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Paper Session II-B - An Approach to Shuttle Evolution

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AN APPROACH TO SHUTTLE EVOLUTION

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ABSTRACT

The benefits of evolving the current Space Shuttle into a system that can meet our country’s manned space transportation needs for the next 30 years are numerous. To address Shuttle evolution, NASA has initiated several programs over the past 2 years, including Assured Shuttle Availability (ASA), “Technology Bridging,” and the Shuttle Evolution System Assessment (SESA) study. ASA is a planned upgrade program that focuses on near-term supportability and operational cost reduction issues. The “Technology Bridging” program, led by NASA’s Offices of Space Flight and Exploration and Technology, identifies key technologies for movement from the laboratory to “field” demonstrations on the Shuttle and future NASA programs. In contrast to these somewhat gradual changes, significant quantum changes leading to a “Block II” upgrade of the current Shuttle system are being explored under SESA.

This paper presents a systematic approach to upgrading the current Space Shuttle to a Block II system while building on and making use of more near-term upgrade plans such as ASA and Technology Bridging. Several options to block changes—based on requirements for increased reliability, improved robustness, lower operating costs, and overall enhanced capability—are discussed. Implications to flight and ground operations, and to the entire space transportation architecture, are also presented.

INTRODUCTION

The Space Shuttle program was originally intended to be relatively short. Four to eight orbiters, each certified for a 100-mission life, were to satisfy NASA’s optimistic flight rate of 60 per year. At that flight rate, system life was projected to be about 10 years.1 As the program became operational in the mid-1980s, somewhat more realistic flight rates of up to 24 per year were projected, extending the program life to an estimated 20 years.

More recently, and as a result of the Challenger loss, conservative rates of up to 12 flights per year have been estimated. Since the 100-mission-certification life still appears valid, the Shuttle program will continue for another 30 years.

This realization, that the Space Shuttle will remain at the core of our manned space flight activities until 2020, has led NASA to start implementing upgrade and evolutionary change programs. The upgrades, which affect all Shuttle elements, are aimed at reducing operational costs, improving safety and reliability, and increasing mission performance. In contrast to these somewhat gradual changes, significant evolutionary changes leading to a Block II upgrade are also being examined.

The benefits of evolving the Space Shuttle are numerous.2 As shown in Figure 1, the decision to upgrade the current system delays the requirement for a new costly system into the next century, when significantly new mission requirements and/or the development of new enabling technology may justify it. As Aaron Cohen, Robert G. Minor, and Joseph P. Loftus concluded in their paper delivered to the International Astronautical Federation, “It does not seem prudent to initiate a new system development as a replacement until there is a substantial program to provide significant new technology alternatives to those used in today’s Shuttle.”3
NEAR-TERM EVOLUTION

The first requirement to be met by Shuttle evolution is supportability. NASA has been addressing supportability issues under programs like Project 2020, which identifies components that are becoming obsolete and will not contribute to efficient and cost-effective operations through the year 2020. Once components and subsystems are identified by Project 2020 as not meeting operational requirements for the next 30 years, they become part of NASA's upgrade program, Assured Shuttle Availability.

ASA is designed to meet supportability requirements while emphasizing long-term operations cost reduction, improved safety and reliability, and increased performance. Figure 2 identifies the current upgrades being considered under the ASA program. Selection criteria for implementation are based on overall contribution to operations cost reduction, and safety, reliability, and performance improvements.

Rockwell's Space Systems Division (SSD) is currently under contract to study the multifunction electronic display system (MEDS) and the integrated orbital maneuvering system/reaction control system (OMS/RCS). MEDS has been a high-priority upgrade because of the increasing failure rates and part obsolescence of the existing cockpit hardware. MEDS will replace the existing electromechanical flight instruments, CRTs, and display driver and processing units with state-of-the-art hardware such as liquid crystal displays to provide the flight crew with a "glass cockpit."

The integrated OMS/RCS upgrade combines the RCS and OMS propellant storage and pressurization systems and stores the on-orbit RCS propellant in the OMS tank. This upgrade is also a high priority because it eliminates approximately 137 components, simplifies ground checkout and maintenance, reduces failure modes, increases reliability, and reduces subsystem weight significantly.

Rockwell is using company IR&D funding in 1991 to collect data that will help NASA make decisions on the other orbiter ASA items and anticipates NASA funding in 1992 to begin implementation.

In addition to the ASA program, Rockwell is contracted by NASA to identify subsystems that do not provide sufficient margin to contribute to high launch probabilities. As discussed above, various upgrades have been proposed for Shuttle evolution: some will result in additional performance margin, some will
provide greater margins of safety, and some will increase subsystem margin. The objective of this study is to determine which enhancements offer the greatest overall benefit to the Shuttle program by converting their additional margin into quantifiable improvements in safety, cost, and time lines. This study contract, referred to as the Shuttle Margin Utilization Study, was initiated in October 1990 and will be completed by June 1990.

NASA is also making significant investments in new technologies that will reduce vehicle processing time and costs. A NASA/contractor working group has been established to move new technologies in the area of automated on-board checkout and verification (OBCV) from the experimental phase into flight vehicles, including the Shuttle. Although the total benefits are yet to be quantified, the reduction in test personnel and test time will significantly reduce Shuttle orbiter operating cost.

To complement an OBCV capability, NASA is also upgrading the launch processing system (LPS). While the original LPS design was advanced for its time (1974), the system's limitations constrain its effectiveness for future launch processing applications and, hence, its long-term viability. A major design goal is to define a flexible architecture that serves as the core of a number of test and checkout applications.

