Experimental Spaceplane (XS-1)

First Step Toward Reducing the Cost of Space Access by Orders of Magnitude

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Program Manager

Program Overview for NRC ASEB
16 October 2014

DARPA

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ASEB Focus Questions for Reusable Launch Systems

• What are 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?
No apparent technical “showstoppers” preventing us from building reusability into launch systems today → philosophical approach is key.

Philosophical Approach being pursued by XS-1 Program:

1. Take distinct, but incremental steps

2. Set aggressive, but achievable goals

3. Design-in operability (“aircraft-like operations”) up front

4. Be open to the form of the solutions, don’t mandate technologies or approaches

5. Design for broad user segment, not exclusively Government/DoD
DC-X Paved the Way

‘Ops Lab’ procured on 2 year schedule, $70M

DC-X/XA Demonstrated

Streamlined Management “Aircraft-like” O&M

- 26 hr turnaround time
- 2-3 hr call up/alert
- Small crews: 6 to 12
- Minimal facilities < $600K

“Aircraft-Like” Flight Ops

- Flight abort/engine out
- Incremental flight test
- All weather

Critical Technologies

20 Years Later …

- A robust commercial sector
- Spaceports proliferating
- Rapidly maturing tech
- Costs down 10-100X

Flew 18 Aug 93 through 1996

IN MEMORIAM

Thank You!

Dr. Bill Gaubatz
U.S. Launch – A Growing Problem

- DoD payloads launched on Evolved ELV at ~$3B/year & growing
- Small payloads launched at ~$50M on few remaining Minotaurs
- Foreign competitors lead commercial launch, once dominated by U.S.
- No surge capability, long call-up times, typically > 2 years
- Budgets continue to decline, threats to space and air assets growing
XS-1 Goals

*Step One to Routine, Low Cost Access to Space*

1. **Break cycle of escalating space system costs**
   - Change how spacecraft are built
   - Enable future space system architectures
   - Leverage interests & capabilities of commercial sector

2. **Provide affordable/routine space access; would fly in 2018**
   - **Responsive launch** → single smallsat or constellations for rapid employment
   - **Disaggregation** → smaller spacecraft, flown more often & more survivable
   - **Resilient** → ability to fight through contested & congested environments
   - **Hypersonic testing** → platform for R&D of hypersonic systems & components

3. **Enable advanced flight vehicles and strategic capabilities**
   - **Space sortie aircraft** → Global ISR, boost-glide, PTP transport
   - **Hypersonic aircraft** → High-speed, thermally-robust technologies

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XS-1 Technical Objectives

- Reusable first stage
- Fly XS-1 10 times in 10 days
- Fly XS-1 to Mach 10+ at least once
- Launch demo payload to orbit
- Design for recurring cost ≤ 1/10 Minotaur IV

(< $5M/flight for 3,000 – 5,000 lbs to LEO at 10+ flts/yr)

Open Design Space, Industry Has Flexibility

- Configuration
- Propellants
- CONOPS
- Materials
- Technologies
- Propulsion
**Mach 10 staging with small upper stage (shown)**
Alternatively, stage at lower speed with larger upper stage

**Booster**
- Engine: 2 Merlins
- GLOW (K lbs): 223.9
- MECO (K lbs): 47.4
- Usable LOX/RP (K lbs): 176.5
- Isp (vac): 310 sec
- Stage PMF: 0.84

**Upper Stage**
- GLOW (lbs): 15.0
- Isp (vac): 336 sec
- Stage PMF: 0.9
- Payload (K lbs): 3.0

**Payload**
- 3,025 lbm
- 100x100 nmi
- 28.5 deg Inclination

**2-Stage Vehicle (GLOW-223.9K lbs)**
- Booster (2 Merlins)
- Propellant = 176.5K lbs
- $I_{sp}$ (vac) = 310 sec
- PMF = 0.84
- Upper Stage (GLOW-15K lbs)
- $I_{sp}$ (vac) = 336 sec
- PMF = 0.90

