

Mission Operations Directorate - Success Legacy of the Space Shuttle Program

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In support of the Space Shuttle Program, as well as NASA's other human space flight programs, the Mission Operations Directorate (MOD) at the Johnson Space Center has become the world leader in human spaceflight operations. From the earliest programs - Mercury, Gemini, Apollo - through Skylab, Shuttle, ISS, and our Exploration initiatives, MOD and its predecessors have pioneered ops concepts and emphasized a history of mission leadership which has added value, maximized mission success, and built on continual improvement of the capabilities to become more efficient and effective. MOD's focus on building and contributing value with diverse teams has been key to their successes both with the US space industry and the broader international community. Since their beginning, MOD has consistently demonstrated their ability to evolve and respond to an ever changing environment, effectively prepare for the expected and successfully respond to the unexpected, and develop leaders, expertise, and a culture that has led to mission and Program success.

MOD Background

To better understand the evolution and successes of MOD during the Shuttle program, one must first understand MOD's current roles and responsibilities. MOD's responsibilities traditionally fall into four categories: flight design and planning, crew and flight controller training, real-time flight execution, and facility operations. MOD is typically described as a "Plan-Train-Fly" organization with facilities support and utilization encompassing all of those aspects. Operational preparation consists of two types of planning and training: Generic and Flight Specific. Generic planning and training includes the development of nominal vehicle operating procedures, generic contingency procedures, and flight rules (e.g. generic operational procedures which are the same for every flight). It also includes development of basic flight systems knowledge, Mission Control Center (MCC) tools usage, Flight Control Team processes and procedures, and generic training simulations leading to basic certification (e.g. generic flight control skills). Flight specific planning and training includes mission specific plans and procedures development, mission specific consumables analysis and planning, flight specific technique and payload training, and joint flight control team and crew mission simulations. A further explanation of MOD's major functions and examples of efficiencies in these areas are covered in the following text.

Plan

The "Plan" part of MOD's description includes mission concept definition, mission requirements integration, flight planning and mission timeline development, flight rules development, procedure development, international partner integration, flight design, and pre-mission analysis. As mentioned above, the planning aspects are divided into generic and flight specific functions. MOD has developed and is responsible for the generic operations knowledge baseline for all missions - an "operator's manual" for human spaceflight systems. Over the course of the Shuttle Program, MOD has refined the generic operational aspects for the Shuttle missions, which has led to similar operational baselines for the ISS Program, as well as considerations for future human spaceflight programs. MOD has developed and

refined baseline operation procedures for both the vehicle and the MCC, including operating procedures for individual systems, and integrated activation and deactivation procedures. MOD has also capitalized on generic flight techniques and flight rules development. MOD has effectively been able to baseline the “best practices” and design generic operational techniques for complex tasks such as rendezvous, landing, and contingency responses. Through the development of their generic Flight Rules, MOD has been able to document critical decision paths for contingency scenarios, vehicle systems operating limits violations, redundancy management, and mission abort criteria. For the Shuttle Program, the Flight Director office (within MOD) chairs Flight Techniques Panels for both Orbit and Ascent/Entry operations. These panels have successfully served as the forums to discuss and implement changes as a result of vehicle issues, mission experiences, and lessons learned. Developing generic flight techniques and generic flight rules have been a critical mechanism for capturing lessons learned and enabling MOD to apply these experiences to not only the Shuttle program but to ISS and future programs as well.

For flight specific planning, MOD is responsible for the development of all the flight-unique timelines, as well as the procedures and rules required by the specifics of a given mission. This includes the mission (crew) timelines, which details the mission related activity for each crew person for every minute of the crew day throughout the mission. This also includes the mission specific crew procedures (i.e. payload ops, ISS assembly, Extra Vehicular Activity (EVA) procedures) and the flight specific Flight Rules. MOD is also responsible for the consumables planning and the mission specific flight design and trajectories. In addition, MOD is also responsible for producing flight specific “recon” products for the vehicle flight software load. Flight specific data loads, and command and telemetry loads are required by the design and architecture of the Shuttle flight systems. This “recon” process collects vehicle specific performance data, mission specific trajectory, and command/telemetry data definitions. MOD has continued to take advantage of their operational expertise, available tools and technology, and the generic operational baselines to make development of the flight specific products more efficient over the course of the Shuttle program. Like the use of generic operational baselines, common missions (e.g. ISS docked mission) and similarity to previously flown missions (e.g. multiple Hubble Space Telescope repair missions) have also made the development of flight specific products less demanding.

Train

Training is a little more straightforward and includes all of the activities involved with the crew and flight controller training, including lesson and curriculum design and development. Like the planning processes described above, MOD supports training for both generic and flight specific efforts. Training includes generic skill development for both crew and flight controllers, as well as the flight specific training required for each mission. Generic training is targeted for the new and less experienced flight controllers as well as the new astronaut candidates. Astronauts must complete generic crew training before becoming eligible for a flight assignment. Generic flight controller training culminates in a formal certification for a specific console position. Generic training (for both flight controllers and crew) consists of general spacecraft knowledge, overview of vehicle systems and operations, detailed systems knowledge base, failure signature recognition and response, procedure and flight rule familiarity, use of MCC tools and processes, and “soft skills” (situational awareness, communication, prioritization, etc.). MOD provides training through the development and delivery of lessons and training materials, including formal instruction and oversight during training and simulation activities.

During flight specific training the assigned crews and mission flight controllers receive additional training to become knowledgeable and proficient in the elements and objectives for that particular mission. Crews are exposed to detailed training for the onboard systems, tools, timeline activities, and mission specific tasks such as rendezvous and docking, payload deploy/retrieval, EVA, and Remote Manipulator Systems (RMS) operations. The assigned crew and the flight control team participate in flight specific integrated

simulations, with the crew in the simulator and the flight control team in the mission control center. These simulations consist of flight-like data flow, communications, and mission scenarios. These simulations function as a rehearsal of the mission timeline, including time-critical and highly integrated and choreographed events. These simulations also serve the purpose of validating the mission timeline and as opportunities to improve the teamwork and proficiency for the crew and ground control teams. Other centers (i.e. MSFC) and International Partners can also be tied into these flight specific simulations. Integration of the International Partners into these simulations, as well as mission decisions and execution, has been a challenge that the ISS Program has continued to wrestle with throughout their program.

Until recently, Flight Control and Training within MOD had been separated into different and various Divisions. Understanding that the skill base and systems knowledge for Instructors and Flight Controllers were similar, MOD looked for ways to manage this seemingly redundant expertise in a more efficient manner. In August of 2007, MOD initiated a Directorate-wide reorganization. One of the many benefits of the re-org was that the instructor/training personnel and functions were integrated with the flight control personnel and functions into joint training/flight control divisions. Because of this, MOD has continued to develop personnel skilled in vehicle systems and mission processes that can serve as both flight controller and instructors. Through this structure, MOD can work towards a “Top Gun” approach to training and have their “best and brightest” serve as the prime instructors for the assigned crews and the flight controllers. MOD has gained many efficiencies in this area and has become more resilient to attrition and other workload demands. This new “ops concept” has been incorporated into ISS operations and is serving as a baseline for future program operational considerations.