For effective Shuttle processing at KSC, the Shuttle processing contractor needs access to the Shuttle design data base containing the Shuttle design drawings. NASA and Rockwell, the Shuttle orbiter contractor, are developing a Drawing Document Imaging System (DDIS) that will put several million up-to-date engineering drawings at the fingertips of anyone who needs Shuttle orbiter engineering data. The DDIS, which will be operational by 1992, will contain all engineering orders, parts costs, specifications, and drawings.
LONG-TERM EVOLUTION

The next step in Shuttle evolution is to test and validate technologies that have been examined only in the laboratory. Emerging technologies must be brought into use to establish the confidence required for them to serve as the basis of new designs. As part of its Technology Bridging program, NASA has identified key technologies that are ready to move from the lab to field demonstration.

An electrical actuation (EA) technology demonstration program has been initiated. General Dynamics will supply an Advanced Launch System (ALS) actuator to test simulated flight loads and dynamics. Rockwell’s SSD will be under contract to define requirements and develop an EA technology plan. The final result will be the implementation of EA technology on a flight vehicle (e.g., Shuttle, personnel launch system, advanced solid rocket motor). The EA Technology Bridging program development flow is shown in Figure 3.

Autonomous guidance, navigation, and control (GN&C) is another capability being examined by the Technology Bridging program. The program targets GN&C improvements for the Shuttle ascent phase, the first of which is an improved winds measurement system for launch that uses lidar. Future plans include the development of autonomous on-board algorithms for ascent, on-orbit, and entry phases that utilize advanced sensor technologies.

A central force behind the Technology Bridging program is Dr. Kenneth Cox, who chairs the Strategic Avionics Technology Working Group. The group’s charter is to “promote improved technology transfer..."
processes, such as bridging, between technologists, developers, contractors, and program managers" and to "provide a forum to support the development of a space avionics technology plan."\textsuperscript{5}

Additional bridging technology programs will be selected to gain the confidence required to apply more technologies to future programs.

**BLOCK CHANGES**

The final step in the evolution of the Space Shuttle system will require major and possibly quantum changes to achieve NASA’s objectives of a significant reduction in operational costs and increase in vehicle safety and reliability. In addition, new requirements emerging from programs like the Space Station Freedom, Space Exploration Initiative, and Extended-Duration Orbiter, as well as Earth observation missions, life sciences and microgravity research, and satellite servicing, require increased Shuttle capabilities and services.

The Office of Management and Budget (OMB) has collected the Shuttle operations cost data and compiled an FY 1991 Shuttle operations cost-per-flight composite (Figure 4). The data indicate that flight and launch operations account for 52 percent of the cost per flight, the remaining 48 percent comprising essentially hardware costs. Since hardware costs probably cannot be reduced very much, the significant reduction in cost per flight must come from the operations activities. Historical data pertaining to program “life cycle cost” have been researched and compiled. The relationship of life cycle cost to program maturity is presented in Figure 5: after full-scale development of a system, 95 percent of the program’s life cycle cost has been fixed. Therefore, to effect any significant reduction in the life cycle cost (operational cost) of the Shuttle program, we must backtrack to the system concept phase and make major changes in the systems and subsystems with high operational costs.

\begin{figure}
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\caption{FY 1991 OMB Shuttle Operations Cost-per-Flight Composite}
\end{figure}
The Shuttle Evolution Study\textsuperscript{6} was performed with the same NASA objectives defined above. The study results identified and prioritized the “top 20” candidate system changes that would result in operational cost savings, increased safety and reliability, and improved performance. The “block changes” listed below are representative candidate changes that offer important Shuttle system benefits.

- On-board system verification and checkout as well as health monitoring capability, with imbedded expert systems, would significantly reduce turnaround time, reduce operations cost, and extend the mean time between failures by reducing ground test requirements.

- Liquid rocket boosters will improve crew safety with their first-stage shutdown capability, which improves the abort options and engine-out capability, and will reduce the ground processing time. If the added performance is traded for margins to the extent possible, significant flight operation cost reductions could also be achieved.\textsuperscript{7}

- A composite/lightweight external tank and lightweight orbiter will significantly increase the Shuttle’s lift capability, which (when traded for margins) would allow lower main engine throttle settings. This would result in improved main engine safety and reliability, increase engine life, and reduce operation costs.

- Unmanned/manned orbiter capability offers the flexibility to perform a normal man-tended Shuttle mission, to deliver a critical payload to orbit without a crew, or to perform automated return and landing in extended-duration missions for minimum risk to crew or vehicle.

These modifications of Shuttle elements result in a safer, more reliable, more cost effective transportation system that will perform all identified missions for the next three decades.
CONCLUSION

The Space Shuttle is the fundamental building block of our nation’s manned space transportation program (Figure 6). Fiscal and technological realities require the Shuttle to evolve into a system that can meet our country’s needs for the next 30 years.

**Figure 6. Transportation Strategy for the Next 30 Years**

<table>
<thead>
<tr>
<th>PRE-STATION EXPANDED SPACE OPS</th>
<th>STATION DEPLOYMENT</th>
<th>STATION SUPPORT</th>
<th>UNMANNED EXPLORATION</th>
<th>MISSION TO PLANET EARTH</th>
<th>RETURN TO THE MOON</th>
<th>MANNED MARS EXPLORATION</th>
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REFERENCES


