Making the Case for Reusable Booster Systems: The Operations Perspective

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National Research Council
Reusable Booster System: Review and Assessment Committee
Washington DC, 05/07/2012

Contents

Kennedy Space Center

- KSC has a rich history of contributions to the programs that have defined US spaceflight.

- Since 1981 - 135 flights & flows over 3 decades of:
    - Reusable orbiters, propulsion, engines
    - Expendable external tanks
    - Refurbishing solid rockets
    - Facilities, control centers, launch pads
    - People, integrating diverse organizations
    - Block upgrades, technology, and operations improvements
    - The preparation, on-ground integration, testing and launch of hundreds of scientific payloads, crews, and a Space Station

- *And contributing this knowledge gained to the questions – what's next? What has been learned?*

Kennedy Space Center and Reusability

- The original notions of Reusability and Shuttle orbiters were about an operable system achieving dramatic improvements in operational complexity, reliability and maintainability.

Circa 1970's Space Shuttle reusable orbiter concept of operations

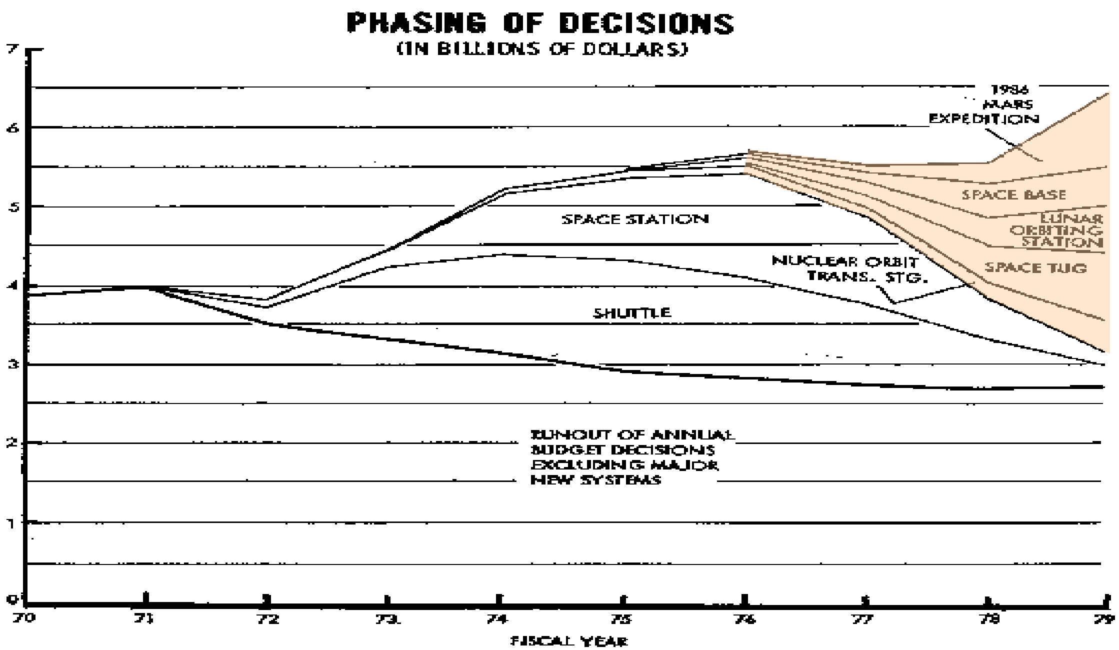
For future reusable systems, we will apply abundant knowledge and experience.

What worked…
…and what didn't.

← What was once envisioned for the very visible technology, vehicle, facilities and people

Kennedy Space Center and Reusability

- Past advocacy about having Reusable elements in a space lift architecture stressed long term budget benefits.



Mars, Lunar…
This future never happened.

What would result from what was envisioned? Numerous exploration advances within unremarkable budgets.

What's new is old? Report of the Space Task Group-1969, NASA Historical Reference Collection, NASA History Office, Wash., D.C.