MOD has continued to refine their operations and training throughout the Shuttle program. One of the core MOD foundations is: *“To always be aware that suddenly and unexpectedly we may find ourselves in a role where our performance has ultimate consequences”*. MOD has adopted this mentality into their training and operational concepts. Apollo 13 demonstrated the need to be able to respond to the unexpected. As part of that Lesson Learned, MOD has continued to analyze the onboard systems and the operational environments to identify the potential failure modes and off-nominal situations. As these potential failures and situations were identified, the required responses were also developed and incorporated into the flight rules and the operational procedures. This type of analysis was re-emphasized after the Challenger accident and MOD conducted a line-by-line review of all the procedures and flight rules in order to make necessary improvements in these areas with consideration to all possible failures. MOD has also continued to refine their procedures and flight rules as new vehicle hardware and software, operational requirements, and programmatic requirements have changed over the years. MOD has also incorporated this philosophy into their training and simulation aspects. Although the typical Shuttle missions have very few major failures, MOD continues to train for and be prepared for the more severe failure scenarios. With this training and operational philosophy, the MOD team can serve as an insurance policy against the unexpected.

Fly

Obviously, the “Fly” part of the MOD’s description covers the real-time flight execution. MOD provides real-time mission support from prelaunch through landing, with responsibilities including vehicle systems monitoring, command and control, anomaly resolution, and interface with the Mission Evaluation Room (MER) team and Mission Management Team (MMT). The purpose of the flight control team, of MOD overall, is to protect the crew and vehicle safety, and to ensure mission success. The flight control team provides trained execution and oversight of nominal operations, and informed and methodical response to malfunctions and emergencies. Duties of the Shuttle flight control team in the MCC include continuous monitoring and support for crew and vehicle, and management of the overall flight plan execution. The flight control team provides technical discipline expertise to actively manage vehicle systems, monitor

ongoing vehicle and consumables status, and provide crew advisory support. The flight control team operates per verified and controlled procedures and flight rules, and devises workarounds or procedure changes in response to failures or unplanned situations. The team is also responsible for providing various status reports daily, including systems operational status for crew and MCC use, consumables and mission status for management and analysts, and updated plan and procedures for the crew and flight control team.

Crew timeline “replanning” is a major part of every mission. Due to a variety of reasons, the crew timeline will need to be modified throughout the mission. Sometimes these changes are subtle and result in only minor modifications. Other times, the changes are significant and result in major changes to the timeline. Typically the team on duty during crew sleep will replan the next day. When certain events (unexpected failures) cause major timeline changes, these changes can be discussed for days before being implemented as a new timeline for the crew. All major timeline changes will have to be discussed with and approved by Mission Management Team (MMT).

For MOD, the Shuttle missions are typically supported around-the-clock by 3 flight control teams working approximately 9 hour shifts per day (1 hour overlap to handover to next team). When failures or unexpected events occur, an additional flight control team (“Team 4”) can be called up to work the issues offline and allow the on-console flight control teams to stay focused on their primary responsibilities. MOD provides call-up access for simulators, trainers, and operational expertise to support the scenarios. MOD personnel will support offline development and validation of off-nominal workaround procedures, Astronaut office evaluation of these new procedures, and support to engineering analysis of off-nominal systems behavior.

Facilities

MOD develops, maintains, and operates several facilities for support of the Plan-Train-Fly functions. For Shuttle, the MOD managed facilities include the Mission Control Center (MCC), the Shuttle Mission Simulator (SMS), the Neutral Buoyancy Laboratory (NBL), and the Space Vehicle Mockup Facility (SVMF). There are also smaller, off-line training environments that will be discussed later in this section. The MOD managed facilities are utilized for every phase of the mission planning, training, and execution activities.

MOD has continued to enhance and improve their facilities throughout the Shuttle Program. Although the early Shuttle missions were supported using the same control rooms that were used for the Apollo program, MOD ushered in a new era when they moved their flight control team operations into the “White FCR” in 1994. This new control center incorporated the latest technologies in fiber optics, communications, and computer technologies, and gave the flight control team more flexibility and capability to build new displays and console applications, and to view vehicle data in a much more efficient manner. The new control room capabilities also allowed the flight control team to “automate” many tasks that had previously been performed by hand. The new control center also allowed for great efficiencies in the areas of “recon” for every mission, greatly streamlining the process for display, communications, and data integration. As technology (and Program demands) has changed over the years, MOD has strived to keep pace with the appropriate control center enhancements. MOD was able to utilize their lessons learned from the Shuttle control rooms (and the early ISS control rooms) and develop a new control room for the ISS flight control team in 2006, again incorporating the latest technologies and increasing the flight control team’s capabilities and efficiencies.

In addition to the large scale facilities and simulators, MOD has a number of smaller “off-line” training environments which are used to train both astronauts and flight controllers. These smaller training environments are used to replicate a variety of onboard systems and control center consoles. Whereas the

large facilities and simulators require a large number of support personnel to function, these smaller training environments require much less people (sometimes only 1 or 2 people) and allow for more personalized training. This type of training has been very effective for system (hardware) specific training, training of less experienced personnel, and more one-on-one and small team type training. MOD also has produced a number of Computer Based Training (CBT) lessons on all aspects of the Shuttle systems and flight operations. These CBT lessons are designed to be self paced lessons and can be viewed by the students (crew and flight controllers) on their office PC or at home. These smaller training environments and media have decreased the dependency on the larger scale training environments and in turn, decreased cost and increased training flexibility.

MOD Contractor Elements

MOD is comprised of about 2000 employees, approximately 1500 of which are contractor employees (both onsite and offsite). MOD is currently covered by four major contracts: SPOC, IMOC, FDOC, and NSOC. United Space Alliance (USA) is the prime contractor for the Space Program Operations Contract (SPOC), providing Plan-Train-Fly (P-T-F) support to the Shuttle efforts within MOD. USA is also the prime contractor for the Integrated Mission Operations Contract (IMOC), which provides support to the Constellation program and ISS P-T-F efforts within MOD. Lockheed-Martin is the prime contractor for the Facilities Development Operations Contract (FDOC), providing facilities development and sustaining support and software development support for the Mission Control Center and the training simulators. Raytheon is the prime contractor for the Neutral Buoyancy Lab (NBL) / Shuttle Vehicle Mockup Facility (SVMF) Operations Contract (NSOC), providing facilities development and sustaining support for the NBL and the SVMF. MOD is also supported by other companies who serve as sub-contractors to the various contracts within MOD.

Throughout the Shuttle Program, the MOD workforce has successfully operated in a seemingly “badgeless” society. The civil servant and contractor personnel have worked hand-in-hand towards the common goal of crew safety and mission success. Although there are designated “contract accountable functions”, by and large, the standard roles in MOD are supported by civil servants and contractors alike. For the onsite MOD workforce, there is no segregation within the organizations. The roles and responsibilities are available to and supported by all MOD personnel, regardless of badge color or company. This has resulted in a very flexible and efficient workforce throughout MOD.

MOD Shuttle Program Success

MOD has had many successes throughout the Shuttle program and has served as a critical component to the overall success of this program. With three decades of experience in operating the Space Shuttle, MOD has demonstrated its ability to adapt to changing missions, developing new operational techniques and tools along the way. MOD’s tough and competent team has extended the Shuttle’s capabilities far beyond those envisioned at the beginning of the program. MOD has continued to learn, improve, and reshape itself with each new opportunity throughout the program.