**Staging:**
- Time = 169.9 sec
- DR = 71.9 nmi
- Altitude = 237,155 ft
- Mach = 10.8

**Expendable stage ~5% of stack weight**
**XS-1 Phase I Awards**

- **Phase I system awards**
  - The Boeing Company working with Blue Origin
  - Northrop Grumman working with Virgin Galactic
  - Masten Space Systems working with XCOR

- **Technology awards/cooperative efforts**
  - Honeywell – Real-time Abort Trajectory Generation
  - Gloyer-Taylor Labs – Composite Cryogen Tank Fabrication and Test
  - NASA Armstrong Flight Test Center – Fiber Optic Sensor System (FOSS)
  - SAS and LLNL – Ox-Rich Staged Combustion / Next-Gen Rocket seedlings
  - ATK/COI – CMC Thermal Protection Systems
  - C-CAT – Advanced Carbon-Carbon Thermal Protection Systems
  - Orbitec – Vortex Combustion Rocket Thrust Chamber Scale-Up and Fabrication
  - Aerojet Rocketdyne – Additively Manufactured Regen-Cooled Thrust Chamber

- **Upcoming:** 1 Comm / Space-Based Range Award
XS-1 Planned Schedule

<table>
<thead>
<tr>
<th>FY 14</th>
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**Source Selection**

**Phase 1 - Initial Design**
- Risk Reduction
- System Design Integration

**Phase 2 – Final Design Fabrication and IA&E**
- Reusable aircraft
- Upper stage

**Phase 3 - Flight Test Campaign**
- Transition Opportunities

**Technology**
- Transition Off-Ramps

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# Legacy of Past Programs

## Initial Goals (requirements)

<table>
<thead>
<tr>
<th>Space Shuttle</th>
<th>NASA human rated Payload – 65K lbs</th>
<th>AF crewed Payload &lt; 10K lbs SSTO, scramjet powered Aircraft-like ops, fast turn</th>
<th>NASA human rated Payload - 65K lbs SSTO, rocket powered Aircraft-like ops, fast turn</th>
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## Technology (at start)

<table>
<thead>
<tr>
<th>Space Shuttle</th>
<th>TRL ~3 and immature design New LOX/LH₂ SSME Unproven materials/TPS Toxic OMS/RCS, etc. 1960s/1970s technology</th>
<th>NASP</th>
<th>TRL ~2 and immature design New LS/RAM/SCRAM/rocket New materials/structures New LOX/LH₂ tanks New hot structure TPS, etc.</th>
<th>VentureStar</th>
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## Approach

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<tr>
<th>Space Shuttle</th>
<th>Expendable launch (SRB, ET) Operational after 4 flights Evolved to “space station”</th>
<th>NASA human rated</th>
<th>x-Plane first Incremental flight test</th>
<th>VentureStar</th>
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## Outcome

<table>
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<tr>
<th>Space Shuttle</th>
<th>Successful flights Very expensive with ground “standing army”</th>
<th>NASP</th>
<th>Never flew Design never closed Technology not available</th>
<th>VentureStar</th>
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**Past programs over-specified the problem (SSTO, scramjet, heavy lift, crewed, etc.) AND relied on immature designs and technology (TRL 2/3)**
What Has Changed?

20 years of investment → Technology mature & affordable

- Affordable Composite Airframe
- Responsive Operations
- Autonomous Operations
- FOCC
- Affordable Infrastructure
- Design Integration
- Aircraft-Like Ops
- “Trimmed” Full Envelope AG&C
- Integrated Systems Health Management
- Thermal Protection Systems
- Low Cost Upper Stage
- Integrated RLV Subsystems
- Ongoing Long Term High Ops Tempo Propulsion
- Off-the-Shelf and Near-Term Propulsion
- Cycle of Prep, Launch, Recovery, and Turnaround within Single Day
- Autonomous Operations
- Responsive Ops
- Affordable Infrastructure
- Design Integration
- Aircraft-Like Ops
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Challenges to Achieving Lower Cost

XS-1 would complement heavy Falcon & EELV payloads

ELV Launch Cost Breakdown

Technical Challenges

- Design and system integration enabling “aircraft-like” operations
- Light weight/highly-integrated airframe, high propellant mass fraction
- Durable thermal structures/protection, -300°F to +3,000°F
- Reusable, long life & affordable propulsion

