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 COMSTAC
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DARPA

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
Experimental Spaceplane (XS-1)

Step One to Routine, Low Cost Access to Space

**XS-1 Vision**

- Break cycle of escalating space system costs
- Aircraft-like operability enabling low cost, responsive access to space
- Accelerate introduction of hypersonic technologies and next generation aircraft
- Responsive platform for global reach national security and commercial applications
- Enable residual capability for responsive launch of 3,000 – 5,000 lb payloads

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**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+ flt/s/yr)

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**Open Design Space**

- Configuration
- Propulsion
- Propellants
- CONOPS

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**Notional Government Reference X-Plane**

One of Many Possible Industry Solutions

Mach 10 staging with small upper stage (shown)
Alternative would be Mach 5 staging with larger upper stage

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**F-15**

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**XS-1**

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**Booster**

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

**Upper Stage**

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

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

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**2-Stage Vehicle (GLOW-223.9K lbs)**

- Booster (2-Merlins)
- Propellant = 176.5K lbs
- Isp (vac) = 310 sec
- PMF = 0.84

- Upper Stage (GLOW-15K lbs)
- Isp (vac) = 336 sec
- PMF = 0.90

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

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**Staging:**

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

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

- **Phase 1 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
  - CCAT – Carbon Carbon Thermal Protection Systems

- **Upcoming awards**
  - 2 Propulsion
  - 1 Comm / Space-Based Range Award

**XS-1 Planned Schedule**

<table>
<thead>
<tr>
<th>FY 14</th>
<th>FY 15</th>
<th>FY 16</th>
<th>FY 17</th>
<th>FY 18</th>
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<td>Source Selection</td>
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<td>Phase 1 - Initial Design</td>
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<td>- Risk Reduction</td>
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<td>- System Design Integration</td>
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<td>Phase 2 - Final Design Fabrication and I&amp;E</td>
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<tr>
<td>- Reusable aircraft</td>
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<td>- Upper stage</td>
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<td>Phase 3 - Flight Test Campaign</td>
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<td>- Transition Opportunities</td>
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</table>

**Technology**

**Transition Off-Ramps**

**USAF, NASA, Industry**

**IDIQ**
### Long Spaceplane History

<table>
<thead>
<tr>
<th>Year</th>
<th>Program Details</th>
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<tbody>
<tr>
<td>80</td>
<td>WWII-era German Sanger Concept</td>
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<tr>
<td>82</td>
<td>X-15 Rocket Plane Program (Plus other rocket planes)</td>
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<td>84</td>
<td>USAF Aerospace Plane Program, early 1960's</td>
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<tr>
<td>86</td>
<td>X-20 Dynasonor Program, 1960s</td>
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<td>88</td>
<td>Science Dawn, Science Realm, TAV, MAV, Copper Canyon</td>
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<tr>
<td>90</td>
<td>National Aero-Space Plane</td>
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<td>92</td>
<td>Have Region</td>
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<td>96</td>
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<td>04</td>
<td>$3,000M</td>
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<td>05</td>
<td>$70M</td>
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### Long USAF Push for Aircraft-Like Access to Space

**Artwork Concept**

**Technology**
- **Space Shuttle**: TRL ~3 and immature design
- **NASP**: New LOX/LH₂, SSME, Unproven materials/TPS, Toxic OMS/RCS, etc. 1960s/1970s technology
- **VentureStar**: TRL ~3 and immature design

**Approach**
- **Space Shuttle**: Expendable launch (SRB, ET) Operational after 4 flights Evolved to "space station"
- **NASP**: X-Plane first Incremental flight test
- **VentureStar**: X-Plane first Incremental flight test

**Outcome**
- **Space Shuttle**: Successful flights Very expensive with ground "standing army"
- **NASP**: Never flew Design never closed Technology not available
- **VentureStar**: Never flew Design never closed Technology not available