The following are just a few examples of where MOD added significant value to the success of the Shuttle program. These examples will illustrate the various ways that MOD has responded to the unexpected and the changing environment throughout the program.

STS-49 Intelsat Repair Mission

The main objective of the STS-49 mission was to repair the Intelsat VI satellite. The Intelsat VI satellite was launched on a Titan rocket, but the upper stage booster failed and left the satellite in an orbit too low and too unstable for it to be of any use. The plan was for the STS-49 EVA crew to capture Intelsat, install a new booster and release it. This entire procedure was expected to be accomplished during one EVA.

The procedure was expected to be accomplished in one day. Two spacewalkers, Pierre Thuot and Rick Hieb, would exit the shuttle through the shuttle's airlock cabin. Thuot would then move toward the satellite with his feet secured on the shuttle's robotic arm controlled from within the cabin by Mission Specialist Bruce Melnick. Once within reach, Thuot would install a specially designed "capture bar" on the aft end of the satellite in a soft attached mode. After it is soft attached, the lock would be tightened by Thuot with the installation of a locking device using a specially built power tool. Thuot would then manually halt the satellite's rotation using a special "steering wheel" on the capture bar. While Thuot would be capturing the satellite, Hieb would be preparing clamps and electrical connections in the shuttle's cargo bay. Once the satellite were stabilized, Melnick would grapple the Intelsat with Endeavour's mechanical arm and pull it to a position vertical with the shuttle's cargo bay. The two spacewalkers would then attach a perigee kick motor to the satellite and release it using timed springs once the two were safely back in the cabin of the shuttle. Ground controllers would then activate the kick motor and send Intelsat from a height of 200 nautical miles to a height of 22,300 nautical miles.¹

In addition to the Intelsat repair EVA (which was planned for Flight Day 3 (FD3)), there was also two other EVAs planned for this mission, both to perform tasks as part of the Assembly of Space Station by EVA Methods (ASEM) experiment. These tasks included building a truss pyramid in the Shuttle payload bay. These EVAs were scheduled to be performed on Flight Day 4 (FD4) and Flight Day 5 (FD5).

During the Intelsat repair EVA on FD3, the crewman (Thuot) was unable to attach the capture bar needed to stabilize the satellite. On his last attempt to attach the capture bar, the satellite began to wobble. No further attempts were made and the crew returned back into the Shuttle.

MOD and the mission managers began discussing options and it was decided that another EVA would be performed on the following day in another effort to attach the capture bar. Although the EVA would basically be a repeat of the initial EVA, MOD would have to not only replan the FD4 activities but the entire mission timeline. Because of the unexpected susceptibility of the satellite to wobble, MOD also developed a "bump test" which would allow the EVA crewman to get a feel for how delicate he needed to be when capturing the satellite.

During the second EVA (on FD4), five additional attempts were also unsuccessful in attaching the capture bar. The problem was determined to be with the capture bar and the fact that its motion was limited and it simply could not grasp the rotating satellite.

Again, MOD and the mission managers discussed options. Options varied from no further attempts to the use of multiple crewmembers to "grab" the satellite and install the capture bar. While options were continued to be discussed, the decision was made to not do any EVA on FD5 in order to give the crew a day off and give the ground team the time to formulate a viable option. Once again, this caused a major replan activity to the mission timeline, not only to move out the EVA activities, but to also move other activities forward into FD5. There were other issues also being worked by MOD because of this problem. The amount of remaining propellant gas ("prop margin") was becoming a concern because of the extra use required for rendezvous ops with the satellite. If too much gas was used for Intelsat rendezvous ops, the mission might have to be shortened because there would not be enough gas to complete the remaining mission. The MOD team was talking with mission managers about the ASEM EVA objectives and how that would be folded into the remaining mission. The MOD team was also working issues like the attitude timeline (to have best available sunlight for the Intelsat ops), additional camera view requirements for Intelsat ops, and payload bay lighting issues for EVA ops. An MOD "Team 4" was called up to work the EVA options and the other associated issues.

After lengthy discussions and analysis, MOD converged on two main options: a 2-person EVA and a 3-person EVA. The 3-person EVA would be more likely to succeed but there were definite challenges involved with a 3-person EVA, including the fact that it had never been performed or even trained. Other

challenges included: EVA comm channels (normally configured for only two EVA crew), would three suited crew fit into the airlock?, choreography for the 3-person EVA (tether options, satellite tasks options, who goes where/who does what, etc.). The MOD flight control team discussed these options with the crew and the crew agreed that the 3-person EVA option had the highest chance of success. The MOD EVA team conducted suited sessions in the Weightless Environment Training Facility (WETF) to dry-run the various options for the 3-person EVA. It was eventually decided that the team would pursue the 3-person EVA option, which involved two crew grabbing and holding the satellite, while the third crewman would attach the capture bar. Also during the course of the WETF sessions, the MOD team determined that the crew could assemble and then use part of the ASEM to provide a platform so that the crew would be able to stand in a triangular formation around the satellite. Once it was officially decided to pursue this course of action, the MOD team worked around the clock to develop and finalize the EVA procedures and replan the mission timeline. The procedures were uplinked to the crew and preparations began for a third Intelsat EVA on FD5. In addition to Thout and Hieb, Tom Akers would participate in this 3-person EVA. The plan called for Hieb to be located on the port rim of the payload bay, Akers would be on the (just assembled) AESM truss structure, and Thuot on the end of the Shuttle robot arm. The 3-person EVA was successful in attaching the capture bar and the Intelsat was able to be repaired and released as planned. The following day Kathy Thornton and Tom Akers performed a shortened version of the AESM experiments. The results of this test helped map out the plans for construction of the International Space Station.

Throughout the STS-49 mission, the MOD team successfully demonstrated their ability to respond to unexpected events, develop creative and innovative solutions, and to effectively manage operational workarounds to achieve mission objectives and success. The innovative solutions and operational techniques used during STS-49 served as the baseline for future hardware integration requirements, EVA training, and mission planning strategies.

TPS Inspection - R-Bar Pitch Maneuver

After the STS-107 Columbia accident, the Space Shuttle Program established a new return-to-flight requirement to inspect the Orbiter thermal tiles on the underside and wing leading edges while on-orbit prior to entry. This supported the Columbia Accident Investigation Board (CAIB) recommendation to: "...develop a practicable capability to inspect and effect emergency repairs to the widest possible range of damage to the Thermal Protection System...taking advantage of additional capabilities available when near to or docked to the International Space Station (ISS)." As part of the return-to-flight effort, new hardware was developed for the Shuttle to perform major parts of the Thermal Protection System (TPS) wing leading edge (WLE) and nose cap inspections. The Orbiter Boom Sensor System (OBSS) is a 50-foot boom and serves as an extension of the existing Shuttle Remote Manipulator System (RMS), doubling its length to a combined total of 100 feet. At the far end of the boom is an instrumentation package of cameras and lasers used to scan the leading edges of the wings, the nose cap, and the crew compartment after each lift-off and before each landing. However, the OBSS capability is limited to a certain degree and cannot survey all of the Shuttle's underside TPS. The NASA engineering and operational communities were called upon to identify viable solutions to get full insight to the integrity of the TPS.