Note: Data extracted from FY12 PE/BPAC data, Excludes AFSPC payroll at launch sites and base O&M

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Facility, support, launch complex, $1.32

Mission Assurance, $0.20

Two Facilities, Small Crew Size
Clean pad

Today’s Launch Complex

Launch Site/Base Manpower Comparisons

Autonomous Ops

ISHM

Incorporate “-ilities”

Autonomous Vehicle, no solid boosters, simple stage, etc.
Incremental Flight Test
Payload Standard Interfaces
On Board Health Monitoring
On Board Self Test
Automated Checkout
Ops Flow Mgmt
Special GSE

Design for Rapid Turn Reduces Manpower

Delta II Baseline Data

Operable Design

Goal: Design and System Integration
Enable “aircraft-like” operations

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Goal: Design Integration
“Clean Pad” Aircraft-Like Operations

- Aircraft-like CONOPS
  - Clean pad - rapid throughput
  - Ops Control Center – like aircraft
  - Containerized payloads

- Aircraft GSE/Facilities where practical
  - Hangars, not specialized buildings
  - Standard interfaces/processes
  - Automated ops, propellant & fluid loading

- Integrated Systems Health Management
  - Determine real-time system health
  - Integrate with Adaptive G&C
  - Enable reliable, rapid turnaround aircraft

- Leverage high ops tempo investments
  - ALASA – Autonomous Flight Termination System
  - ALASA – Rangeless range, space based command, control & data acquisition
  - Adaptive GN&C – safe, reliable recovery/abort

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**Goal:** Highly-Integrated, Low-Complexity Airframe

*High Propellant Mass Fraction (PMF)*

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**Mission Assurance, $0.20**

- **Launch Vehicles, $1.44**

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**Affordable Structure**

- Composite Structures Can Reduce Weight ~30%
- NASA Open-Core Tank in Fabrication
- USAF Monocoque Tank in Test

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**Tank/Structure Integration**

- Integral load bearing structure
- High PMF key to performance
  \[ \Delta V = I_{SP} \cdot g \cdot \ln \left( \frac{1}{1 - PMF} \right) \]
- 10X fewer parts & lower cost
- Reusable vehicle cost would be amortized rapidly ...

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**Design tank / airframe structure to enable high PMF/ΔV**

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Goal: Durable Thermal Structures / Protection
-300°F to +3,000°F

Many Thermal Protection Options
AFRSI and CRI
Quick-Release Fastener
Leading Edges
ACC, C/SiC, TUFROC
Mechanical Attach

Emerging Thermal Structures
Composite Hot Structures
Fibrous Opacified Insulation
Honeycomb Composites
Airframe Hot Wash Structures

How you design & fly is key!

Heat Rate (BTU/ft²/sec)

- Reentry AOA – 30°
- Reentry AOA – 70°
- Mach 10 suborbital

POST Results Ref Heating on 1 ft Radii Leading Edge

<2K BTU’s/ft²
51K BTU’s/ft²
13.3K BTU’s/ft²

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Goal: Reusable, Long Life and Affordable Propulsion

Multiple Options – Design Integration Challenge

- Use existing and near-term propulsion technologies, emphasizing:
  - Long life, rapid call up/turnaround
  - High reliability
- Design as Line Replaceable Unit
  - Rapid remove and replace
  - Support high ops tempo flight rate
- Leverage commercial sector developments

Multiple Propulsion Options

- Merlin Commercial Rocket
- Bantam Family of Rockets
- STA
- XCOR
- Ventions
Flexible Launch & Landing Options
Fly from Anywhere, Anytime

Would deliver affordable, routine space access - On path to global reach capability
XS-1 Capabilities Would Evolve Over Time

- **Core capability ≥ 3,000 lbs to LEO**
  - ✓ Option: Grow capability with modular launch

- **Payload disaggregation could shrink sizes**
  - ✓ Downsize & modernize payloads
  - ✓ Single payload simplified spacecraft

- **Stage disaggregation would grow effective payload**
  - ✓ Launch satellite payloads separately
    - ✓ Dock stage on-orbit with satellite

