THE NATIONAL ACADEMIES

Focus Session on Reusability in Launch Systems

Aeronautics and Space Engineering Board

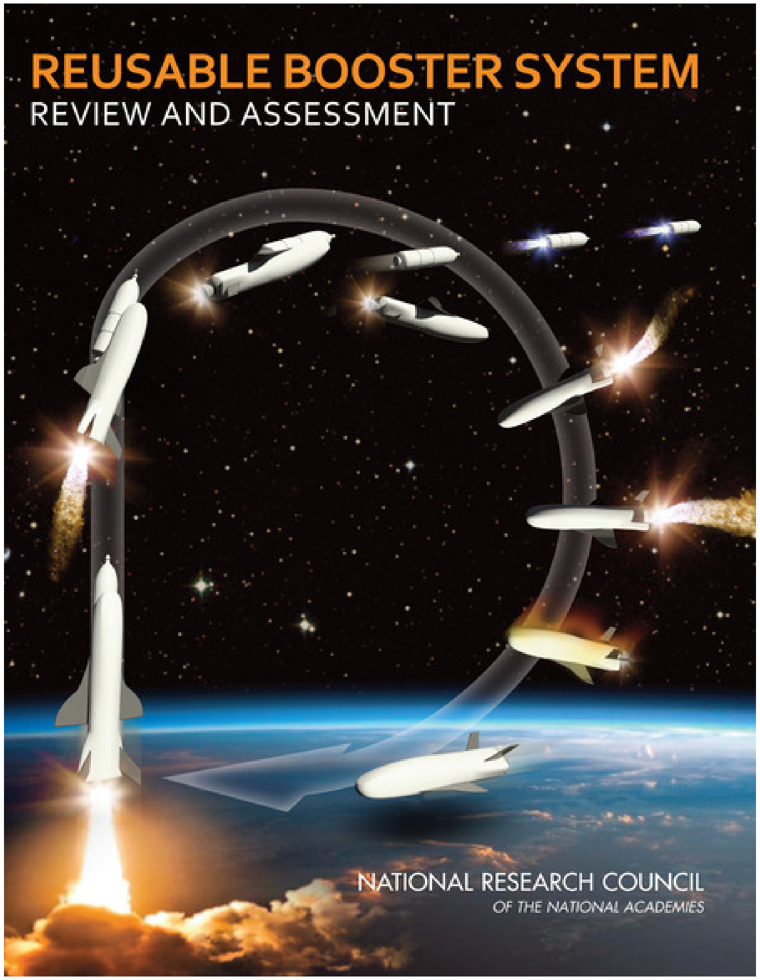
16 October 2014

THE NATIONAL ACADEMIES
Advisers to the Nation on Science, Engineering, and Medicine

National Academy of Sciences
National Academy of Engineering
Institute of Medicine
National Research Council

Background

- Reusable Booster System study - Jan-Sep 2012
- Current Air Force medium and heavy launch capability provided by Evolved Expendable Launch Vehicles (EELV)
- Rising launch costs led to interest in potential alternatives
- Air Force Space Command (AFSPC) identified long-term Science & Technology challenge to provide full-spectrum launch capability at dramatically lower costs
- The Space and Missile Systems Center (SMC), in conjunction with the Air Force Research Laboratory (AFRL), developed the concept of a Reusable Booster System (RBS)