The MOD team, utilizing their expertise in rendezvous techniques, developed a rendezvous maneuver technique that would satisfy the new tile inspection requirements and make use of ISS-based imaging. The MOD team designed a nose-over-tail flip maneuver the Shuttle would perform as it approaches ISS. The flip maneuver will allow the ISS crew to take detailed photographs of the underside of the Orbiter. This maneuver is called the "R-Bar Pitch Maneuver" (RPM), where R-Bar is one of the reference lines used in the rendezvous approach to the ISS. The shuttle approaches the ISS along the R-bar line and at a small distance from the ISS, usually around 600 feet, the shuttle performs a slow 360° pitch, during which

it exposes its underside to the ISS. The crew inside the ISS visually inspects and photographs the TPS areas to determine whether or not it has been damaged. This maneuver requires skilled piloting, as the shuttle commander must fly very close to the ISS without the station always in full view. After the maneuver is complete the shuttle will continue on a normal approach to the ISS, eventually completing the docking.

This maneuver also requires the use of some of the existing rendezvous tools (computer applications) that are available onboard the Shuttle. The Rendezvous and Proximity Operations Program (RPOP) is a real-time piloting aid software that runs on a laptop computer onboard, providing relative navigation and guidance trajectory data to the crew to enhance their situational awareness. In the course of developing the RPM techniques, the MOD team also had to make several enhancements to the RPOP application. These enhancements provide the crew with an accurate relative trajectory estimate during the RPM when no visual contact from the Orbiter to the ISS is available. These enhancements also result in a reduction to the mean propellant usage and a significant reduction in the variation in propellant usage.

The RPM technique has become a critical piece of the TPS inspection process and is utilized on every ISS docked Shuttle mission. Inability to perform the RPM would require an alternative (more challenging, less desirable) option to satisfy the TPS inspection requirements.

On STS-114, imagery from the RPM survey identified two protruding gap fillers on the underside of the Shuttle. Because of concerns that these protruding gap fillers might pose a danger to the Shuttle's re-entry and landing, an EVA was performed to remove these gap fillers.

The MOD team played a large part in the Return-to-Flight effort, and has successfully incorporated the wide-range of TPS inspection elements into their standard operational concepts and procedures. Development of the RPM techniques is another example of MOD's ability to respond to the changing environment and to shape creative solutions to achieve desired results. Once again, the MOD team was able to capitalize on their experience and their expertise to develop a technique that would serve as the foundation for crew safety and mission success.

STS-400 Rescue Mission Development

STS-400 was a conceptual flight and was designated as the Launch-On-Need (LON) mission to rescue the STS-125 crew in the event that a contingency would have prevented a safe return of the STS-125 vehicle. Because the STS-125 mission was a Hubble Space Telescope repair mission, and not an ISS docked mission, the ISS would not be available as a contingency "life boat" for the Shuttle crew. The proposed concept would provide the capability to launch a rescue mission within 7 days of the STS-125 launch if a contingency situation had been declared. This would require dual pad processing at KSC for STS-125.

Because this mission, if required, would be launched within just a few days of the STS-125 launch, the planning for this mission would have to be coordinated well in advance of the STS-125 launch. Like the various elements throughout the Shuttle program, MOD would treat this STS-400 mission just like any other (real) mission, and prepare all of the required operational products and procedures. MOD utilized a full team of discipline specialists to plan, design, analyze, and generate products for this mission. There would be separate operational technique meetings and STS-400 flight specific training sessions and simulations. Because of the unique nature of this mission, there would be several challenges facing every facet of the MOD community, including trajectory and vehicle control of dual shuttles, RMS grapple (mating) between shuttles, transfer of 7 crew members (some non-EVA certified) with only 4 EMUs, communication limitations, and flight control team management and mission control center utilization for two full flight control teams. MOD would also have to develop a plan to manage the STS-125 vehicle and limited consumables, depending on the contingency situation that required a crew rescue.

The MOD team was able to develop a complete mission timeline, operational procedures, and flight rules, which would dictate the necessary elements to ensure a successful rendezvous and capture of the STS-125 vehicle, an effective transfer of the STS-125 astronauts, and a safe return of both crews on the STS-400 vehicle. MOD provided crew training for the STS-400 objectives and participated in integrated simulations for this mission. The MOD team had developed a plan that would have ensured a successful rescue mission and was ready to support that effort, if required, after the STS-125 launch.

MOD's effort in the development of the STS-400 mission was an example of their ability to effectively respond to the Program's requirements and plan an entire contingency mission to ensure a safe return of the crew. MOD utilized their expertise in the vehicle and onboard systems capabilities, EVA experiences, crew systems and environments, as well as their expertise in rendezvous and vehicle attitude management.

Summary

The above serves as only a few examples of the many MOD success stories and contributions throughout the Shuttle Program. MOD is in the process of compiling and capturing all of their Shuttle unique knowledge, experiences, and lessons learned as part of their Directorate-wide Shuttle Knowledge Capture effort.

MOD has continued to evolve in all areas of their Plan-Train-Fly roles and responsibilities, becoming a more effective and flexible team, providing dependable and unfailing support to the Shuttle program customer. MOD has continued to take advantage of technology advancements to provide world-class facilities and mission support infrastructures. MOD has proven to be a resilient and flexible organization with the ability to effectively respond to changing environments and programmatic requirements. MOD's experiences during the Shuttle Program have served as a foundation for operations of the ISS and the MOD support provided to that Program. Over the last several years, the MOD team has also been able to make significant contributions to the Constellation Program. The MOD team has utilized their vehicle systems knowledge and operational expertise obtained during the Shuttle program to influence the Orion vehicle design and programmatic requirements.

The MOD team has been a vital part of the success of the Shuttle Program, consistently demonstrating their ability to provide mission preparation, training, and outstanding real-time support to ensure safe and successful missions.

References

¹ David S. F. Portree and Robert C. Treviño, "STS-49, The Rescue of Intelsat-VI 603", *Walking to Olympus: An EVA Chronology: Monographs in Aerospace History Series #7*, October 1997

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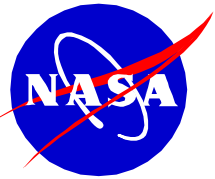
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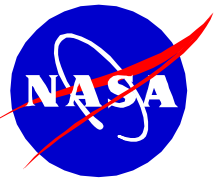
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MOD Responsibilities



- MOD's responsibilities traditionally fall into four categories:
 - Flight Design and Planning
 - Crew and Flight Controller Training
 - Flight Execution for Ascent, Orbit, & Entry
 - Facility Operations
- MOD is typically described as a “Plan-Train-Fly” organization with facilities support and utilization encompassing all of those aspects.