**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

XS-1 Goals

1. Break cycle of escalating space system costs
   - Seeking path to affordable space
   - Would enable disaggregation & resiliency strategies
   - 10X lower launch cost changes how spacecraft are built

2. Enable new types of aircraft & test capabilities
   - Space access aircraft → Global ISR and protection
   - Affordable hypersonic aircraft → Low parts count & CTE structures/TPS
   - Hypersonic testbed → boost-glide systems & hypersonics

3. Enable residual capability
   - ORS Launch → single smallsat or constellations for rapid employment
   - Support growth options including near-term modular options
**DARPA Leadership Perspective:**

*Attack the cost equation*

Collectively the space portfolio is supporting responsiveness and cost reduction of launch through ground-based systems.

**Airborne Launch Assist Space Access** (ALASA) aims to enable responsive launch of 100 lb payloads from existing globally distributed airfields to enable next-generation tactical missions.

**The Experimental Spaceplane (XS-1)** reusable vehicle capability would extend this capability to 3,000 lb payloads with “aircraft-like” access to space at 10X lower costs.

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**Challenges to Achieving Lower Cost**

*XS-1 would complement heavy Falcon & EELV payloads*

**ELV Launch Cost Breakdown**

- **Mission Assurance**, $0.20
- **Facility, support, launch complex**, $1.32
- **Launch Vehicles**, $1.44
- **Conventional Launch Vehicle Trendline**
- **Small Solid Launchers**
- **Delta II Variants**
- **EELV Variants**
- **ALASA**
- **XS-1 Trade Space**
- **Falcon 9**

**Technical Challenges**

- Design and system integration enabling “aircraft-like” operations
- Light weight/high energy 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.*

**Distribution Statement A – Approved for Public Release, Distribution Unlimited**
Goal: Design and System Integration
Enable "aircraft-like" operations

- Few Facilities, Small Crew Size
- Autonomous Ops
- Incorporate "ilities"
- Complex to Simplex

Launch Site/Base Manpower Comparisons
- Delta II Baseline Data
- Design for Rapid Turn Reduces Manpower
- Turnaround (hours)
- Delta II Baseline Data

Mission Assurance, $0.20
Facility, support, launch complex, $1.32

Launch Site
- Clean pad
- Complex to Simplex
- Autonomous Ops

Today’s Launch Complex
- Few Facilities, Small Crew Size
- Autonomous Ops

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

Distribution Statement A – Approved for Public Release, Distribution Unlimited
**Goal: Light Weight / High Energy Airframe**

*High Propellant Mass Fraction (PMF)*

- **Mission Assurance, $0.20**
- **Launch Vehicles, $1.44**

**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
- *aka X-55*
- Reusable vehicle cost would be amortized rapidly...

**Design tank / airframe structure to enable high PMF/\(\Delta V\)**

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**Goal: Durable Thermal Structures / Protection**

*~300 °F to +3,000 °F*

**How you design & fly is key!**

- POST Results Ref Heating on 1 ft Radii Leading
- Mach 10 suborbital

**Many Thermal Protection Options**

- AFRSI and CRI
- Quick-Release Fastener
- Leading Edges ACC, C/SiC, TUFROC
- Mechanical Atch
- Space Shuttle Post-Flight CMC/TUF1 Tiles

**Emerging Thermal Structures**

- Composite Hot Structures
- Fibrous Opacified Insulation
- Honeycomb Composites
- Aircraft Hot Wash Structures

**Distribution Statement A – Approved for Public Release, Distribution Unlimited**
Goal: Reusable, Long Life and Affordable Propulsion

Multiple Options – Design Integration Challenge

- Use existing propulsion with mods for:
  - Long life ... rapid call up/turaround ... deep throttle
  - High reliability ... historically, most launch failures caused by propulsion
- Design as Line Replaceable Unit
  - Rapid remove and replace
  - Support high ops tempo flight rate

Multiple Affordable Propulsion Options

- Merlin Commercial Rocket
- NK-33 Stockpiled Russian Rocket
- SSME Space Shuttle Engines

