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Paper Session I-A - Space Shuttle to Reusable Launch Vehicle

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ABSTRACT

The National Space Transportation Policy "establishes national policy, guidelines, and implementing actions for the conduct of National space transportation programs that will sustain and revitalize U.S. space transportation capabilities...". The direction to the National Aeronautics and Space Administration (NASA) is to "provide for the improvement of the Space Shuttle system focusing on reliability, safety, and cost effectiveness." as well as "be the lead agency for technology development and demonstration for next generation reusable space transportation systems, such as the single-stage-to-orbit concept."

With this vision, NASA has initiated Cooperative Agreement Notices between NASA and the private sector for X-33 (Reusable Launch Vehicle-Advanced Technology Demonstrator) and X-34 (Reusable Launch Vehicle-Small Reusable Booster) which would provide insight to a decision by December 1996 to proceed with sub-scale flight demonstration to prove the single-stage-to-orbit (SSTO) concept. This paper deals with operational issues which must be dealt with in order to achieve SSTO goals of reliable low cost space transportation and order of magnitude reductions in operating costs.

VISION

Reliable and affordable access to space is the stated goal of future space transportation vehicles. From an operational perspective, we believe that this goal can be achieved only when system operational functions drive vehicle design. Research should be focused on those areas which minimize the number of subsystems & fluids used, the total parts count, and the amount of testing required to validate system integrity.

In the development of the Reusable Launch Vehicle (RLV) a joint Government/Industry Operations Synergy Team (OST) was commissioned to ensure that lessons learned from previous space transportation programs were applied to RLV. The OST has developed a vision concept which is directly applicable to RLV and any next generation space transportation vehicle. This vision concept is based on the findings of the Access To Space Advanced Technology Team (Option 3)[1] and the vast experience base from previous programs. The Advanced Technology Team findings are contained in four basic requirements:

- Define the mission narrowly to transportation only.
- Apply modern advanced technology to design a simple vehicle with less complex subsystems and fewer elements.
- Avoid flight-to-flight certification through a prototype development and flight test program.
- Adopt a management philosophy that empowers individuals to make

decisions at the lowest possible level replacing today's committee and duplicative review process.

Building on this, the OST developed an RLV Operations Concept "Vision" which comprised ten goals focused on operational improvements which are geared towards minimizing ground test time and resource dependence while maximizing vehicle self-diagnosis, dependability and minimum servicing requirements[2]:

- Provide a simplified, **very highly automated** vehicle enabling **minimum periodic and repetitive maintenance** (aircraft-like) and resultent short turnaround time between missions (hours, not months).
- Strive to isolate vehicle ground processing from **dependence on facilities and GSE**. Routine, scheduled turnaround should replenish consumables only.
- Promote **vehicle health monitoring/management** systems and self-test at a level which supplies only operations and maintenance (O&M) anomaly related information that requires corrective action prior to next flight. Let the vehicle "talk" to the ground remotely for processing and maintenance needs. Incorporete special vehicle engineering instrumentation only on specifically assigned technology demonstration vehicles (i.e. X-33).
- Eliminate "flight readiness-style" vehicle certification for every flight. Provide **aircraft-style vehicle-type certificate** for repetitive commercial flight operations.
- Design-in **performance margins** and flight hardware allowances to **eliminate processing impact**, i.e., strive to eliminate unplanned work. Mission design and flight operations are **very highly** autonomous by design. No dedicated software maintenance function is required to support operations.
- Reduce **operations and hardware complexity** for maximum utilization of resources and reduce opportunity for human-induced system failures: Less "hands-on", less human factor.
- Employ near autonomous ground management planning at top levels. Focus on **automatic interactive scheduling** of flight vehicle, ground support fecilities, and support logistics.
- Adapt **minimum** standardized **payload** interfaces to assure maximum flexibility and affordability. The most affordable vehicle will be blind to payload needs; like a truck, not a hospitel lifa support system. Eliminate **payload impact** on the launch vehicle system infrastructure.
- Ensure joint participation AND application of the synergism aveilable between Operations, Avionics, Propulsion, Payloeds, and Vehicle Design to the preliminary architecture/vehicle concapt, and operations development process (i.e. Integrated Product Team - IPT). This entails **identification of technologies** that can enable development of a vehicle system meeting attributes of the *National Space Transportation Policy*[3].
- The **role of engineering** (concept, development, and technology) during the **operational era** will be to perform **continuous improvement** and **technology advancement** for **future market driven needs** (retain X-33 capability).

