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ABSTRACT

This is a brief overview of logically expected advancements in the area of space simulation over the next twenty years. Current NASA Space Shuttle simulations will be upgraded to support more complex payload and on-orbit tasks. This includes the ability to integrate various remote ground facilities with a real time space mission simulator and an expanded use of efficient part-task simulations. Software compatibilities between simulators will increase and each simulator will have a more combined training and engineering role. Software development processors will be increasingly internetted to an integrated data processing system.

INTRODUCTION

Since the creation of the National Aeronautics and Space Administration (NASA) in 1958 the strides this country has made in space travel and exploration have been remarkable. A manned landing on the moon, exploration of our neighboring planets, Skylab and the Apollo/-Soyuz mission are proud achievements; however, in the last few years we have seen NASA bring the space program to the beginning of a continuing era where space can be used economically by a growing population of businesses, academic institutions, and even individuals.

The milestones of the past and the achievement of an operational Space Transportation System (STS) would not have been possible without equally remarkable advancements in space simulation. These advancements have been distributed into both manned and unmanned systems; however, the manned systems illustrate the growth and potential for both engineering and training simulations. For this reason, the primary focus of this paper is on the simulation of manned space systems. In addition, time does not permit the complete exploration of all applicable simulations; therefore, a group of major computational simulations was selected which provide a good illustration of future simulation trends.

CURRENT SPACE SHUTTLE SIMULATIONS

The full scale development of the Space Shuttle brought major changes in NASA's simulation capabilities and techniques. During earlier manned space flight programs, most of the training simulation was conducted in NASA facilities while the majority of engineering development simulations were scattered among various contractor facilities. Today the engineering and training simulations are increasingly combined in major simulation complexes, most of which are located on NASA sites. The emphasis of a particular simulator may be engineering or training but they all have dual roles. These major simulations are the Shuttle Mission Simulator (SMS), Shuttle Avionics Integration Laboratory (SAIL), Flight Simulation Laboratory (FSL), Shuttle Engineering Simulation (SES), Manipulator Development Facility (MDF), Software Production Facility (SPF), Space Vehicle Dynamics Simulation (SVDS), and the Vertical Motion Simulator (VMS). All except the FSL and VMS are located on the Johnson Space Center. The following paragraphs briefly describe the purpose and capability of each simulator.

The Shuttle Mission Simulator (SMS) provides a complete pre-liftoff to landing mission simulation. It is the primary device used to train flight crews and flight control personnel to a mission ready status. The visuals use a full digital image generation system which replaced older camera model boards. The SMS also employs extremely sophisticated environment and equations of motion models which provide an accurate simulation of in-space heating and cooling effects on Orbiter systems, the space to aerodynamic flight transition and accurate Orbiter and payload response to forces. It also uses actual Orbiter flight software which executes in flight-type General Purpose Computers (GPC's) interfaced to high fidelity system math models.

Co-located with the SMS, is a Network Simulation System (NSS) which simulates the real world Ground Space Flight Tracking and Data Network (GSTDN) and its associated interface to the Mission Control Center (MCC). The GSTDN is a worldwide network of stations, tied to the MCC through the Goddard Space Flight Center (GSFC) which provides telemetry, tracking and communication capability with manned space systems.

The NSS links the SMS and MCC together for integrated simulations. This presents a real time simulation of flight interfaces to both the crew in the SMS and MCC flight controllers. Integrated simulations allow the SMS to act as a real orbiter to the ground control system and exercise MCC operational data and communications links. The SMS-generated telemetry can dynamically drive the console displays in the MCC and it will react properly to uplink commands. This capability allows the rehearsal of crew and ground personnel interactions, flight planning and procedures validation, ground control of on-board systems practice, time critical decision making and team integration.

The SAIL was developed to provide validation of the Orbiter's Avionics subsystem. It has a full cockpit representation with an attached payload bay structure. The entire Avionics subsystem including GPC's, Multiplexers Demultiplexers (MDM's), wiring harnesses and data buses are all positioned as they are in the real vehicle. Real flight software is used with a multi-minicomputer system supplying feedback sensor data from simulated aerosurfaces, main engines, reaction control jets, etc. Real hardware can, however, be interfaced to the Avionics system in place of its software representation. Breakout and breakthrough boxes can also be positioned at various locations to simulate malfunctions. The SAIL is also used for crew training in that the astronauts are called upon to exercise operating procedures in the cockpit during validation simulations.