OV-1 Derived Capabilities

Step One: S-1
- 3.5K Payload
- 10X lower cost

Enabled Futures
- Global Reach Capability
- 100X lower cost

Delivers 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
  - Hypersonic testing / release of free-flyers

### 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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**Worldwide Projected Payloads: 2013 to 2022**

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<thead>
<tr>
<th>Year</th>
<th>No. Payloads</th>
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<td>2013</td>
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<td>600</td>
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<tr>
<td>2021</td>
<td>650</td>
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<tr>
<td>2022</td>
<td>700</td>
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**Note:** Data from ILS, SpaceX, Blue Origin, Arianespace, Virgin Galactic, and United Launch Alliance.
XS-1 Could Facilitate Next Gen 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**
- 15 Mach No.
- Downrange (nm)
- Burn Out Mach No.
- Free Flyers
- Captive Carry
- Constant Q Test Time
  - ~90 sec
  - ~120 sec
  - ~300 sec

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

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

Industry Would Lead Commercial and Military Transition Options
Stepping Stone to Future Capabilities
Technology scalable to future capability

Proposed XS-1 Program

Scalable/Traceable to Future Capability

National Concepts

Near Term Transition Options

Many Transition Options

Aircraft-Like operability
National security global reach architectures

Commercial Launch for ORS, AF & Intel
Enable AFSPC Full Spectrum Launch Capability

Flight Test Build

F-15 (Size Ref) XS-1

DARPA

Flight Test
Mach 10 Would Validate Critical Access to Space Technology

- Micro Meteoroid Environment
- Max Heat Load Integrated Temperature Effects
- Emissivity Effects
- Oxidation Effects
- High-Temperature Seal Integrity
- Catalytic Heating Effects
- Real Gas Aero Effects
- Boundary Layer Transition
- Hypersonic Aero, Vacuum Environment
- Peak Power Loads, TPS Waterproofing, Thermal Cycles (>10 fits)
- TPS Bondline Integrity, NDE Inspection Techniques, VHLM Approaches
- Thermal Conductivity, Temperature Profiles, Fatigue Properties (>10 fits)
- Cryopumping/low Accumulation, Insulation Properties, Dynamic Pressure Loads
- Facilities/GSE, MMTR/MTBF/MLHTR (>10 fits), Ground Crew Size, Supersonic Aero
- Propellant Density Properties, Max Acoustic Loads, Cryo Insulation Properties, Weather Effects
- Max Mechanical Loads, Stress/Strain Profiles, Strength/Density Properties, Subsonic Aero
- Flight Weights/Gages, Production/DOT&E Costs, Manufacturability/Tooling/Tolerances/Non-Optimiz

XS-1 will mature technology for 1st Stage AND fully reusable flight to space

Distribution Statement A – Approved for Public Release, Distribution Unlimited
XS-1 Seeks to ...

- Push Mach capability well beyond suborbital tourism
- Engage FAA-DOD-Industry teams to establish safe standards of practice for new launch systems
- Leverage commercial sector technology (Blue Origin, Virgin Galactic, XCOR, etc.)
- Transition vendor/subcontractor technology to commercial sector
- Transition some system prime technology to commercial sector
- Transition launch capability to commercial sector
- Explore new missions like hypersonic testing and point-to-point transport
- Enable more affordable launch expanding satellite opportunities
- Serve as a step to fully reusable access to space technologies

Trailblaze next generation commercial space ... technology, flight envelope, regulatory, new markets, etc.

Summary

Highlights
- New era — Launch costs growing, budgets declining and threats proliferating
- Disruptive — Order of magnitude lower cost → new game changing capabilities
- Leverage — Emerging suborbital and launch technology & entrepreneurs
- Transition — Industry leads, many paths forward → Commercial, DoD, civil

XS-1 program could be an agent for change ...
... DARPA open to innovative industry proposals

Several Notional Concepts