The goal of driving the total transportation system design rather than reacting to the vehicle design should result in the realization of overall economic goals associated with future spaca transportation systems. We are losing today's market as international competition continues to drive reduced cost of annual mass to orbit. Vehicle sizing should be optimized around identified POTENTIAL payload user requirements and not focused on a single user's needs. In order to promote domestic launch opportunities (market growth) we must rethink our current mind set and approaches to vehicle certification which are currently measured in months rather than hours.

During the course of the Commercial Space Transport Study (CSTS) the industry alliance recognized that "Early identification and definition of system attributes and requirements is essential to ensuring the transportation system meets the user's needs."[4]. Table 1, Common CSTS Attributes, is an overview of identified attributes which must be found in the next generation launch system as identified in CSTS Final Report in order for the system to be both operationally & economically feasible.

Table 1 - Common CSTS Attributes

Category	Attribute
Dependability	High probability of Launching on Schedule
Schedule	Minimum Advanced Booking Time
Reliability	> Current Systems
Cost	Minimum Cost Per Launch
Operations	Standardized and Simplified Payload Interfaces
Capabilities	• Support Multiple Payload Classes • Provide Delivery to Multiple Destinations • Provide On-Orbit Rendezvous and Docking Capabilities • Provide Delivery and Return Capabilities
Availability	High Probability System Will Be In An Operational Rather Than a Standdown State
Responsiveness	Minimum Response Time for Launching On Need

SHUTTLE EVOLUTION

During the Apollo Lunar Exploration Program it became apparent that the next step was a trip to Mars. In order to go to Mars, man needed to gain a thorough understanding of living in space for longer duration's than a moon flight. A manned space station in earth orbit seemed to be the answer; however, the cost of access to space in support of a space station was not supported by NASA's projected annual budget. The solution was an interim space station, Skylab, and the development of a reusable space transportation system, the Space Shuttle.

The economic plan used to develop the operations scenario for the shuttle was a five orbiter fleet with a projected flight rate of forty flights per year from the John F. Kennedy Space Center (KSC) and an additional twenty flights per year from Vandenberg Air Force Base (VAFB). Early analyses confirmed that forty flights from KSC could only be achieved if vehicle ground turnaround could be completed within 160 hours, hence the 160 hour turnaround allocation. The 160 hour allocation processing timeline included initial operations and safing, orbiter test operations, post flight trouble-shooting, Space Shuttle Main Engine/Main Propulsion System (SSME/MPS) operations, cargo operations, Thermal Protection System (TPS) maintenance & repair, maintenance & servicing, element integration, fluid servicing and countdown. Allocations were also developed for facility maintenance and turnaround. These timelines were accepted and used as program requirements/goals and assessments of the allocated timelines were performed. The process used to focus improvements at the launch site and to provide visibility to the shuttle program manager was the Shuttle Turnaround and Analysis Report (STAR). This report was updated on a quarterly basis by the

Shuttle Turnaround and Analysis Group (STAG).

The goal of operational efficiency was visualized in concept development of the shuttle and the STAR. This is illustrated in Figure 1, Artist Concept - Shuttle Mating With Payload.