KSC and the Air Force Reusable Booster System

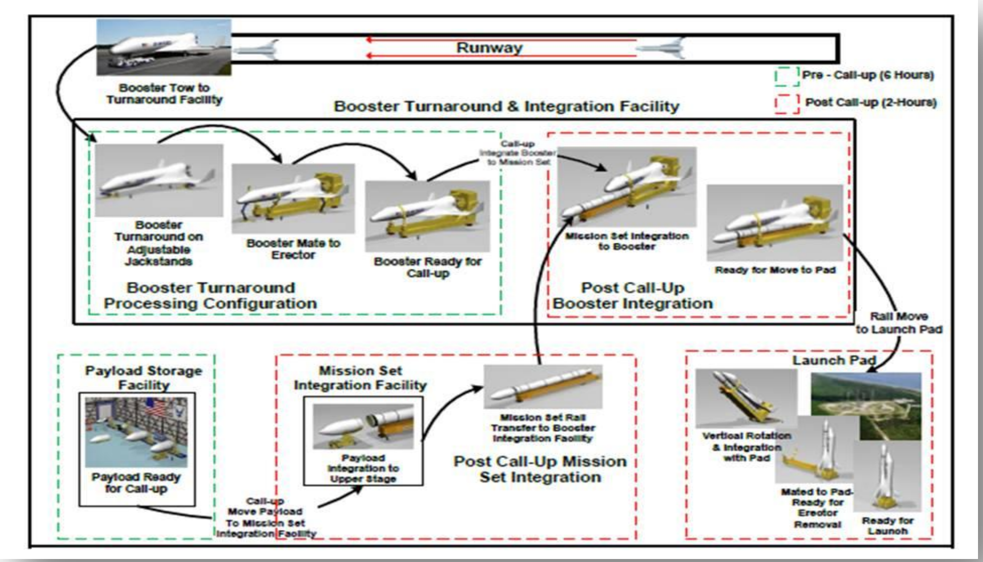
- Collaboration with AFRL has been ongoing over the last decade.
- Current KSC collaboration with AFRL emphasizes:
  - Connecting an operational vision to traditionally non-KSC areas such as research and technology directions, development, and manufacturing/production, reusable and expendables.
  - Applying the knowledge and experience of working with industry over decades on the only operational launch system with a major reusable element – Shuttle orbiters.

KSC and the Air Force Reusable Booster System

- 2010: KSC collaborated with the Air Force Research Lab (AFRL) to develop a "CONOPS" document for the AF RBS.
- Finding: Designing to assure the systems integrity of the vehicle can be maintained in normal turnaround operations was found to be key going forward to achieve *the necessary combination of RBS responsiveness and cost.*

You can buy responsiveness, up to a point, beyond which buying more increases the risk of programmatic failure (due to cost).

To go beyond the barriers to responsiveness – the AF RBS program is planning at inception, bringing in diverse operator experience.

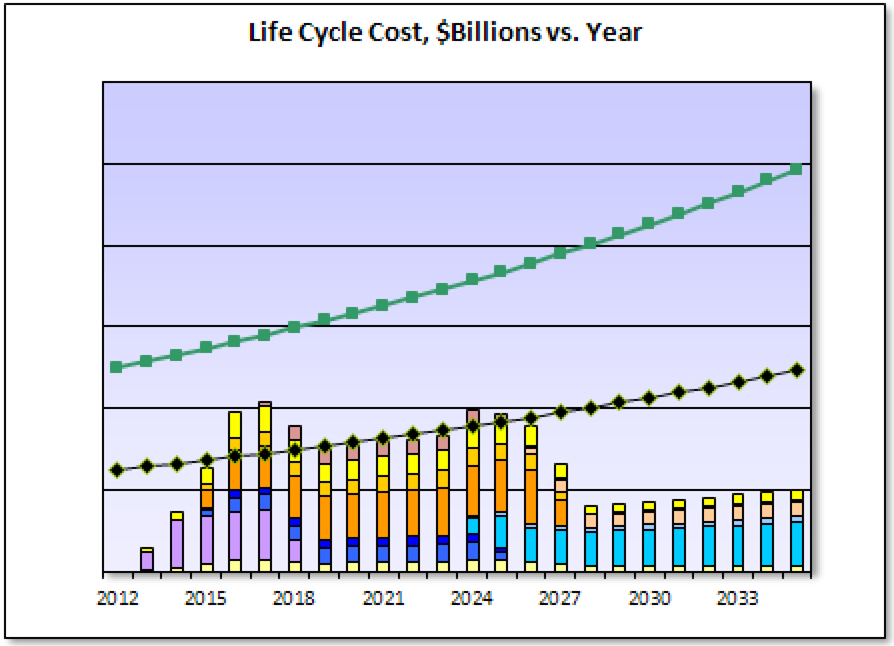


PUBLIC: Figure – Conceptual Operational Flow from the "*Reusable Booster System, Concept of Operations, A Ground Systems and Ground Operations Analysis for Rapid Response Orbital Space Delivery*". Available to the public at the NASA Technical Reports Server, *ntrs.nasa.gov.*

KSC and the Air Force Reusable Booster System

- 2011-12: KSC continues it’s collaboration with AFRL
  - Life-cycle cost modeling and analysis
  - Defining operable designs and technology
  - Overall integrating our data and knowledge into RBS planning
  - Identifying drivers of life cycle scenarios

- Ground rules and assumptions as scenarios.
- Methods emphasizing *connections* between potential actions, both programmatic and technical, and outcomes, responsiveness and cost.
- Robustness through understanding uncertainty and context.