- **Grow launch markets**
  - • Capture / recapture commercial launch
  - • Enable new military / ORS capabilities
  - • Growth versions could enable full spectrum AFSPC launch capability
  - • Hypersonic testing / release of free-flyers

**Legend:**
- Deploy mated satellite & stage
- Modular Bi-mese
- Disaggregated Satellite Missions
- Autonomous Dock of Chemical Stage/Sat
- Solar Electric Propulsion

**Graphs:**
- Burn Out Mach No.
- Downrange Constant Q Flight Profile
- Free Flyer Hypersonic Test
- Boost Glide

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Potential XS-1 DoD and Commercial Satellite Markets

Responsive launch of 3 to 5K lb payloads

- ‘97-‘99 spike due to Iridium and Globalstar
- Lost commercial opportunities
  - Commercial launch migrated overseas
    - ... $Billions in lost revenue
    - ... Grew cost of DOD launch
- New constellations hard to finance
  - ... Teledesic

- Potential to leverage commercial sector

- Missions potentially enabled by XS-1
  - USAF ORS & “disaggregated” satellites
  - Recapture commercial launch
    - Historical avg of 3-5 launches/yr at 5,000 lbs
    - Projected market much higher

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**XS-1 Capture of Historical U.S. Launches: 1993 to 2012**

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<th>Satellite/Stage Mass</th>
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<tr>
<td>10,000–15,000 lbs</td>
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<tr>
<td>5,000–10,000 lbs</td>
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<tr>
<td>&lt; 5,000 lbs (XS-1)</td>
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**Worldwide Projected Payloads: 2013 to 2022**

- > 70 Launches/yr
- Historical avg of 3-5 launches/yr at 5,000 lbs
- Projected market much higher
XS-1 Could Facilitate Next-Generation Hypersonics

Multiple Test Options

• Captive carry experiments
  • May Limit Q and thermal testing
  • Propulsion (RAM/SCRAM/Turbine)
  • Airframe/Structures
  • Thermal Protection
• Release free-flyer experiments
  • Unpowered constant Q reentry
  • Long test time vs. ground test
  • Aerodynamic & thermal test
  • Laminar flow/boundary layer transition
  • Controls/avionics
• Powered test vehicle
  • Longer flight tests
  • Useful test data limited only by scale and cost

Constant Q Unpowered Glide from Engine Burn Out

Projected Cost of Flight Test < Many (Not All) Ground Tests
Test of component/systems ◆ RAM/SCRAM/turbine ◆ Boost-glide vehicles
Flight Test

Mach 10 Would Validate Critical Space Access Technology

XS-1 would mature technology for 1st Stage and fully reusable flight to space
XS-1 Transition Path Would Require Proactive Industry

✓ Robust DOD and commercial launch industry with ideas

Growing small satellite industry building low-cost satellites
- Commercial
- Military
- Civil

Emerging DOD requirements for disaggregation & resiliency
- Disaggregation: downsize spacecraft for routine, responsive & affordable launch
- Resiliency: ability to operate in the harsh space environment
• What are technically feasible approaches for transitioning to a launch system with reusable components?
  • XS-1 program pursuing 3 prime contractor approaches, all different
  • Reusable 1\textsuperscript{st} Stage, Expendable 2\textsuperscript{nd} Stage

• What are the near- and mid-term opportunities to demonstrate technologies and capabilities needed for launch vehicles with more reusable components?
  • XS-1 program would be a near-term opportunity
  • Aggressive goals ensure technology would feed commercial RLV concepts
  • Stepping stone to fully reusable vehicles in future

• What approaches should be taken to overcome the development challenges associated with reusable boost propulsion systems?
  • XS-1 program is leveraging private sector engine technology
  • Advanced engine technology helpful, emphasize both operability and $I_{SP}$
XS-1 seeks to:

• Address growing launch costs in an era of declining budgets
• Lower operating costs to enable new, game-changing capabilities
• Leverage emerging commercial launch technology & entrepreneurs
• Demonstrate technology for transition to government and commercial users

XS-1 aims to create a new paradigm for more routine, responsive and affordable space operations.

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