CONCEPT STUDY OF AN ARES HYBRID-OS LAUNCH SYSTEM

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Introduction
- Based on Analysis-of-Alternatives (AoA) study and recommendations, U.S. Air Force was interested in studying a partially-reusable space-launcher capable of delivering 15,000 lbs. payload to LEO
- Premise is that an all-rocket system with a reusable booster and expendable upperstage will significantly reduce costs and improve operability and responsiveness
- Fully-reusable booster releases the expendable upperstage at ~Mach 7 in hopes that flight conditions will permit minimal TPS on the booster stage
- System will attempt to maximize use of existing hardware (e.g. engines) and limit new technology developments

Objective
- SpaceWorks Engineering Inc. (SEI) created an all-rocket Hybrid-OS reference design for comparison purposes with current and future concept studies

Ground Rules and Assumptions:
- Winged-body booster with two-stage expendable upperstage
- Booster propellants: RP-1 and LOX
- Initial liftoff T/W of 1.3 with stage ignition in series
- Booster RTLS using turbine-power at subsonic speeds
- Payload: 15Klbs to final orbit of 28.5° at 100 nmi. circular with MECO at 50x100 nmi.
- Booster propulsion system parameters-
  - T/W)sls : 105:1
  - Isp,sls : 305.0 seconds
- Other necessary design details, performance values, etc. generated in-house by SEI

Hybrid-OS Introduction and Overview

Analysis-of-Alternatives (AOA) Study Hybrid-OS (non-SEI) Designs
### Design Tools Utilized for *Hybrid-OS* Concept Analysis

<table>
<thead>
<tr>
<th>Discipline</th>
<th>Tools, Models, Simulations</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAD and Packaging</td>
<td>Solid Edge</td>
</tr>
<tr>
<td>Aerodynamics</td>
<td>APAS, S/HABP, NASCAR-GT</td>
</tr>
<tr>
<td>Propulsion</td>
<td>REDTOP-2</td>
</tr>
<tr>
<td>Trajectory Optimization</td>
<td>POST-2 (trimmed), Flyback-Sim</td>
</tr>
<tr>
<td>Aeroheating and TPS</td>
<td>S/HABP and Sentry</td>
</tr>
<tr>
<td>Weights and Sizing</td>
<td>Parametric MERs, historical databases, Excel-based sizing model</td>
</tr>
<tr>
<td>Subsystems</td>
<td>SESAW (avionics), Fairing-Sizer</td>
</tr>
<tr>
<td>Operations</td>
<td>AATe and TAPS</td>
</tr>
<tr>
<td>Safety and Reliability</td>
<td>GT-Safety II</td>
</tr>
<tr>
<td>Economics and Cost</td>
<td>CABAM and NAFCOM 2004</td>
</tr>
<tr>
<td>Facilities and Ground Equipment</td>
<td>FGOA</td>
</tr>
<tr>
<td>System Engineering</td>
<td>ProbWorks, ModelCenter®, Analysis Server</td>
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</tbody>
</table>

**Vehicle Performance Toolset**

**Economic Closure Toolset**

**Collaborative Design and Optimization**
Concept Overview

- Partially reusable, all-rocket, Earth-to-Orbit (ETO) launch vehicle
- Capable of delivering a 15 klb payload to Low Earth Orbit (LEO)

**Booster Stage:**
- LOX / RP-1 ascent propellants
- Wing-body configuration
- Jet powered flyback

**Upper Stage:**
- LOX / RP-1 two-stage upper stage
- Derived from SpaceX Falcon 1 small launch vehicle
- SpaceX Merlin (2nd stage) and Kestrel (3rd stage) engines
- Advanced systems engineering tools and processes used for conceptual design
Mission Profile: Hybrid-OS Concept

Liftoff from Cape Canaveral, FL Military Space Port
T/W = 1.3, GLOW = 710,750 lbs

Booster RTLS using turbine engines at Mach 0.6 and 23 kft
Approximately 320 nmi. downrange

Booster staging event
Mach 7, 167 kft,

Upperstage staging event
21.6 kft/s (relative), 421 kft,

15 klbs payload delivery
MECO at 50x100 nmi. orbit
Circularize to 100x100 nmi.
28.5 degree inclination
Concept Results
**Hybrid-OS Booster**

<table>
<thead>
<tr>
<th>Item</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross Weight</td>
<td>710,750 lb</td>
</tr>
<tr>
<td>Dry Weight</td>
<td>78,870 lb</td>
</tr>
<tr>
<td>Stage Gross Weight (w/o payload)</td>
<td>568,980 lb</td>
</tr>
<tr>
<td>Ascent Mass Ratio</td>
<td>2.96</td>
</tr>
<tr>
<td>Flyback Mass Ratio</td>
<td>1.15</td>
</tr>
<tr>
<td>Ascent Mixture Ratio</td>
<td>2.7</td>
</tr>
<tr>
<td>Length</td>
<td>105 ft</td>
</tr>
</tbody>
</table>
Hybrid-OS: Booster Internal View
**Hybrid-OS Upper Stages**

<table>
<thead>
<tr>
<th>Item</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross Weight</td>
<td>141,760 lbs</td>
</tr>
<tr>
<td>Dry Weight *</td>
<td>6,820 lbs</td>
</tr>
<tr>
<td>Mass Ratio **</td>
<td>4.63, 1.32</td>
</tr>
<tr>
<td>Mixture Ratio **</td>
<td>2.17, 2.35</td>
</tr>
<tr>
<td>Length</td>
<td>96 ft</td>
</tr>
</tbody>
</table>

