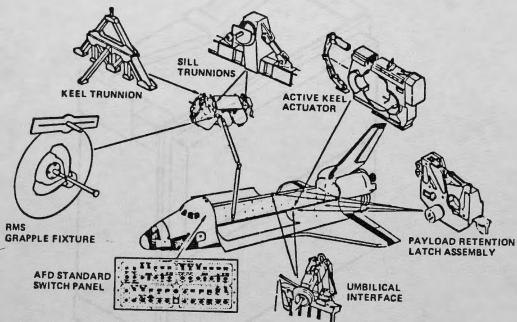


Figure 5. GRO Electrical/Mechanical Interfaces with Orbiter