Figure 1 Artist Concept - Shuttle Mating With Payload

This concept, dated April 8 '74, stressed the use of mobile platforms to gain access to the crew compartment and payload bay areas for reconfiguration of the vehicle. Additionally, the original shuttle concepts recognized the benefits of reduced recurring costs. This can be seen in the limited number of personnel supporting ground turnaround operations in the orbiter processing facility (OPF). The space shuttle transportation economics was determined using an operations scenario that was based on previously mentioned allocation timelines. Assessments of the design highlighted incompatibilities with the allocation timelines which required system modifications. However, because 1) non-recurring cost, 2) Design, Development, Test, and Evaluation (DDT&E) schedule, and 3) weight penalties were a higher priority than long-term operational benefits, most recommendations for a more supportive design were not adopted. Therefore, supporting the design was not compatible with allocated timelines or reaching the mission cost goal of $15 million/flight.

In order for a space transportation architecture to be affordable, vehicle design architecture must be driven by operations functions so that operations requirements are well understood before the concept is frozen. This will allow a complete understanding of operational requirements/economics which are required to provide program affordability. In the case of the shuttle, the operations concept was frozen before operational requirements/economics were understood and compromises to the concept were permitted well into the production phase in order to 1) try to reach system performance goals, 2) reduce vehicle weight, and 3) reduce development cost through utilization of old technologies from previous programs to minimize development risk in schedule and hardware. Each of these compromises resulted in changes to flight and ground hardware as well as the shuttle operations concept. In order for RLV to achieve its stated goals, similar compromises must be eliminated. If in the case of RLV, operational compromises are allowed, one might expect that the outcome would be similar to that illustrated in Figure 2, Shuttle Orbiter Columbia In Workstand.

Since 1979 five vehicles have been processed through launch facilities at KSC. In that time the average turnaround time for vehicle processing through the OPF has been approximately sixty days (3 shifts/day), five days through the Vehicle Assembly Building (VAB) (3 shifts/day), and twenty-two days at the launch pad (3 shifts/day). Due to the complexity of the vehicle and connections to ground support equipment, multiple vehicle service umbilicals are required. Connection and verification between the vehicle and the

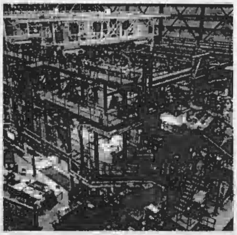

Figure 2 – Shuttle Orbiter Columbia In Workstand

corresponding facility to insure safety of personnel, facilities, and equipment. Each of these vehicle service umbilicals provide some combination of fluids, gases, ground power, and data to the vehicle enabling ground test capabilities, safing, operations and servicing.

These vehicle service umbilical connections are connected immediately after landing at either Edwards Air Force Base (EAFB) or KSC. A set of dedicated vehicle service umbilicals are connected at each ground station as the elements are processed through the respective facilities (i.e. Shuttle Landing Facility, Orbiter Processing Facility, Vehicle Assembly Building, Launch Pad, etc.). Each time an element is moved between ground stations, the vehicle service umbilical must be disconnected from one facility and reconnected at the next. In addition, system integrity must be verified at each facility before any processing operations can take place. The vehicle is dependent on these vehicle service umbilicals until T-31 seconds at which time the vehicle is operating on internal power controlled by on-board computers. This support the design approach drove a large ground infrastructure resulting in high recurring costs and lengthly processing times measured in months rather than hours.

In other words, this vehicle is highly dependent on ground connections and support services to perform ground procedures. The vast majority of these test procedures are required servicing, irrespective of scheduled maintenance or in-flight failures. As stated earlier, future space transportation systems should strive to isolate vehicle ground processing from dependence on facilities and GSE. By adopting this, the cost of recurring operations will be significantly reduced thereby achieving the stated goal of reliable and affordable access to space.

EVOLUTIONARY CONCEPTS

Since 1984 the government has investigated numerous concepts for the development of a replacement to the shuttle. Each of these concepts focused on the vehicle only and did not address the entire flight and ground systems. Major emphasis was placed on the reduction of flight element production costs and retained the support the design approach, starting with the rocket engines, then the vehicle, and then the ground facilities and support equipment required. It was recognized that operations experience was needed to evolve to a more operable approach for the future. However, due to priorities at the launch operations center, personnel with hands-on experience were not actively involved in these advanced study efforts. In many cases the concept was targeted to replace shuttle; however, there was no definitive plan to bridge the gap from shuttle until the new program was certified as operational. Additionally, the lack of definition of a mission model in many cases led to the premature termination of each effort.