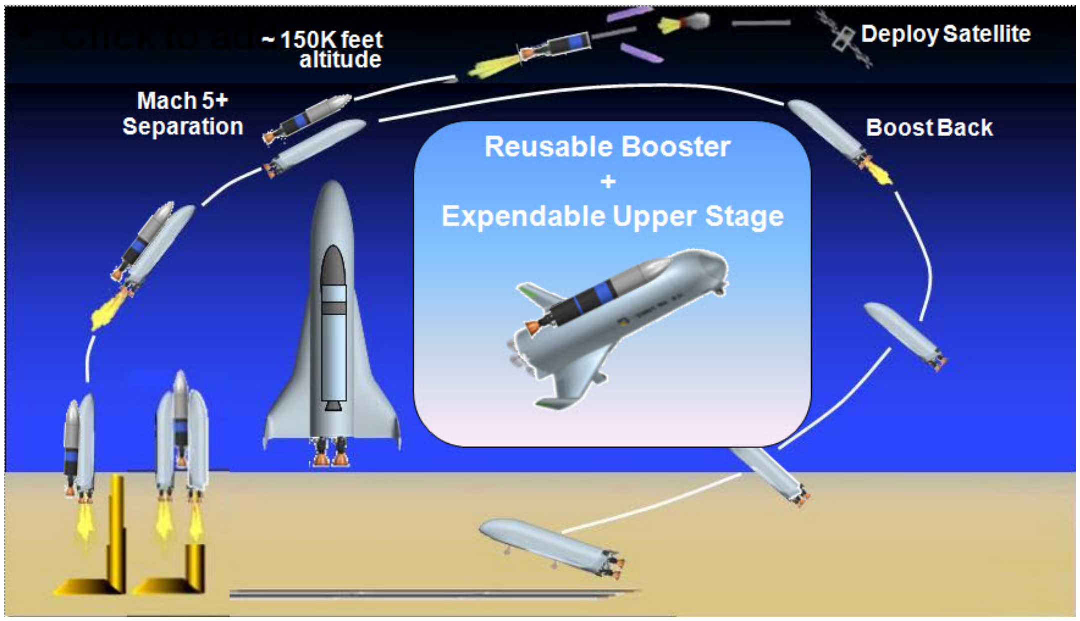


THE NATIONAL ACADEMIES

Statement of Task

- Review and assess the U.S. Air Force Reusable Booster System (RBS) concept.
- Among the items the committee will consider are:
  - Criteria and assumptions used in the formulation of current RBS plans
  - Methodologies used in the cost estimates
  - Modeling methodology used to frame the business case for an RBS capability
  - Technical maturity of key elements critical to RBS implementation
  - Ability of current technology development plans to meet technical milestones

Reusable Booster System (RBS) Concept



Key System Features

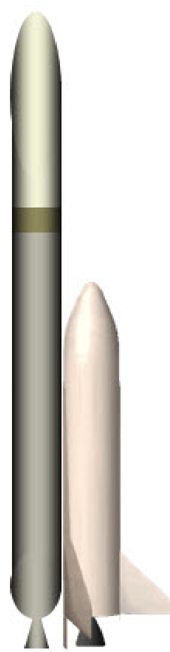
- Reusable 1st stage
  - Lower thermal protection system requirements
- Expendable upper stage
- Hydrocarbon-fueled booster engine
- "Rocketback" return-to-launch-site (RTLS) maneuver

Basic premise: Hybrid reusable launch system will reduce amount of expendable hardware, which will lead to reduced launch costs