The FSL is a Rockwell simulator located at Downey, California and is similar to the SAIL in that it uses actual avionics hardware and flight software but lacks the full scale payload bay. The FSL has had an important role in development and validation of flight hardware, primarily in the entry environment. Occasionally, it also uses astronauts to man the cockpit during test runs.

The SES is a high fidelity engineering simulation emphasizing the Orbiter Guidance, Navigation and Control subsystem with all its sensors and effectors. It uses functionally represented flight software and has no actual flight hardware. This simulator has been used primarily for flight techniques and procedures development for all mission phases. It also has an active crew training role in a manner similar to the SAIL.

The MDF provides a realistic simulation of the Remote Manipulator System (RMS). It consists primarily of a mechanical representation of the RMS operating in a full scale payload bay and is controlled from a medium fidelity Aft Crew Station. Its major purpose is development of payload handling procedures, techniques and hardware. As with the SAIL and SES, this simulator provides an important role in crew training.

The SPF and SVDS do not have crew stations associated with them and are subsequently not used directly for crew training. Their resident simulations are, however, quite high fidelity. The SPF is used for validation of Orbiter Flight Software and production of the software loads to be flown on-board the vehicle. It uses a sophisticated Orbiter systems and environment model which interfaces with the flight software to accommodate the validation process. The SVDS employs an extremely high fidelity environment model for the trajectory analysis aspects of flight planning.

The VMS is found at the NASA's Ames Research Center in California and can accurately simulate the true motion of the in-flight Space Shuttle. This is used to analyze human performance, operational factors and physiological stress.

THE FUTURE

The simulators mentioned in the previous section were built to develop the Space Shuttle and bring it to an operational status. This goal has been initially reached; however, major changes in simulation concepts and hardware/software capability will be required to achieve future goals. These goals will initially cause an upgrading of some current simulators and phasing out of others. The later years should see the evolution of new systems but it is quite unlikely that we would see any that did not use or build upon existing facilities.

ENGINEERING SIMULATIONS

As the Space Shuttle matures through the 1980s, less and less simulation resources will be required to maintain the vehicle itself. These simulators will, however, not be decreasing but rather changing their utilization. Their dual role will become increasingly important as more demands for crew training come from an ever increasing flight rate. The engineering role itself will shift more to the detailed exploration of performance boundaries or investigations into any systems related area of interest. Development of vehicle hardware or procedures techniques relating to ascent and entry mission phases will gradually diminish and simulations will tend to shift more to on-orbit related activities. Procedures development in this area will continue to expand and hardware/software validations of payload interfaces will place ever increasing demands on the system. In addition, it is likely that new simulations will be developed to support expanded on-orbit capabilities such as Manned Maneuvering Unit operations and manned geosynchronous missions.

Specifically, the SAIL will continue on for many years as will the SES. The SAIL should see expansion of its capability to efficiently validate payload support devices. This has already been accomplished for such items as the Payload Assist Module-D (PAM-D) and Inertial Upper Stage (IUS) payload bay support equipment. It should also see a continuing role in validating hardware and software interfaces as a result of changes to the vehicle and as a diagnostic tool used in investigating avionics anomalies. The SES currently has a good on-orbit and payload simulation capability with a high fidelity dynamic Remote Manipulator System (RMS) simulation. Its on-orbit procedures development and crew training roles will continue to expand based on this capability and the ascent/entry simulations will be maintained for future anomaly analysis.

The SVDS and the SPF will also remain active. The SVDS should not see major changes but the SPF role will grow in importance. Its excellent Shuttle simulation model and real flight software could allow it to transition into an integrated data processing facility. This facility could supply systems and flight software to remote processors used for training and/or engineering development. It could also serve as the validation system for remotely developed software.

The MDF's role in RMS procedures development and validation as well as in crew training will additionally continue in the out years and, because of the full size payload bay, will be an excellent tool in developing future payload handling techniques.

The FSL at the Rockwell facility is scheduled to be phased out, with the SAIL assuming its role. The VMS at the Ames Research Center will be utilized much more for aircraft development projects and less for shuttle use.

In addition to the changes mentioned so far, development of new large space structures will greatly impact engineering simulators. These structures would provide the support for such items as large solar panels, unmanned space platforms and a permanent on-orbit space station. It is, of course, difficult to ground test zero gravity structures. Therefore, accurate engineering simulations are essential. Today this is possible but extremely time consuming due to the enormous computational requirements of structural analysis models. NASA does not currently possess the necessary computer resources to efficiently accomplish these analyses. It is likely that a careful study of model fidelity requirements, task modularizations and computer upgrades will be necessary to conduct this essential development activity. Expansion of space environment models may also be necessary to evaluate the long term effects of severe heating and cooling on large structures.