The following is a brief overview of some of these concepts:

- **The Space Transportation Architecture Study** (STAS) recognized the need for an affordable space transportation system capable of achieving lower life-cycle costs with simplified and streamlined operations. STAS focused it's efforts in five areas: (1) logistics support systems (ground & space), (2) spacecraft modularization, (3) launch vehicle & orbit transfer systems, (4) technology assessment & development programs, and (5) mission control systems. Each of these arees drove architecture synthesis and systems development. While STAS attempted to drive system design, the evolutionary architecture approach encompassed as many as four different architectures over a fifteen year period while each one addressed upwards of four vehicles. The operations concept for each of these candidate architectures was complex and neither user friendly nor operationally efficient.
- **The Advanced Launch System** (ALS) architecture allocated a goal for cost to orbit. Unlike STAS which was a combination of reusable and expendable vehicles, the ALS architecture was comprised of expendable vehicles. ALS stressed high reliability, robustness, flexibility and cost. The ALS technology demonstration program was focused on reducing system complexity while significantly reducing program cost. With ALS being a DoD effort and Shuttle-C being a NASA effort congressional support was limited. One program was acceptable but the development of both was unrealistic. In the case of ALS, the emphasis on the reduction of flight element production costs did not necessarily equate to reduced operations costs.

Shuttle-C was envisioned to fill the gap between shuttle and ALS[5]. Using an unmanned cargo carrier in place of the orbiter, Shuttle-C was compatible with existing shuttle infrastructure and offered a heavy-lift capability (up to 150K lbs. to low earth orbit) within a four year window. In the spring of 1989 a Shuttle-C Users Conference was sponsored at Huntsville, Alabama to enlighten the user community of system capabilities and determine a preliminary mission model. The then Space Station Freedom was targeted at that time as a potential user in the space station assembly sequence and the logistics resupply missions. Due to sharing the development costs, the space station community was not ready to commit to using the Shuttle-C. The message from other potential users was "build it and we will come"; however, no one was willing to step up and commit to Shuttle-C. With no clear definition of annual utilization the program was ultimately terminated.

- **The National Launch System** (NLS) consisted of three vehicle configurations (1) a two stage heavy-lift launch vehicle (HLLV) capable of delivering 135K lbs. to low earth orbit -- NLS1, (2) a 1.5 stage vehicle capable of delivering 50 K lbs. to low earth orbit -- NLS2, and (3) a single stage vehicle capable of delivering 20K lbs. to low earth orbit -- NLS3. NLS1 and NLS2 utilized a common core and a common propulsion module. NLS2 and NLS3 utilized a common upper stage. NLS was a design to cost approach based on allocated cost targets. NLS cost models used cost estimating relationships (CER's) which had been in use for years. The lesson learned in NLS was, in order for true cost savings to be realized, these CER's must be evaluated against achieved actuals (i.e. Shuttle, Delta, etc.) so that the differences can be both understood and accounted for. If not, the goal of low recurring costs will be projected, but are not likely to be achieved. Throughout NLS concept development a new Space Transportation Main Engine (STME) was under development. STME concept developers recognized the need for product development teams and STME development was structured around this approach. Interaction between each of the PDT's helped to maintain focus of system capability design goals. Again the lack of a market and utilization goals was a limiting factor in concept development.