Notional life cycle cost phasing scenario through a given year for a unique set of technical and organizational design variables.

The Committee's Task

- The questions of this committee about the Air Force Reusable Booster Systems are the same questions KSC has lived, breathed and labored to understand - for decades.

"the **criteria and assumptions** used in the formulation of current RBS plans;
--the **methodologies used in the current cost estimates** for RBS;
--the modeling methodology used to frame **the business case** for an RBS capability including:

--the **data** used in the analysis,
--the models' **robustness** if new data become available, and
--the impact of unclassified government **data** that was previously unavailable and which will be supplied by the USAF;
--the **technical maturity** of key elements critical to RBS implementation and the ability of current **technology** development plans to meet technical readiness milestones."

Contents

Productivity (Flight Rate) ═ Growth

- Flight rate does not cure, solve or otherwise make a reusable vehicles business case. It is “why” –because we seek to grow an industry or capability, not “how”.

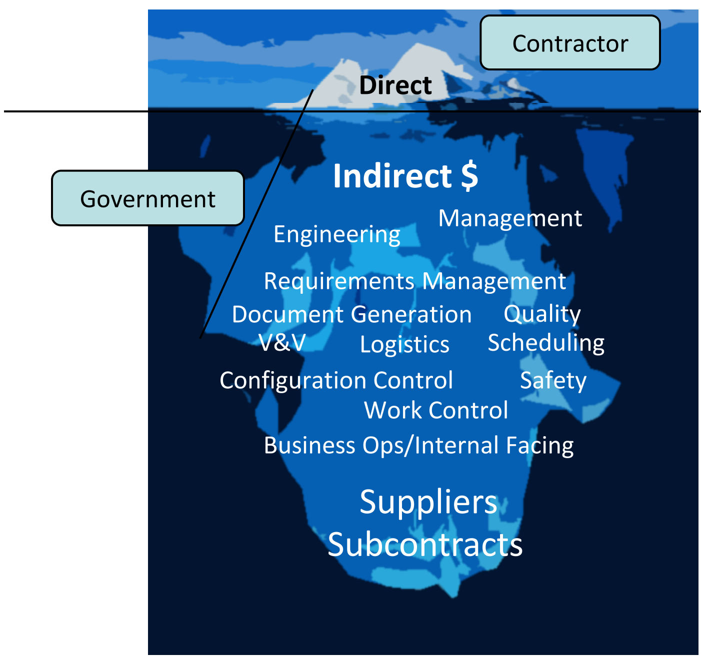
- How to frame a business case for any Reusable Booster System is a question interchangeable with:
  - How do we wish to grow the number of US space launches per year, and the space launch industry that provides these?

- If we assume an ever increasing growth in our desires for mission capability, and budget growth unlikely to ever match that growth in our ambitions – then, Productivity is key.

- Traditional thinking uses flight rate to justify reusability.
  - Reusability will be justified assuming a desire to go beyond the limits of improvements possible with only expendables.
  - Flight rate demand – separate from flight rate capability, potential supply – can encourage, or drive, the creation of low cost, more responsive systems, but responsive, low cost systems are not caused by high flight rates. (More ahead).
  - Responsive, high flight rate, or surge capable systems, at lower cost, are a supply-side result, caused by improved vehicle, organization and infrastructure, by design.

Productivity and Costs (Price) Are Inseparable

- Most aerospace space transportation costs are contractor costs.
  - R&D, development, production or operations (ground or flight)
  - Shuttle, ELV and other historical data
- Most contractor costs are indirect costs, far away from a vehicle, facility, far from the touch, close-in effort at hardware/software.
- Direct productive effort and their costs are the tip of the iceberg.



↑ Visible, closer to hardware/software

↓ Less visible, farther away from the flight/ground/production/development of flight hardware/software/infrastructure

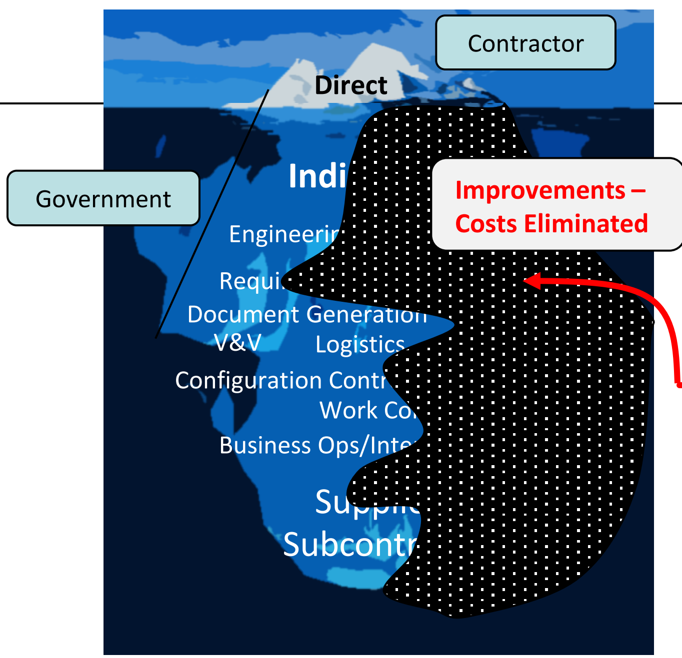
These indirect costs dampen demand, which favors a supply, a flight rate, at current levels.