TRAINING SIMULATIONS

As the economic utilization of space becomes more developed, space systems will become more autonomous, automatic and reliable with crew training shifting from vehicle systems knowledge to task accomplishment. These tasks primarily include direct payload operations, payload support activities and coordinated ground/space operations for complex on-orbit tasks.

NASA's current simulation systems are oriented toward crew and vehicle safety. Consequently, a very high fidelity SMS orbiter systems and environment model is provided with nearly 3000 selectable malfunctions. The payload portions of the simulation are, however, quite limited. For example, the SMS RMS simulation uses a kinetic rather than a dynamic arm representation and the aft/overhead visual system is limited in resolution. It also lacks the color and scene content necessary for more complex on-orbit task simulations. (These aft/overhead visuals do, however, have an extremely wide angle of view and use a state of the art liquid light crystal projection system to obtain the best resolution possible for this type of system). In addition, the payload representations themselves are extremely limited and primarily emphasize orbiter interactions with payloads located in the bay.

Current simulator planning calls for major upgrades in order to support the increasingly complex on-orbit mission. The aft/overhead visuals should add color, brightness and the number of programmable edges for increased scene content. The RMS model should go to a dynamic simulation that could accurately simulate the action of the RMS grappled to a large mass and proper reactions to arm contacts with fixed structures or a free flying payload.

Payload simulation upgrades are trending to a separate, independent payload simulator. This simulator would have the computing power to provide a high fidelity representation of up to four payloads at one time. It would conform to a standard payload interface developed within a Shuttle mission simulator or an aft crew station simulator. The payload simulator would be able to generate downlink telemetry to and accept uplink commands from either an operational ground control center or a simulator aft crew station. The simulation would also include payload environment modeling for power utilization, heating and cooling, payload mass properties and equations of motion. In short, this simulator would provide a high fidelity payload simulation for in-the-bay and detached payloads. It also could serve as a real world payload interface to ground locations or to a Shuttle simulator for development of special procedures and to conduct crew training. An additional advantage of the payload simulator is that it provides a much more efficient and flexible use of simulator resources through independent software development and the ability to schedule stand-alone payload simulations that don't tie up the mission simulator.

Overlaying all of these simulation upgrades is an increasingly important requirement for efficient simulator reconfiguration. Space simulations are primarily payload or payload support related which require frequent reconfiguration to support different types of missions. This reconfiguration process is currently complex and unwieldy. The trend is toward standardizing as much simulation code as possible and using various data sets to build the proper configuration. These data sets would be set up in a cataloged computer file system oriented toward payload and mission characteristics. Simulations would be built by executing a series of prompt-driven run streams which would ask for appropriate data selections and resolve data conflicts. The data base for building simulations grow as real world payload development and historical flight data is added. An early version of this system is currently under development for NASA's SMS.

Another area that should experience rapid growth due primarily to advancements in microcomputer technology is that of part-task simulations. This will range from advanced Computer Aided Instruction Systems with CRT graphics to complex high fidelity part-task simulations using a realistic crew station or other real world type representation.

The future for part-task simulations indicates a much wider use of these economical and efficient devices. Many of the initial payload training simulations are expected to be on part-task systems. Many aspects of payload support activities also lend to this such as Extravehicular Activity (EVA), basic rendezvous and RMS procedures. As the demands for time on the full mission simulator expand, part-task simulation will grow in depth and scope. This will assure that the mission simulation is used only for procedure applications within the total mission environment and not for basic procedures instruction. Part-task simulations also have the potential of being linked together to form more complex and flexible training systems.

Integrated simulations should also experience major changes. Today the SMS/MCC integration has seen a limited expansion to include an interface to the Marshall Space Flight Center (MSFC) for Spacelab experiment simulations and the Air Force Satellite Test Center for STS 6 simulations. These integrated simulations should increase in sophistication and scope until it will be routine to run multi-organization real time high fidelity mission or payload simulations using operational data and communication links. The goal is to link together multiple facilities that all have time critical roles in executing complex and perhaps hazardous on-orbit tasks.