- **Access to Space** was "... a study responding to a Congressional request in the NASA FY1993 Appropriations Act."[6]. "The goals of the study were to identify the best vehicles and transportation architectures to make major reductions in the cost of space transportation (at least 50 per cent), while at the same time increasing safety for flight crews for the existing shuttle option by at least an order magnitude. In addition, vehicle reliability was to exceed 0.98 percent, and, as important, the robustness, pad time, turnaround time, and other aspects of operability were to be vastly improved. The study examined three major optional architectures: (1) retain and upgrade the Space Shuttle and expendable launch vehicles, (2) develop new vehicles using conventional technologies and transition from current vehicles beginning in 2005, and (3) develop new reusable vehicles using advanced technologies, and transition from current vehicles beginning in 2008."[6]. Like shuttle, the advanced technology option operations scenario was built on allocated timelines and an assumed set of launch site facilities (using existing facilities to the greatest extent possible). The approach again was to support the vehicle design and not design for support. In the case of affordable access to space, the question is, will a fifty percent reduction in recurring costs provide a competitive transportation system. Even more important, will the access to space concepts stimulate market growth in domestic launch opportunities.
- **The Reusable Launch Vehicle** (RLV)/X-33 is an outgrowth of Option 3 from the Access to Space Studies. In the observations and conclusions section of the report NASA states "... an architecture featuring a new advanced technology single-stage-to-orbit pure-rocket launch vehicle was recommended as the most attractive option. It has the greatest potential for reducing annual operations costs as well as life-cycle costs, it would develop important new technologies with dual-use in industry (such as composite vehicle structures for cars and airplanes), it would place the U.S. in an extremely advantageous position with respect to international competition, and would leapfrog the U.S. into a next-generation launch capability." [6]. The Cooperative Agreement Notices previously mentioned are the government's attempt to bring industry into a pro-active role in the development of requirements and the direction this concept will take. Additionally, industry is being tapped to share in the cost of the X-33/RLV to insure that vehicle designs indeed meet established goals of reliability and affordable access to space in an international market place.

THE NEXT STEP

In response to the President's Space Transportation Policy, NASA and other designated government agencies have responded by initiating three efforts:

- In response to the challenge of single-stage-to-orbit development, NASA has issued NASA Research Announcements (NRA's) and Cooperative Agreement Notices (CAN's) with industry leading to the development of a sub-scale SSTO prototype known as X-33, ultimately leading to industry's development and operation of a full-scale RLV.
- NASA's Space Shuttle Program has advocated the use of the shuttle as a

flying test-bed for common technology demonstrations with the RLV.

- The Department of Defense (DoD) has initiated an evolutionary upgrade path for it's current fleet of expendable launch vehicles (ELV). The ELV modernization program will play a helpful role in gaining experience in certain technologies regarding flight experience required prior to RLV operations.

CONCLUSIONS

In closing we feel it is appropriate to restate the experiences from previous launch programs which led to the development of goals in the OST RLV Operations Concept Vision:

- Reduce system integrity verification impacts through automation.
- Simplify and reduce support equipment damands and functions.
- Strive for one time vehicle certification.
- Eliminate payload impect to launch vehicle system infrastructure and operations.
- Empower PT's to design architecture/vehicle concept with a focus on reliability and affordability.
- Optimize annual/mass to orbit and single vehicle utilization and not cost/lb. to orbit in one launch.

Additionally, CSTS findings indicate thet both domestic and international launch markets require a system focused on market needs rather than one which is designed around one user and forced to fit all others. The CSTS final report also highlighted the benefit for user's to be involved in up-front requirements development and preliminary designs. To reiterate, "... the goal is to provide a system which meets all of the attributes of the market area."[4].

As advanced vehicle concepts are developed, concept analysis should be realistically evaluated by reviewing candidate design concepts and asking the following questions:

- What has changed in this design concept that realistically supports CER projections ?
- What reductions/functions have been minimized/eliminated as a result of this analysis in comparison to previous transportation systems which support infrastructure simplification?
- Based on the above, will the vehicle meet stated design and cost objectives without compromising either operability, maintainability, or supportability goals during system operation ?

Some efforts for the RLV have started off using the same approach as shuttle, but the pre-eminent lesson learned from shuttle is to design for support and not simply support the design. If you do what you did before, you will get what you got before.

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