Life According to Aerospace

…ref. "the methodologies used in the current cost estimates for RBS"…and "the data used in the analysis"

Technology is not just Technical

- Worthwhile cost estimates include methodologies that explore the attributes of *efficiency* of the performing organization (indirect), process and practices, fixed costs, and their supply chain management (SCM), moving materials *and information.*
- What is different in process/practices (P/p) and SCM technologies? What is their connection to lower costs vs. historical data?



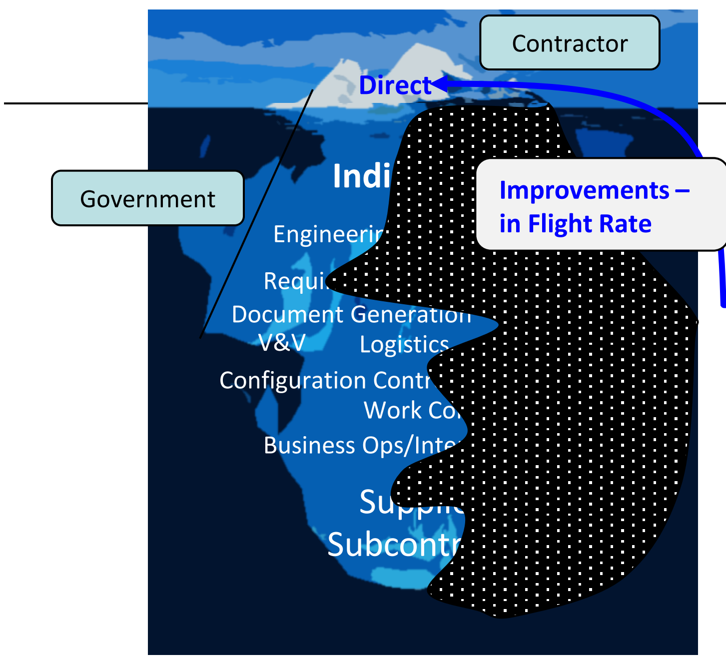
Improvements in COST *at same productivity*

Technology is the making, usage, and knowledge of tools, machines, **techniques**, **crafts, systems or methods of organization** in order to solve a problem or perform a specific function. It can also refer to the collection of such tools, machinery, **and procedures**.

…ref. "the methodologies used in the current cost estimates for RBS"…and "the data used in the analysis"

Productivity → Costs → Technology

- Once affordability is achieved, efficient organizations can take advantage of enabling "technology" for improving their "direct" effort/effectiveness, producing MORE flights, responsiveness, a HIGHER tempo of operations or other unique product/services.
- Now the system can scale. Flight rate, sustainability, responsiveness, and industry revenue/growth can follow *causally.*



Then TECHNOLOGY ***for greater productivity***

-more electric vehicle, EHA's, EMA's
-non-toxic, higher Isp, more maintainable propulsion
-health management
-automated umbilical's and handling
-simpler propulsion, ceramic NFS engine parts
-materials advances , composites, aluminum lithium…more.

…ref. "the methodologies used in the current cost estimates for RBS"…and "the data used in the analysis"

Investment Choices (R&D) Connecting Productivity (why) to Costs (how) and Technology (what) are about Supply

- Most of the insights about improving life cycle costs could apply to expendable systems as well as reusable systems.

- For expendables, promising confirmation of these insights can be found in the Space-X Falcon 9 developments.
  - Cost of Falcon 9 development, initial production and test flight (not recurring operations) has been [1,2]confirmed by government analyst to have been between 10% to 32% of what government models would otherwise have required.

- KSC "iceberg" data and later models would have confirmed this promise and the viability of these connections over a decade ago.