Scope of Mission Operations



Plan

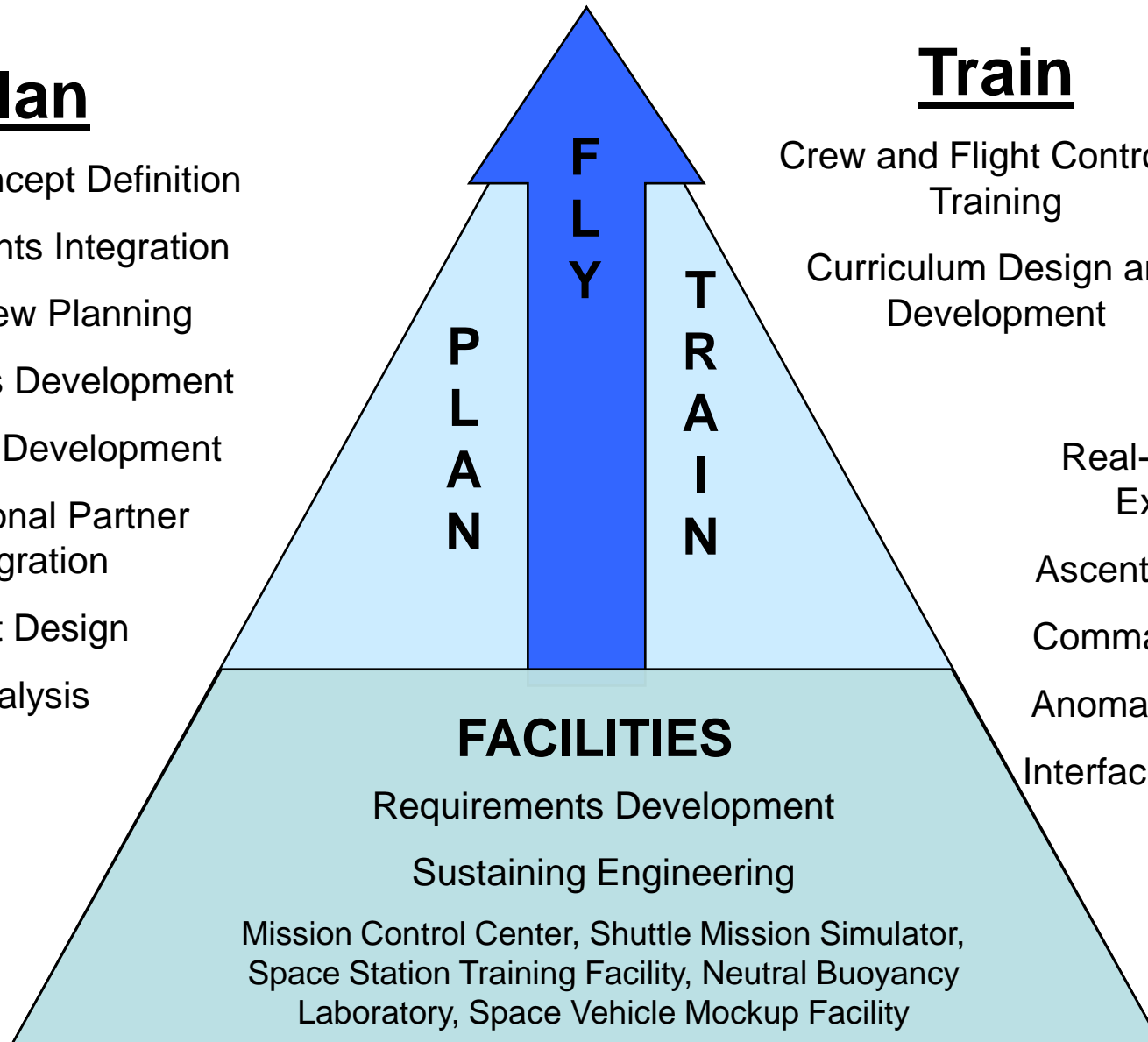
Mission Concept Definition
Requirements Integration
Flight Crew Planning
Flight Rules Development
Procedure Development
International Partner
Integration
Flight Design
Analysis

Train

Crew and Flight Controller
Training
Curriculum Design and
Development

Fly

Real-Time Flight
Execution
Ascent, Orbit, Entry
Command & Control
Anomaly Resolution
Interface w/MER and
MMT





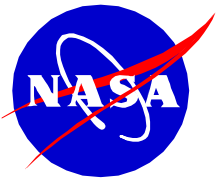
Prime Responsibilities



Flight Design and Flight Planning

- Space Shuttle and Space Station program and payload requirements integration
- Flight systems operations safety analysis
- Trajectory analysis and design
- Flight specific consumables analysis
- Flight Planning and crew timeline scheduling
- Systems and integrated procedures development
- Flight and ground software development
- Shuttle flight software data development
- Command and control systems development and reconfiguration
- Extra-Vehicular Activity (EVA) planning and procedures development
- Robotics activity planning and procedures development
- Onboard Flight Data File Development and maintenance





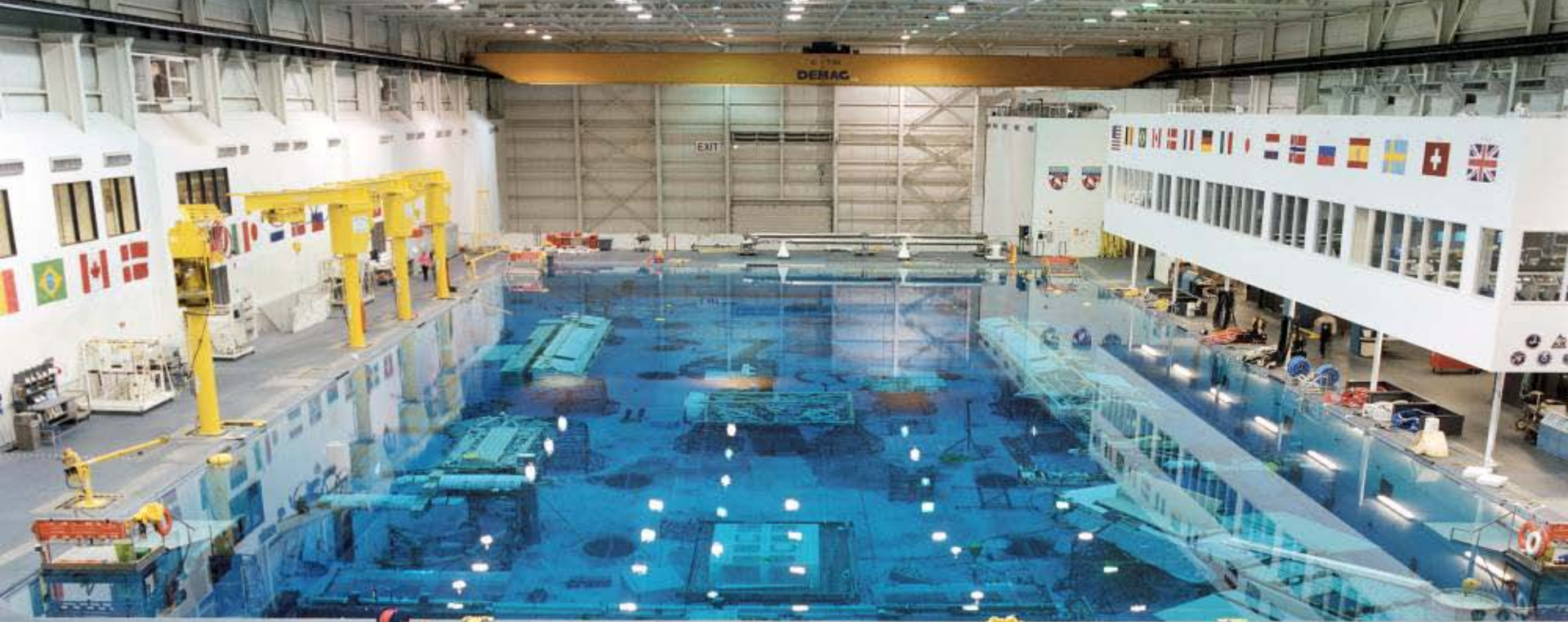
Prime Responsibilities (cont.)