Comparing RBS to Atlas V

Atlas V

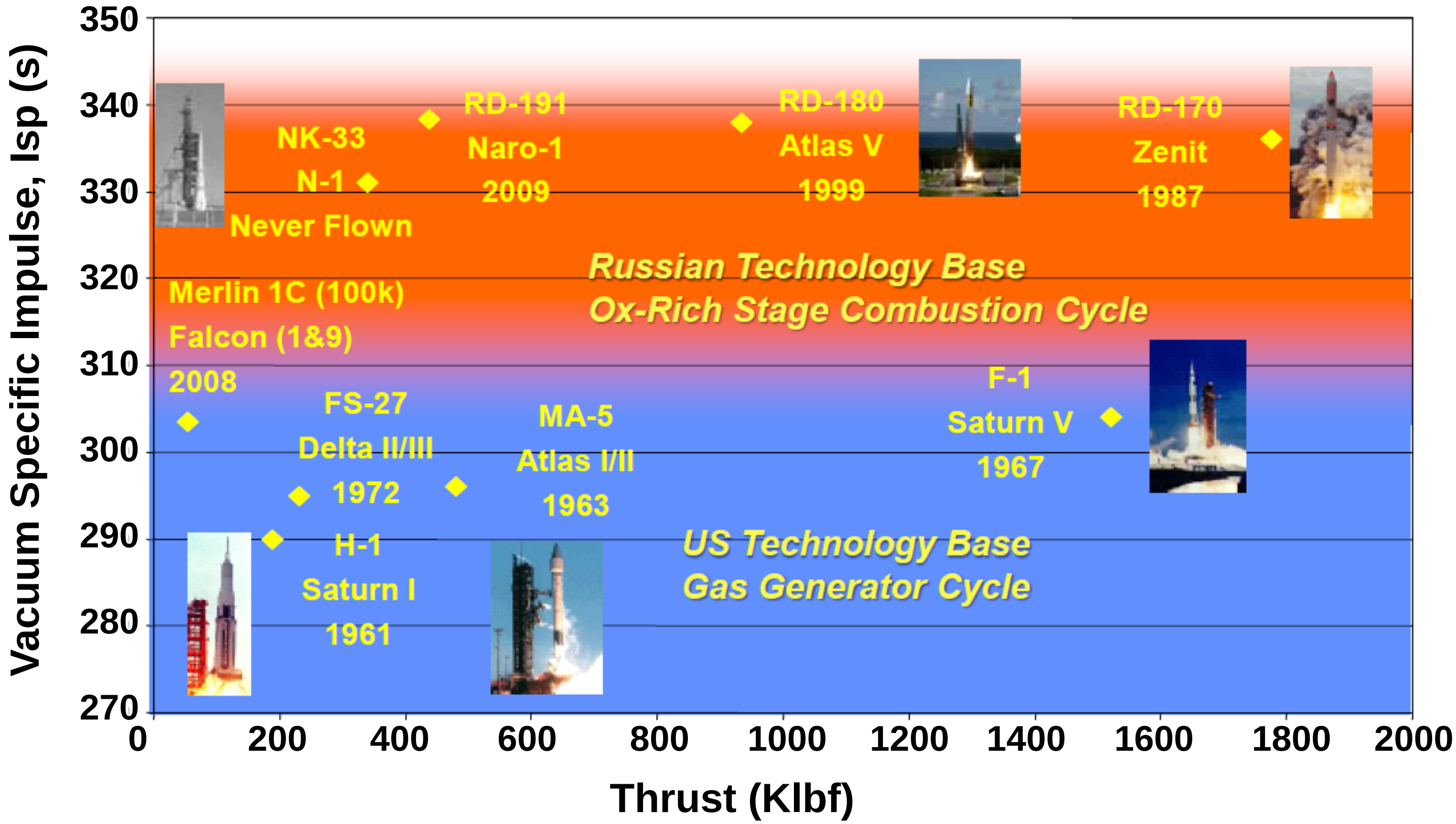
RBS



	RBS (Approx)	Atlas V-551
Booster	5 AJ-26	1 RD-180
Inert Mass (klb)	105	41.7
Propellant Mass (klb)	900	626.3
Thrust (klbf)	1,655	860
Solid Rocket Strap-On	n/a	5
Mass (klb)	n/a	514.7
Thrust (klbf)	n/a	1,898
Second Stage	1 RS-25E	1 RL-10
Inert Mass (klb)	38	4.9
Propellant Mass (klb)	340	45.9
Thrust (klbf)	500	22.3
Gross Lift-Off-Weight (klb)	1,340	1,298
Sea Level Thrust (klbf)	1,655	2,548

RBS and Atlas V-551 Gross Lift-Off Weight (GLOW) similar (1,340 vs 1298 lbm)
RBS expendable mass lower (38 vs 46.6 klbm plus solid rockets)
RBS 2nd stage significantly larger (378 vs 50.8 klbm)

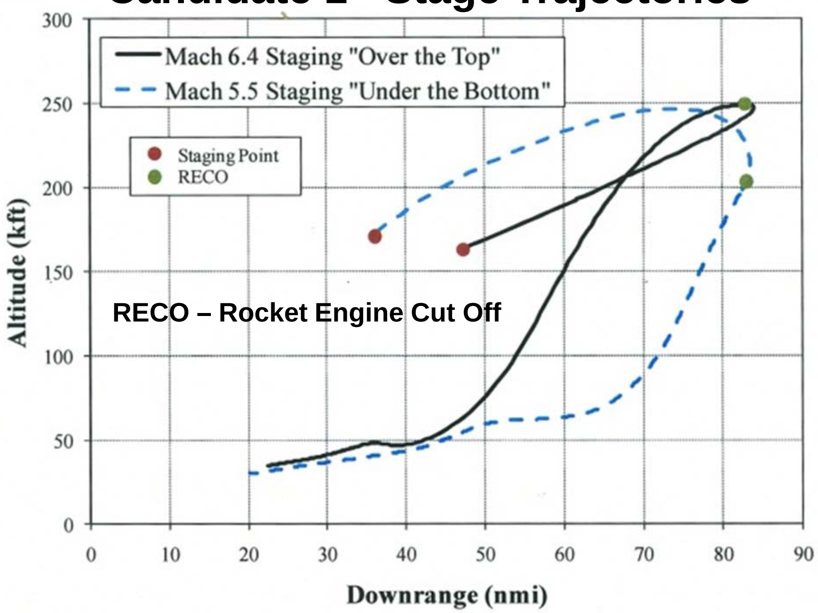
Liquid Oxygen/Hydrocarbon Fuel Boosters



- **Russia is principal producer of high performance LO2/LHC rocket booster engines**
- **New development and testing required to produce U.S. engine**