(1) **PUBLIC**: Commercial Market Assessment for Crew and Cargo Systems, Pursuant to Section 403 of the NASA Authorization Act of 2010 (P.L. 111-267), Appendix B, April 27, 2011. Available at http://www.nasa.gov/pdf/543572main_Section%20403%28b%29%20Commercial%20Market%20Assessment%20Report%20Final.pdf

(2) **PUBLIC**: Falcon 9 Launch Vehicle NAFCOM Cost Estimates, NASA Associate Deputy Administrator for Policy, August 2011. Available at: http://www.nasa.gov/pdf/586023main_8-3-11_NAFCOM.pdf

Investment Choices (R&D) Connecting Productivity (why) to Costs (how) and Technology (what) are about Supply

- Advancing hybrid RBS systems means applying the previous knowledge to both expendable and reusable components, their infrastructure and organizations, and planning for acquisitions.

- As confirmed in many analysis - an eventual *direction* toward full or greater reusability occurs as the cost advantage or “ROI” of reusing elements in operations, even at higher one-time development or production costs, is more advantageous than the cost of manufacturing expendable elements for each launch.
  - Albeit - most such past analysis by industry et al, including assumptions, causal links, drivers, or absolute values require much improvement to become a rigorous basis of estimates.
  - KSC is now assisting AFRL in life cycle costing of RBS.

…ref. “the methodologies used in the current cost estimates for RBS”…and “the data used in the analysis”

Productivity (why) → Costs (how) → Technology (what) → Supply → Demand (who)

- Supply must meet with demand. esp. given what may be an inelastic market *as currently structured*.

- Flight rate capable systems of the type envisioned for Air Force Reusable Booster Systems would have one type of demand, the DoD customer seeking responsive access to space et al (at some acceptable cost, relative to other choices, budget available, etc).

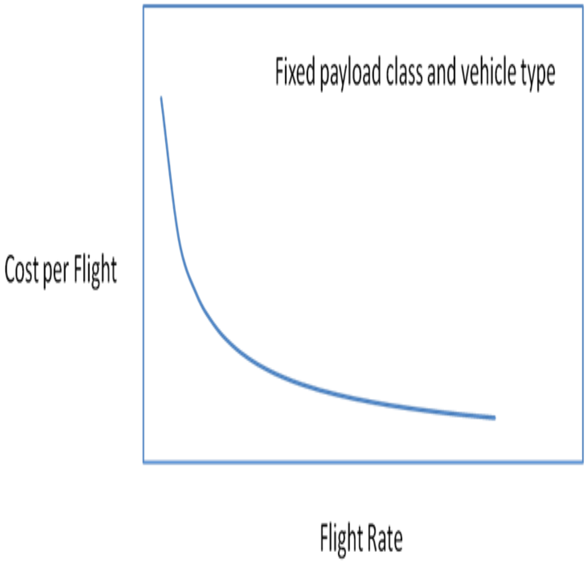
- In making the case for a reusable vs. expendable system, total cost of ownership, the result of assuming just a single user, may preclude justifying the desired capability (responsiveness, et al).
  - To address this, new business models, including commercial, must inform RBS business case analysis.

Back

Productivity (why) → Costs (how) → Technology (what) → Supply → Demand (who)

- Demand/flight rate can encourage supply/low cost.
  - Assuming a competitive environment.
  - Assuming a scalable system in the first place.
  - Not as a cause, but as an incentive.
  - Responsive, high flight rate, or surge capable systems, at lower cost, are a supply-side result, caused by improved vehicle, organization and infrastructure, by design.

- Relationships here are also about the “net” sum behavior of industry players in such an environment.
  - Poor players would not manifest the pronounced curve, instead being relatively flat; these would be eliminated by players with better curves as these meet supply.
  - The relationship curve over time becomes a “net” industry effect, a sum over providers.



Notional *- such a flight rate to cost relationship may bear on “the criteria and assumptions used in the formulation of current RBS plans” …as the case for an AF RBS matures.*

Productivity (why) → Costs (how) → Technology (what) → Supply → Demand (who)

- RBS costs analysis should explore amortizing ownership costs through other business case development
  - e.g., Commercial – other uses left to the private sector to decide and develop as business cases
  - e.g., Propellant depots – as an example of other government demand stimulus (NASA, exploration)
  - e.g., New industry models/structures – operators independent of manufacturers (re. Backup 1, 2, 3)

- Current KSC support to the AF RBS is strengthened and informed by:
  - These factors integrated into life cycle consideration
  - Previous such attempts (that failed), such as the lessons of commercial factors in the EELV program in the 1990’s

Risk and Uncertainty

- Based on our collaboration with AFRL, the "technical maturity of key elements critical to RBS implementation" are being addressed through technology development, testing, and plans for pathfinders and demonstrators.
  - Enlisting KSC experience to develop a rigorous foundation for:
    - Understanding industry costs and implications for an RBS
    - Where improvements are required
    - Defining actions where improvements are required and their link to productive, responsive, operational systems
    - The link between far term operational systems and near term actions for improvement in R&D, demonstration, development, production

…ref. "the technical maturity of key elements critical to RBS implementation…"

Risk and Uncertainty

- Risks to further address include:
    - Industry / industrial base capability to "show up", to improve on costs, to implement the aforementioned knowledge via specific new ways of doing business (NWODB).
        - Then, our understanding in acquisition of a companies/industry readiness to execute known, details of NWODB (addressing cost and schedule) and technology (addressing outcomes, esp. responsiveness).
        - Confidence.