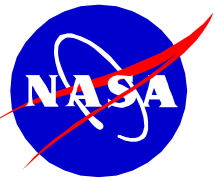


Flight Crew and Flight Controller Training

- Provide crew and flight controller training at the following major training facilities :
 - Shuttle Mission Simulator
 - Space Station Training Facility
 - Space Vehicle Mockup Facility
 - Neutral Buoyancy Laboratory
 - Part Task Trainers
 - MCC Training Flight Control Room
- Lesson and facility development
- Certification of critical personnel
- Simulation scripting and scenario development
- Training Instructors







Prime Responsibilities (cont.)

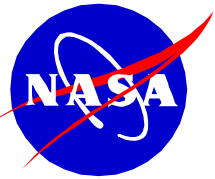


Mission Management and Flight Execution

- Real Time Operations
 - Mission Operations Director
 - Flight Directors
 - Flight Controllers
 - Spacecraft Analysis Managers
 - Integration between programs and International Partners
 - Mission Control Center- Facility
 - Operations Support Team



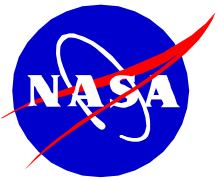
- The purpose of the Flight Control Team – of MOD overall – is to protect the crew and vehicle safety and achieve mission success
- FCT provides trained execution and oversight of nominal operations
- FCT provides informed and methodical response to malfunctions and emergencies



A Brief History of MOD



- Origins trace back to the Mercury Program at KSC in 1958
 - Chris Kraft founded the Flight Operations Division as part of the Space Task Group
 - Responsible for plans and arrangements for operation of the Mercury spacecraft during flight and control and monitoring of missions from the ground
 - Creation of the Mission Control Center, Flight Director and Flight Control Team functions and processes
- Mission Control operations moved to JSC (Manned Spacecraft Center) in 1965
 - Supported Gemini 3 as backup to KSC
 - Primary control for Gemini 4



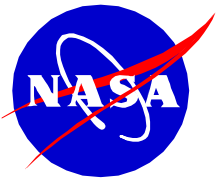
Operations Capability and Evolution throughout Shuttle Program



The evolution and advancement in human space operations is evident in the shuttle mission portfolio table below. Over the 30 years, mission complexity increased significantly and the operations capabilities were a key enabler for success.

Mission Type ¹	# of Missions	% of Portfolio	~ Time Period
Development & Test Vehicle	4	3%	early 80s
Interplanetary/GEO Satellite Deploy	25	19%	early 80s - late 90s
LEO Satellite Deploy/Retrieve	19	14%	early 80s - late 90s
LEO Research (micro-g, observations)	30	23%	early 80s - late 90s
DOD (classified) Missions	10	7%	mid 80s - early 90s
Shuttle-Mir Joint Missions	10	7%	mid - late 90s
ISS Assembly Missions	36	27%	late 90s - present
Total	134	100%	

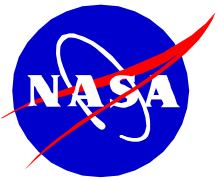
¹ Unofficial classification by the presenter. Many missions had cross-over objectives for multiple mission types (e.g. deploy and micro-g), but counted only once.



Operations Capability and Evolution throughout Shuttle Program



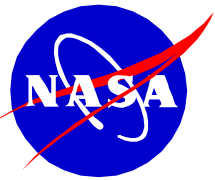
- Shuttle program is majority of ascent/entry and orbit experience for MOD's support to the NASA human spaceflight programs.
 - MOD was able to cut their teeth with the Mercury and Gemini programs; lay the foundations of MOD during Apollo and Skylab; but turned human spaceflight operations into science during the Shuttle program.
- New activities that were performed during the Shuttle program allowed MOD to develop and refine to associated operational processes
 - Satellite deploy/retrieval/repair
 - On-orbit assembly
 - Complex EVA activities
 - TPS inspection
 - In Flight Maintenance (IFM)



Operations Capability and Evolution throughout Shuttle Program



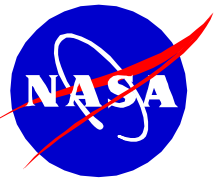
- MOD operational processes continued to evolve as the Shuttle Program itself evolved with changing mission priorities and requirements
- Over the years MOD has helped expand the certification envelope as new missions and new requirements necessitated pushing out the envelope
- Over the course of the Shuttle Program, MOD has refined the generic operational aspects for the Shuttle missions
- As one example of the increase in mission complexity and operational capabilities, consider the evolution of the Shuttle Flight Rules.
 - For STS-1, Shuttle Flight Rules contained 130 pages
 - For STS-132, Shuttle Flight Rules amassed 2600 pages
 - 1800 pages in Vol A (generic) and 800 in Vol C (joint) and Flight Specific



Operations Capability and Evolution throughout Shuttle Program



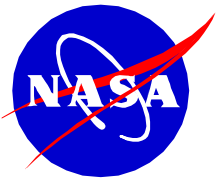
- **Controlled Operations baseline for all missions**
 - MOD has created a generic operating knowledge base; the “operator’s manual” for the human spaceflight systems
- **Evolution of the Flight Rules and Flight Techniques**
 - Developed and refined based on analysis, testing, complex mission simulations, and real flight experience.
 - Although these are based on the shuttle, many of the lessons learned and philosophies apply to all human spaceflight.
- **Flight Design efficiencies**
 - Evolution of flight design processes and products (to routine off-the-shelf flight design)
 - Learning how to fly (and land) a dynamic, high energy winged vehicle
- **Payload Operations**
 - Integration with Principal Investigators and International Partners
 - Payload Operators who are certified to a core base but who become experts on a variety of payloads over the course of the program.



Operations Capability and Evolution throughout Shuttle Program



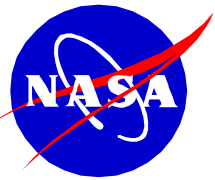
- **Flight Control Team Sizing in the MCC**
 - Reduction of team sizes and FCR/MPSR configurations throughout program
 - Larger team sizes and multiple positions for STS-1
 - Reduced / eliminated positions; FCR only for quiescent ops
 - As we've reduced the team size, we've increased the efficiency and capability of the team to match a much more capable vehicle (today vs STS-1) and refined tools and processes.
- **MOD Contractor Relationship**
 - MOD has continued to have a unique relationship with our contractor community; working in a seemingly "badgeless" society.
 - Very effective and efficient working environment – all working towards common goal of crew safety and mission success
 - Increased flexibility and utilization of our expertise.



MOD's Real-Time Ability to Respond to the Unknown



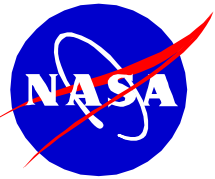
- MOD solutions and workarounds for unexpected failures have resulted in mission success on many occasions throughout the Shuttle program
- MOD has utilized expertise in IFM techniques, mission timeline replanning, systems/hardware management, and consumables management to accomplish mission objectives that would have otherwise been unachieved.