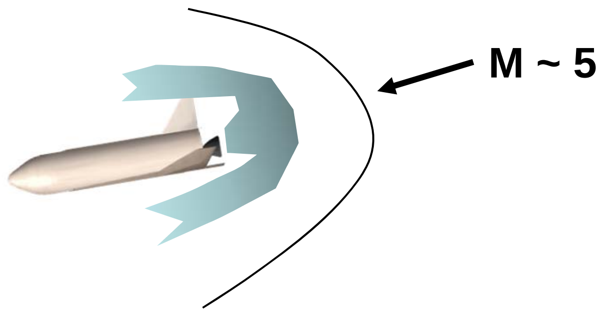
Rocketback Return-to-Launch-Site (RTLS) Operation

Candidate 1st Stage Trajectories



Ref: Hellman, B.M., et. al, AIAA-2010-8668, 2010.

Plume-Aero Interactions During Rocketback Maneuver

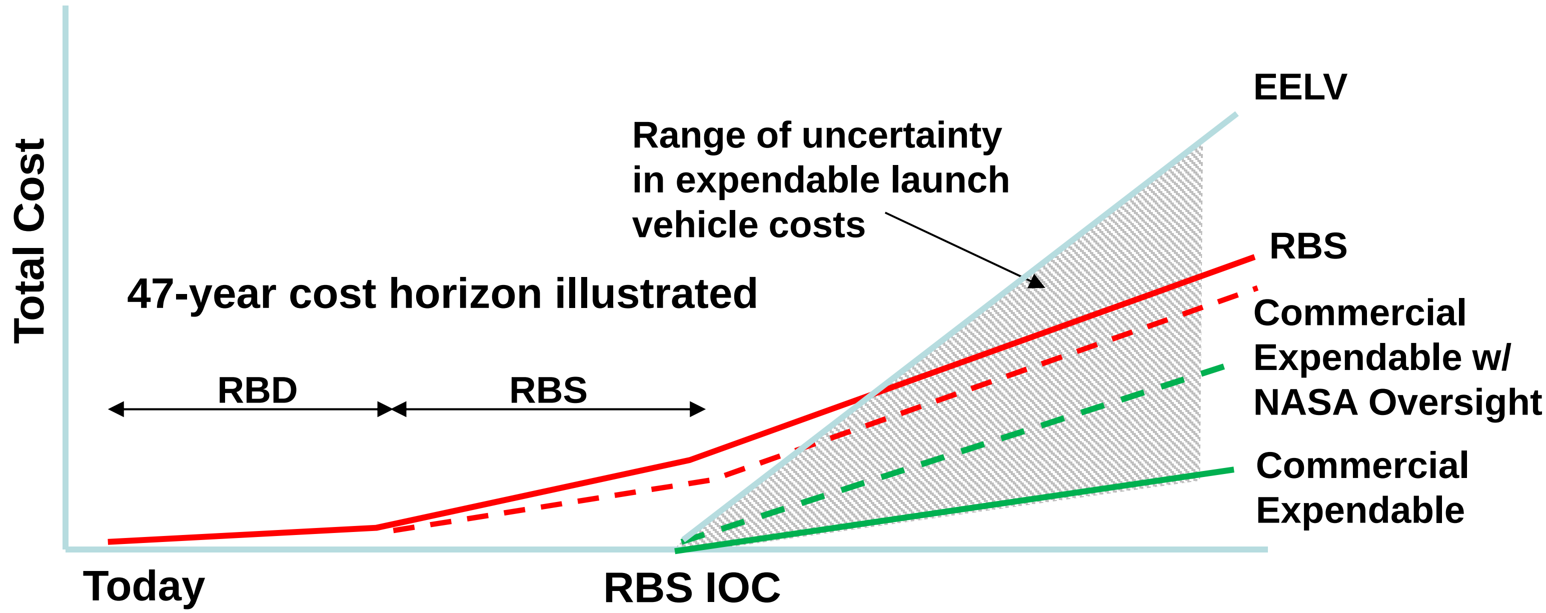


AFRL "Pathfinder" program aims to reduce risk using subscale flight vehicle

Rocketback RTLS maneuver technology development needs include:

- Impact of plume interactions on vehicle aerodynamics
- Propellant management within tanks during maneuver
- Effective transition to equilibrium glide trajectory

Potential Alternative Scenarios Concerning Future Launch Costs



- Significant variation exists in projected costs for expendable vehicles
- RBS costs may be impacted by reduced expendable costs, but may also increase due to assumptions regarding operations costs
- RBS business case unclear due to large cost uncertainties

Findings (1/2)

1. **Cost estimate uncertainties may significantly affect estimated RBS life-cycle costs**
2. **RBS business case is incomplete and cannot be closed at present time because it does not adequately account for:**
   - **New entrant commercial launch providers**
   - **Impacts of single source suppliers**
   - **USAF needs for independent launch sources**
   - **Technical risk**
3. **Reusability remains a potential option for achieving full spectrum launch capabilities at reduced cost with important launch flexibility to enable significant new capabilities**
4. **To significantly impact USAF operations, RBS must be more responsive than current systems, but no responsiveness requirement has been identified**

THE NATIONAL ACADEMIES

Findings (2/2)

5. Technology areas identified where continued applied research and advanced development is required prior to proceeding into large-scale launch vehicle development
   - Oxygen-rich, staged-combustion, hydrocarbon-fueled engines
   - Rocketback Return-to-Launch-Site (RTLS) operation
   - Vehicle health management systems
   - Adaptive guidance and control
6. Given uncertainties in business case and yet-to-be mitigated technology risks, it is premature for AFPC to program significant investments in RBS development

THE NATIONAL ACADEMIES

Recommendations (1/2)

1. **USAF should establish specific launch responsiveness objectives to drive associated technology development**
2. **USAF should proceed with technology development in key areas:**
   - **Reusable oxygen-rich staged combustion hydrocarbon-fueled rocket engines**
   - **Rocketback return-to-launch site operations**
   - **Vehicle health management systems**
   - **Adaptive guidance and control concepts**
3. **AFRL should develop and fly more than one Pathfinder test vehicle design to increase chances for success**

Recommendations (2/2)

4. **Decision to proceed with RBS development should be based on the success of Pathfinder and adequate technical risk mitigations in key areas:**
   - **Reusable oxygen-rich staged combustion hydrocarbon-fueled rocket engines**
   - **Rocketback return-to-launch site operations**
   - **Vehicle health management systems**
   - **Adaptive guidance and control concepts**
5. **Following successful completion of Pathfinder, USAF should re-evaluate RBS business case accounting for:**
   - **New entrant commercial launch providers**
   - **Potential impacts of single-source providers**
   - **USAF needs for independent launchers**
6. **When constructing a future RBS program, go/no-go decision points should be structured as on-ramps to subsequent stages**

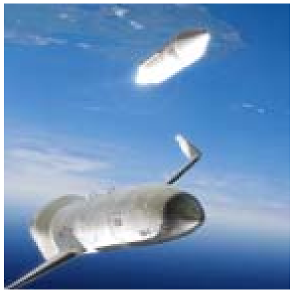
Relevant Events Since RBS Study

- SpaceX (2012) and Orbital (2013) begin ISS cargo delivery
- SpaceX Grasshopper flown (2012)
- DARPA XS-1 program started (2014)
- Russian intervention in Ukraine (2014)
- NASA Commercial Crew Program (downselect in 2014)
- Blue Origin BE-4 engine announced (2014)

SpaceX Falcon 9

Orbital Antares

DARPA XS-1



Ukraine

BE-4

Topics for Discussion

- What are the technically feasible approaches for transitioning to a launch system with reusable components?
- What are the near- and mid-term opportunities to demonstrate technologies and capabilities needed for launch vehicles with more reusable components?
- What approaches should be taken to overcome the development challenges associated with reusable boost propulsion systems?

Presentations

- “SpaceX Reusable Booster Update,” Lars Hoffman, SpaceX
- “Experimental Spaceplane (XS-1): First Step Toward Reducing the Cost of Space Access by Orders of Magnitude,” Vijay Ramasubramanian, Mantech System Technologies