    - RBS business model definition – encouraging competition, a commercial aspect, and other aforementioned strategies.

…ref. "the technical maturity of key elements critical to RBS implementation…"

Risk and Reliability

- The responsiveness and reliability of an RBS system are a whole.
    - Volume of production enables learning, expendable element especially, but also reusable element and system infrastructure.
    - A design / organization geared for responsiveness, which also meets programmatic / cost goals, enables more flights within any resource constraints. More flights, more learning, equals more reliability as system improvements are integrated.
    - Reliability on the ground, from production through to servicing, and preparations for flight, is inseparable from mission reliability, in flight.

Summary 1 of 2

- The knowledge and experience exists with which the AF RBS program can succeed, meeting objectives for their desired combination of responsiveness and cost.

- Low-hanging fruit is abundant at the programmatic level.
  - Risks are in scaling, acquisition and maintaining the connections between actions at the design and organizational level and program objectives.

- Challenges are in productivity, realizing the full advantage of the reusability and enabling technologies in the initial hybrid system.

- KSC collaboration with AFRL RBS is communicating these same themes in detail, supporting their quantitative analysis and qualitative understanding for integration into program planning.

Summary 2 of 2

- The AF RBS planning is on target with pathfinder / demonstrators, flight tests, test-beds, and operability ground experiments.
  - At a fidelity reflecting on (1) flight segment effectiveness (flyback, deploy) and/or (2) ground segment effectiveness (responsiveness, cost, reliability, maintainability, the “-ilities”)

“…learning through doing…”

Recommendations

- Recommend continuing the rigorous connection of actions to costs to productivity in RBS life cycle planning with a firm basis in experience, data, and knowledge to mature the definitive case for Reusable Booster Systems.

- Risks in business models, especially competition as a factor, and industry’s ability to transform programmatically, must inform the measures of possible outcomes
  - Outcomes - achieving combinations of responsiveness and cost.

Questions?

Backup

Growth, Flight Rate and Productivity vs. Paths

- [1]Disruptive innovation path
  - A new product or technology of inferior performance to existing product lines nonetheless meets a demand.
  - New markets arise.
  - Eventually the new market defined by this supply/demand disrupts the existing market, achieving and exceeding past performance.
- Maturation path
  - Productivity advances define investments.
  - e.g., new trains, oil rather than coal, each cost more up-front, and each cost more to operate, per year.
  - The investment is favorable through the metric of greater productivity: The number of passengers that can be served with the investment increases, increasing total yearly revenue, even as per passenger mile costs (and prices) drop, which further encourages demand.
  - Assumes growth of the total demand is possible.

1. "The Innovators Dilemma" available at http://www.businessweek.com/chapter/christensen.htm

Cautionary Observations on Life Cycle Costing

- Beware cost estimates where there is ANY cost as an input.
  - Understand the limits of such analysis when costs are inputs.
  - Useful in "what-if's".
  - These are more fairly called "calculations", or the integrating of information, but are not true "estimates".
  - Garbage in, garbage out.

- Rigorous life cycle cost estimation and business case development is characterized by defining actions as causes of costs.
  - Cost is an output of actions.
  - Actions by design, both technical (flight technology, ground systems, vehicle design) and non-technical (organizational technology, processes, practices, and business approaches).
  - Demand should be an element met or not by these actionable scenarios, not a cure for poor design.

Industry Operators Independent of Manufacturers 1 of 3

"Vertical integration does not appear to be a systemic problem today but warrants caution.

The Task Force found little evidence that vertical integration is creating systemic problems for DoD products today. A few vertical concerns have been identified and remedied in defense merger and acquisition reviews. In existing DoD acquisition programs, firms are less likely to use newly acquired vertical businesses to replace current suppliers because of the cost and risk of switching suppliers.

However, the Task Force believes vertical integration poses future concern to DoD. Many industry mergers and acquisitions are very recent, and all of their effects cannot yet be assessed. The concentrated defense industry and few new DoD program opportunities create a potentially static business environment."