MOD's Real-Time Ability to Respond to the Unknown



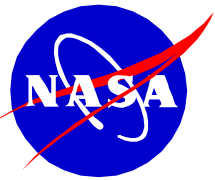
- **51-D**
 - “Flyswatter” Invention/Development to Recover Failed Syncom Satellite
- **51-F**
 - Multiple sensor failures cause Center Main Engine shutdown and “Abort to Orbit” situation; real-time flight controller call to inhibit limits to prevent potential for second engine shutdown
- **STS-49 Intelsat Repair**
 - Extensive development and replan required to utilize three crew for EVA to attach capture bar to Intelsat
- **STS-75 Tethered Space Satellite (TSS) Break**
 - With tethered mission scrapped, MOD developed new plans to conduct science as a free-flying satellite
 - MOD worked extensive plan to retrieve satellite (but Program decided not to pursue retrieval)
 - Worked Prop budgets, trajectories and burn plans, timelines, EVA and RMS techniques for retrieving wayward satellite, etc.
- **STS-87 Spartan retrieval**
 - Plan developed to do unscheduled EVA to retrieve satellite



STS-49 Intelsat Repair



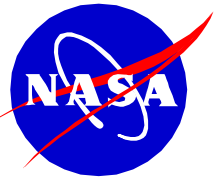
- Intelsat VI satellite launched on a Titan rocket but upper stage booster failed leaving the satellite in an orbit too and too unstable for use
- Plan was for Shuttle crew to capture satellite, install new booster, and release it. (entire procedure to be accomplished in one EVA)
- 2 EVA crewman – one to grab satellite and attach capture bar used to manually halt satellite's rotation
 - Once captured, both crewman would install the perigee kick motor and then release it using timed springs
- Two other EVAs scheduled on mission
 - ASEM experiments (building truss pyramid in PLB to demonstrate ISS assembly capability)
- Original Plan was Intelsat EVA on FD3, AESM EVAs on FD4 and FD5.



STS-49 Intelsat Repair (cont.)



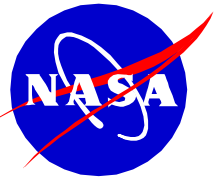
- Initial EVA unsuccessful in attaching capture bar
 - Caused satellite to “wobble” during attempts
- Program decided to try again next day (FD4)
- MOD
 - Major replanning effort for mission timeline (entire remaining mission not just FD4)
 - WETF ops (to determine what might be causing problem)
 - Developed “bump test”



STS-49 Intelsat Repair (cont.)



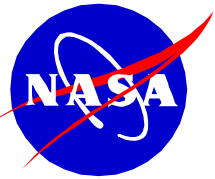
- Second EVA – still no joy after 5 attempts
 - Problem determined to be with capture bar (limited motion and simply could not grab a rotating satellite)
- MOD and mission managers discussed options
 - 2 man vs. 3 man EVA
 - No further attempts
- Other issues
 - Prop margin (mission duration implications)
 - ASEM objectives
 - PLB floodlights
 - Attitude timeline, comm plans, camera views, etc.
- Program decided to try again on FD6 and utilize 3 person EVA



STS-49 Intelsat Repair (cont.)



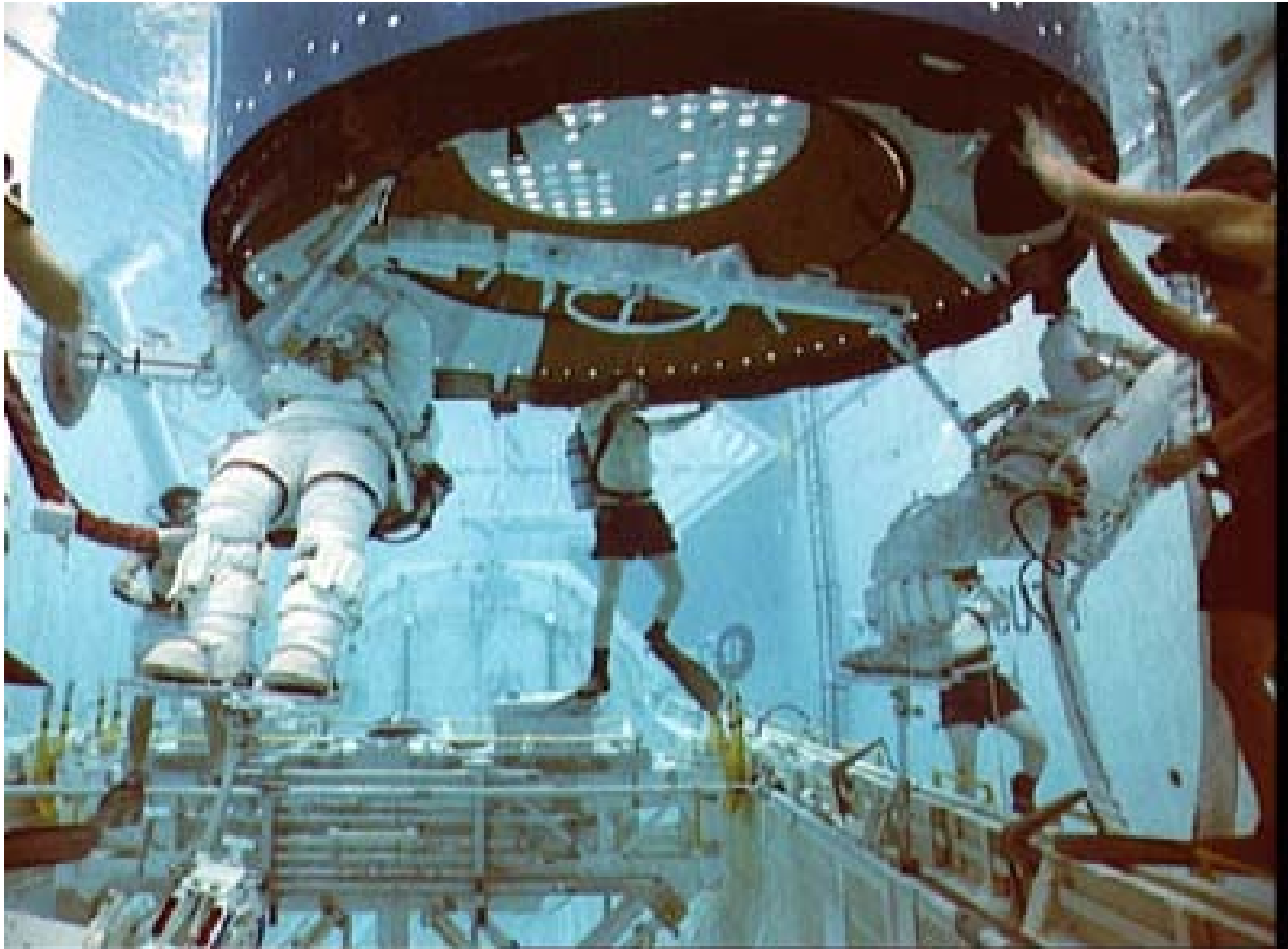
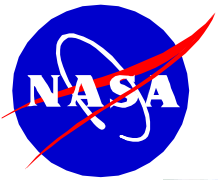
- 3 person EVA challenges (it had never been performed or trained)
 - EVA comm channels (normally configured for only 2 crew)
 - Choreography for 3 person EVA (tether options, satellite task options, who goes where/who does what, etc.)
- Major timeline replan
- Consumables management (Prop, Cryo)
- WETF activity
- EVA procedures
- Use of ASEM platform

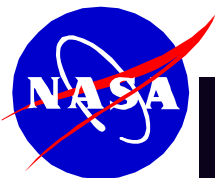


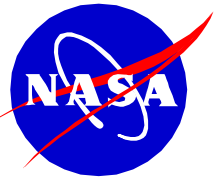
STS-49 Intelsat Repair (cont.)