The mission simulator, in conjunction with a separate payload simulator, should be able to generate a downlink telemetry stream and accept uplink commands. This data stream then serves as the common element between all non-simulator facilities that need to participate in the integrated simulation. All data from and to the vehicle and payload simulator would go through a primary control center such as the MCC at JSC. This primary control center would then retransmit data and receive return data from participating control centers via operational data and communications links. Remote part-task simulations could also be brought in if necessary through a data interface directly into the mission simulator. Communications through the operational net would then bring all participants together for realistic task rehearsals capable of exercising data control and analysis, crew/ground coordination, outside agency interfaces and mission rule applications.

SPACE STATION, 2003

At this point, let us project twenty years into the future and envision what simulations are active and how they are utilized to support a fully operational on-orbit space station. This continually manned space station is orbiting in formation with a nearby unmanned experiments platform. Routine visits are made to the station by Space Shuttle Orbiters. Teleoperator Maneuvering Systems and Orbital Transfer Vehicles are permanently assigned to the station to visit the experiments platform and take and return payloads to geosynchronous orbit. On board systems are primarily autonomous although ground based computers are available via data link for high capacity computations and data storage.

Full scale development for the Space Station began in the late 1980s with gradual modifications and conversions of Space Shuttle engineering simulations. The major Shuttle software production facility was upgraded to an integrated data processing system internetted with various system compatible remote processors. The remote processors did most of the actual software development work but used the central processor to obtain new system and flight software releases and verify their latest builds. New facilities dedicated to Space Station software development were minimized. Computer upgrades were accomplished in a continuous evolutionary fashion keeping pace with advances in technology. This provided a fast, high capacity system to efficiently process huge structural analysis programs. Avionics development and validation was accomplished using a Space Station dedicated simulation similar to the SAIL but was again made compatible with the integrated data processing system so simulation software would not have to be separately developed.

Initial crew training was accomplished in a manner similar to earlier Shuttle training. Part-task simulators were used for systems and procedures familiarization while crew member participation in the avionics simulations provided additional procedures training.

The Shuttle mission simulations were still quite active so a separate Space Station mission simulation was developed. It was interfaced with the integrated data processing system and required less software model complexity due to system autonomy and an on-board automated fault isolation and reporting system. System malfunction training was subsequently minimized with systems management, systems operations, and various task accomplishments emphasized. Ground control was minimal after initial system checkout and subsequently a high fidelity downlink telemetry stream was not designed into the mission simulation. An offline telemetry generator was used to provide ground controllers with the initial systems management training. Another major factor in reducing the overall depth of the mission simulation was the ability to provide initial on-orbit systems checkout in an unmanned mode with the support of a nearby Orbiter.

The major simulation element in Space Station construction and in post operational expansion concerns integrated simulations. On-orbit assembly of major components is a complex and hazardous task requiring a coordinated effort of many people both in-space and at ground positions. Training simulations for these tasks involve internetting various simulations and ground sites. The Space Shuttle Mission Simulator and the Space Station Mission Simulator run together synchronously with data and communications flowing to a primary ground center. This center would then retransmit both data and voice to several secondary and/or support centers that are used during critical operations. Part-task simulations are interfaced to the Shuttle or Space Station simulator to add specific payload or payload support activities. A scenario would then be exercised with everyone participating in a realistic rehearsal of that activity. Various problem situations are introduced as required to assure all parties are sufficiently trained.

When the operational phase of the Space Station was reached, the integrated data processing system began to serve as a standardized system for all space systems software maintenance and operations. Hardware validation facilities used for Shuttle and Space Station development were maintained for validation of vehicle interfaces after hardware changes and checkout of new payload system interfaces. The part-task and mission simulations used for initial crew training were also maintained for new crew member qualification and proficiency training. The main difference over earlier Shuttle training systems, however, is that a repertoire of part-task simulations are maintained on-board the Space Station, executed on call in the systems computer and displayed to crew members through a CRT. The simulations are then used to maintain crew proficiency on critical procedures and provide lessons on various payload operations. Updates are prepared on the ground and uplinked directly to the computer to assure that all available lessons are current.

SUMMARY

The major trends that we can expect to see in space simulation over the next 20 years center around conservation of resources. Increased utility and flexibility of small microcomputers will greatly expand the use of part-task simulators which in turn lessen the burden of basic procedures training on the complex mission simulations. Integrated data processing reduces the cost of simulation software development and integration of simulations greatly increases the efficiency of training for complex tasks involving multiple organizations at various locations. The end result is that space simulation takes a form that is a natural extension of economic space operations. As the goal of economic exploration of space becomes a real possibility, whatever simulation advancements are necessary to achieve that goal will naturally precede it.

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