Defense Science Board Task Force on Vertical Integration and Supplier Decisions, May 1997, Office of the Secretary of Defense

Industry Operators Independent of Manufacturers 2 of 3

“Independent Space Transportation Operator Concept, A Breakthrough Acquisition Strategy Using Independent Space Transportation Operators, Making Affordable and Sustainable Space Transportation Possible”, C. McCleskey, NASA John F. Kennedy Space Center, Florida, May 18, 2004, publicly available at:
http://science.ksc.nasa.gov/shuttle/nexgen/Nexgen_Downloads/On_the_Need_for_Independent_Operators.pdf

Industry Operators Independent of Manufacturers 3 of 3

"I have been on the ground side for 30 years and realistically when you get a program the major emphasis is typically on hardware which is something people can touch, see and identify with. We're in a situation where typically the ground is treated as a key component but not at the same priority as space hardware – it doesn't have the glamour.

The space system can't work without a solid, effective ground system that makes sure data gets to the right place at the right time.

I think the hesitation [at going this route] is because it's something that hasn't been done before. There are some arguments that you can get better integration between the ground segment and the spacecraft by procuring them together, but I don't believe our systems can be operated in a stovepipe kind of mode. You need to be able to have interoperability across these systems. The viable place to do that is on the ground where all the pieces come together."

Raymond L. Kolibaba, Vice President for Space Systems,
Raytheon Intelligence and Information Systems
Space News, September 26, 2005

KSC's future concept as a multi-user spaceport requires support for diverse space transportation systems, operated by both government and private entities. What drives the space transportation demand is the full spectrum of current and emerging user markets for human spaceflight, space resource applications in earth orbit, exploration and eventual resource development beyond earth orbit, national security needs, and sponsored research/STEM activities.

Only one space transportation system, NASA's developing heavy lift Space Launch System, is required by its size and architecture to use a KSC launch site during the 2012-2031 planning horizon. All others, both existing and expected to be available, can be supported by other launch sites and support infrastructure outside KSC's institutional base. Even the Atlas V system, a candidate booster for commercial human spaceflight and workhorse for lifting national defense payloads, is functionally integrated with the Cape Canaveral Air Force Station (CCAFS) base infrastructure even though it is on KSC's land.

The FDC therefore relies on a transformation of KSC's business model and concept of operations to achieve its vision for hosting and enabling space access for all.

3.1 SPACE TRANSPORTATION USER-DEMAND FORECASTS

The global space industry is evolving rapidly to meet the needs of expanding national markets, and compete for both existing and emerging commercial markets.

The user demand that supports the 2012-2031 flight operations analysis contained in this FDC is predominantly in markets that have yet to be firmly established. These include the government and commercial demand for exploration beyond earth orbit, government and commercial demand for transport of humans into earth orbit, and the emerging suborbital market for commercial human spaceflight, research, and STEM activities.

National security, civil, and commercial demand for space lift to deploy orbital spacecraft or NASA robotic/science missions will remain relatively flat. At best, a fairly steady pace of launches per year will be required. These needs can be largely if not entirely met by existing space launch capabilities on CCAFS, other U.S. sites, and overseas spaceports that have captured the major share of available commercial satellite business.

The actual market demand for human spaceflight, both orbital and suborbital, or for other potentially large markets such as research and STEM experiments, depend on a much lower price point for space access than ever before achieved. However, systems are currently in development to provide suborbital access for humans at $200,000 or less per flight, and for experiments ranging as low as a few thousand dollars per flight. Commercial orbital flight to ISS was introduced by the Russian Soyuz system at an initial cost of approximately $25 million, and the cost per seat for U.S. astronauts now exceeds $50 million.

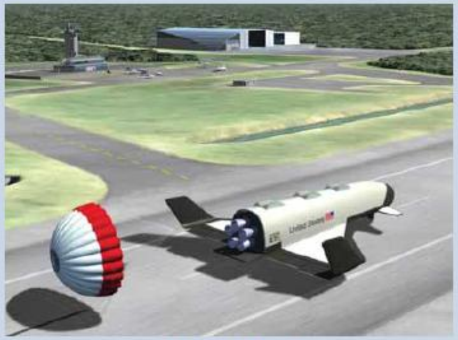
3.2 ANTICIPATED AND POTENTIAL SPACEFLIGHT SYSTEMS 2012-2031

The principal space transportation systems which will or potentially could operate from KSC sites during the 2012-2031 timeframe include:

NASA's SLS heavy lift booster, initially offering a 70 metric ton lift capability and coupled with the Orion multipurpose crew vehicle, is in development to make its first test launch in late 2017 and first crewed flight in 2021 from Pad 39B at KSC. Initially reliant on legacy Shuttle hardware such as the Solid Rocket Boosters and Shuttle Main Engines, a competition for booster elements is planned early in the program development to establish the vehicle's future configuration. System development and flight rate will depend on NASA budget resources assigned to it.