- MOD worked around the clock to develop EVA procedures and uplink them to crew for review
- During the third EVA, crew assembled an ASEM platform, and was able to successfully grab Intelsat and install the capture bar
- Crew installed a new perigee kick motor and successfully released Intelsat
- Following day, crew performed 4th EVA to perform a subset of the ASEM tasks.
- MOD's performance in response to these unexpected events resulted in a successful accomplishment of the mission objectives



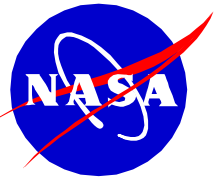




End of Program Knowledge Capture



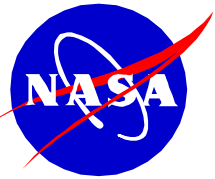
- MOD-wide effort to capture Shuttle unique operational information and lessons learned
- Capturing information that is at risk to be lost at end of program (and too costly to recreate in the future)



End of Program Knowledge Capture



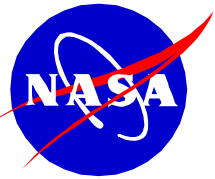
- Ascent/Entry Operations Training
 - Video documentary of scripted ascent simulations depicting various ascent related operations and failure scenarios
 - Interviews with Flight Directors, Training personnel, and Flight Controllers discussing Ascent (Entry) operational environment and associated protocols and priorities.
- Shuttle Knowledge Capture Effort
 - Captured Shuttle knowledge and information across MOD
 - Combination of existing information and creation of new Lessons Learned type information
 - Utilizing JSC Lessons Learned Database as repository



MOD Facilities Operational Experiences



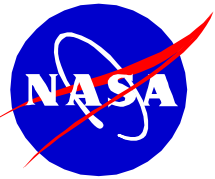
- MOD lessons learned and best practices of facility operations and management
- Evolution of MOD managed facilities in response to Program changes, operational experiences, and technology advancements



MOD Facilities Operational Experiences



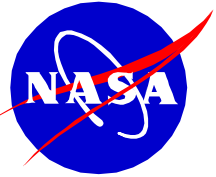
- What works and doesn't work in a control center (processes, technologies)
- Lessons learned from crew training in fixed and motion based simulators
- Off-line training environments
 - Reduced dependency on “big rig” simulator and control center
- Transition of operations from one control room to another
 - Old FCR to new FCR
- Technology advancements
 - Transition from Mainframe/dedicated consoles to workstation environment
 - Communication and data delivery improvements
- Remote access
 - Ability to view real-time mission data (and simulation data) from remote locations
 - Emergency Control Center Ops (EMCC)
 - In response to contingency situations where primary MCC would be unavailable (i.e Hurricane)
 - Ability to do operations (command and control) to Shuttle and ISS from location other than Mission Control Center in Houston (i.e. MSFC, Round Rock, Texas)



MOD Value



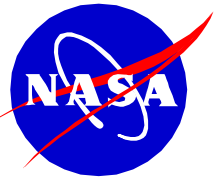
- MOD has a vast operational experience base that has been and continues to be beneficial to all of NASA's human spaceflight programs
- 30 years of flying a wide variety of Shuttle flights and establishing expertise in all aspects of the mission profiles (Ascent/entry, rendezvous (w/free flyers, MIR, ISS), Spacelabs, microgravity, astrophysics, satellite repair/servicing, Earth observation, RMS, EVA, etc.)



MOD's Benefit to Other Programs



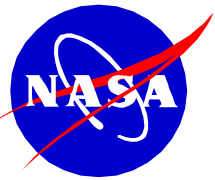
- MOD's operational experience and techniques have not only benefitted the Shuttle program but other programs within NASA, government and the commercial community.



MOD's Benefit to Other Programs



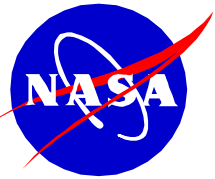
- How to fly (and land) a dynamic, high energy winged vehicle
 - Flight Design techniques developed and refined during Shuttle program are being used in other NASA programs
- How to prioritize and execute critical activities during high energy and complex events
- How to perform operations on a reconfigurable platform
 - Operation of the Shuttle (which largely stays the same) but in many configurations and carrying hundreds of unique payloads



MOD's Benefit to Other Programs



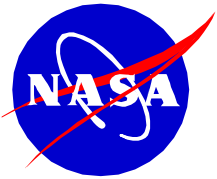
- EVA techniques
 - Shuttle provided the test bed to prototype and verify many of the ISS assembly techniques
- Joint vehicle operational techniques, including:
 - ISS; MIR; retrievable payloads; Spacelab
 - RNDZ / Prox ops techniques and joint vehicle attitude control
 - Joint atmosphere management
 - Joint power/data/comm management techniques
 - Integrated plans, procedures, flight rules, inventory management, etc
- Rendezvous techniques
 - Developed and executed during Gemini and Apollo, but refined to a science during the Shuttle program
- Orbital Debris Avoidance
 - Techniques developed and improved during Shuttle program have resulted in significant risk reduction capabilities of other government and commercial satellite operators
 - Allowed GSFC to develop collision risk reduction program for various Earth observation satellites
 - Essential in standard on-orbit ISS operations



MOD's Benefit to Other Programs



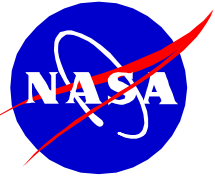
- MPCV support
 - MOD has been able to utilize our systems and operational experiences and expertise to influence the vehicle and operational design for MPCV.



MOD's Capability to Supplement Vehicle Capabilities



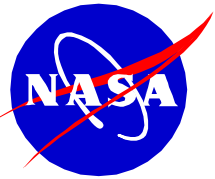
- MOD continued to utilize their Plan-Train-Fly knowledge, expertise, and experiences to expand and enhance the Shuttle baseline capabilities



MOD's Capability to Supplement Vehicle Capabilities



- Abort Region Determinator (ARD)
 - Enhanced ascent performance and failure response capability to determine abort mode boundaries
- Real-time replanning of mission timelines, trajectory, and consumables to maximize payload capability and mission duration in order to achieve mission success and program requirements
- Flight Control Team and Crew interaction
 - Mission success greatly increased through crew and ground teamwork
- Operational experiences that have allowed expansion (relaxing) of hardware constraints and further flexibilities with mission profiles
 - Operational considerations in the event of hardware failure
 - EOM determination
- Remote Controlled Orbiter (unmanned landing capability)
 - MOD's role in the development of the RCO capabilities (commanding, vehicle integration, procedures, etc.).



MOD Future



- MOD is posed to provide operational (P-T-F) leadership to any Program NASA chooses next (Orion, Flagship, Robotic precursor, NEO, Lunar, Mars, etc.)
 - Utilize Shuttle experience to influence vehicle and operational design of future missions
 - Developing operational requirements including lessons learned
 - Performing trade studies on vehicle and ground requirements
 - Generating design reference missions
 - Developing operations concept
 - Executing test and verification
 - Developing ground systems
 - Developing crew interface design requirements
 - Developing command and telemetry requirements