Both existing systems in the USAF Evolved Expendable Launch Vehicle Program (EELV) could adapt to fly from KSC's Complex 39 in addition to Complex 41 and the Cape's Complex 37. Current and growth versions are planned at least through 2030, when the USAF has targeted a replacement system for the EELVs. That future system could emerge during this time frame as a development program to demonstrate and field a fly-back first stage booster that would be fully reusable and reduce mission launch costs. The existing EELVs and enhanced versions could support a wide range of user missions, including support for commercial human spaceflight, NASA and commercial exploration missions, and "game changing" markets that could emerge, such as incorporating propellant depots into exploration architecture or developing space-based solar power.

The new and evolving family of Falcon launch vehicles privately developed and operated by SpaceX also is targeted to address the user needs described above, and is already contracted for NASA cargo delivery to ISS. In addition, other launch vehicles commercially-developed and operated using technology derived from legacy programs may emerge. These could include ATK's proposed Liberty rocket.



Reusable Fly-Back Booster

Re-usable Booster System

"A new way of doing business for a new generation of explorers"

OPPOSITE PAGE: View of NASA's planned Space Launch System (SLS) on Pad 39B. In background, a commercial reusable launch vehicle is taking off on a suborbital flight. NASA art by Pat Rawlings.

KSC Master Planning and the AF RBS

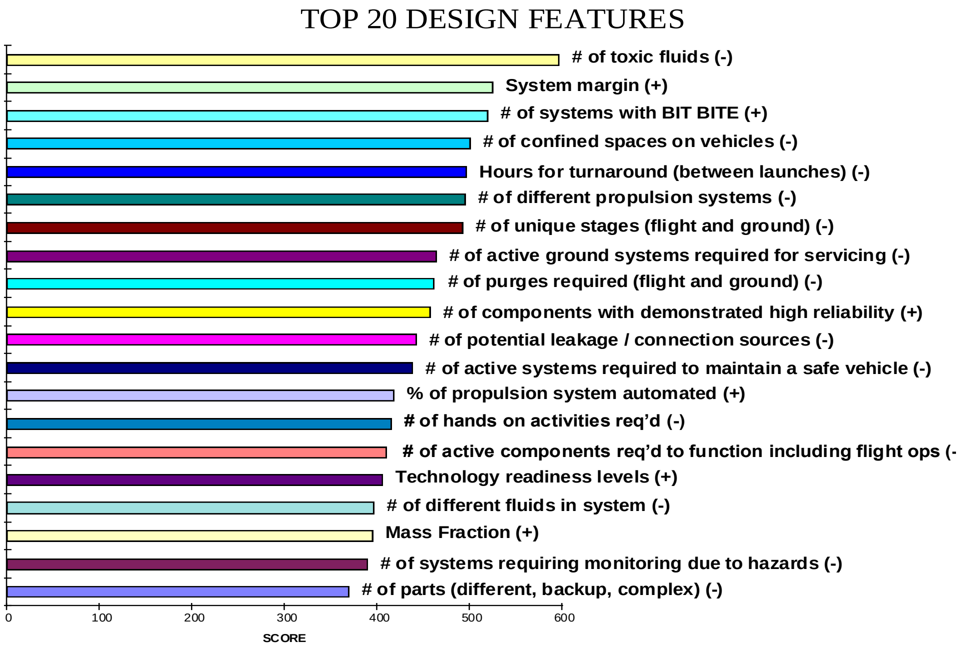
Public at:

http://www.nasa.gov/centers/kennedy/pdf/634026main_future-concept.pdf

Technology and Operability

- 1997: "A Guide for the Design of Highly Reusable Space Transportation", publicly available at: http://science.ksc.nasa.gov/shuttle/nexgen/hrst_main.htm

Figure 1: Prioritized Measurable Criteria



About the Presenter

Edgar Zapata

Mr. Zapata has worked with NASA at the Kennedy Space Center since 1988. In that time he has held responsibility for Shuttle systems including the Shuttle External Tank and the Shuttle liquid oxygen ground systems. Since the mid 90's he began work to translate the operations experience into improvements in flight and ground system designs. He participated in the Explorations Systems Architecture Study (ESAS) in 2005, contributing launch and landing ground operations cost estimates.

Most recently Mr. Zapata supported (1) agency level, Constellation life cycle cost scenario analysis, (2) ground systems cost analysis supporting the Constellation Standing Review Board, (3) analysis and recommendations as part of the NASA Programmatic Risk Assessment team in support of the 2009 Presidentially Appointed Review of Human Space Flight Plans Committee, and (4) life cycle cost lead, in 2011, for the depot architecture alternative within the Human Space-flight Architecture Team (HAT).