* Sum of Both Stages  
** 2nd Stage, 3rd Stage
**Stage Derived from Falcon I First Stage:**
- Uses two (2) SpaceX Merlin engines
- Common materials and technologies with SpaceX Falcon I launch vehicle

**Interstage Derived from Falcon I**

**Small Circularization Stage Derived from Falcon I Second Stage:**
- Uses one (1) SpaceX Kestrel engine
- Common materials and technologies with SpaceX Falcon I launch vehicle
- Totally redesigned payload fairing suitable for ARES mission requirements

**Hybrid OS: Upper Stage Components**
**Key Concept Technologies and Features**

Vertical take-off, horizontal landing
All-new, domestic (United States) LOX/RP-1 main rocket engines
Limited thermal protection system (TPS) including coverage of leading edges
Aluminum Airframe primary and secondary structure
Cylindrical, integral Al fuel and oxidizer tanks
Two (2) low bypass turbofan jet engines for flyback capability
EHA's (electro-hydraulic actuators) for control surfaces
No OMS engine requirement
Integrated Vehicle Health Monitoring (IVHM) systems

Booster Specific

All-rocket, two stage upperstage derived from Space Exploration Technologies’ (SpaceX) Falcon-1 launch vehicle
SpaceX Merlin LOX/RP-1 engine on 2nd stage
SpaceX Kestrel LOX/RP-1 engine on 3rd stage
EMAs (electro-mechanical actuators) for pitch and yaw control

Upperstage Specific

Integrated Vehicle Health Monitoring (IVHM)
Advanced avionics for autonomous flight capability

Entire System
Trajectory Analysis
Ascent Trajectory: Altitude vs. Time and Mach Number

**Altitude vs. Time**

- **Booster Staging**: (Mach 7, 167 kft)
- **2nd Stage Staging**
- **Payload Insertion**

**Altitude vs. Mach Number**

- **Booster Staging (Mach 7, 167 kft)**
Ascent Trajectory: Dynamic Pressure and Acceleration vs. Mach Number
Ascent Trajectory: Engine Thrust and Isp vs. Mach Number

Throttling
Ascent and Flyback Trajectory: Altitude and Booster Heat Rate vs. Time
Detailed Results
## Hybrid-OS Payload Fairing Design

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Payload Density</td>
<td>10.0 lbs/ft³</td>
</tr>
<tr>
<td>Fairing Diameter</td>
<td>8.33 ft</td>
</tr>
<tr>
<td>Fairing Length</td>
<td>30 ft</td>
</tr>
<tr>
<td>Material Type</td>
<td>Aluminum</td>
</tr>
<tr>
<td>Total Weight</td>
<td>2,000 lbs</td>
</tr>
<tr>
<td>Total Volume</td>
<td>1,500 ft³</td>
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</table>
Three (3) main engines on Hybrid-OS booster

All new U.S. engine design

RP-1 and LOX propellants

Oxidizer-rich staged combustion cycle with single preburner and turbine

No restart or air-start capability required

Gimbals

Sized to provide a booster T/W of 1.3 at liftoff

### ENGINE SPECIFICATIONS:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxidizer/Fuel (OF) Ratio</td>
<td>2.7</td>
</tr>
<tr>
<td>Isp – Vacuum/Sea-Level (s)</td>
<td>332 / 305</td>
</tr>
<tr>
<td>Thrust - Vacuum/Sea-Level (each, lbs)</td>
<td>336,000 / 308,000</td>
</tr>
<tr>
<td>Engine T/W –Vacuum / SLS</td>
<td>115 / 106</td>
</tr>
</tbody>
</table>
- Two (2) SpaceX “Merlin” engines on Hybrid-OS 2\textsuperscript{nd} Stage
- RP-1 and LOX propellants
- Gas-generator cycle
- Pintle style injector

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxidizer/Fuel (OF) Ratio</td>
<td>2.17</td>
</tr>
<tr>
<td>Isp – Vacuum/Sea-Level (s)</td>
<td>304 / 255</td>
</tr>
<tr>
<td>Thrust – Vacuum/Sea-Level (lbs)</td>
<td>92,000 / 77,000</td>
</tr>
<tr>
<td>Uninstalled Weight (each, lbs)</td>
<td>960</td>
</tr>
<tr>
<td>Engine T/W – Vacuum</td>
<td>96</td>
</tr>
</tbody>
</table>

2nd Stage Propulsion System
One (1) SpaceX “Kestrel” engine on *Hybrid-OS 3*rd Stage

- **RP-1** and **LOX** propellants
- **Pressure-fed cycle**
- Pintle style injector
- **Restart required** for circularization burn at apogee of 50x100 nmi. MECO orbit

### ENGINE SPECIFICATIONS:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxidizer/Fuel (OF) Ratio</td>
<td>2.35</td>
</tr>
<tr>
<td>Isp – Vacuum (s)</td>
<td>327</td>
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<tr>
<td>Thrust - Vacuum (lbs)</td>
<td>7,000</td>
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<tr>
<td>Uninstalled Weight (each, lbs)</td>
<td>167</td>
</tr>
<tr>
<td>Engine T/W – Vacuum</td>
<td>42</td>
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**3rd Stage Propulsion System**
### Booster Aerodynamics

#### APAS Analysis Grid

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Wings</th>
<th>Tails</th>
<th>Canards</th>
</tr>
</thead>
<tbody>
<tr>
<td>Span/Height (ft)</td>
<td>55</td>
<td>18</td>
<td>12</td>
</tr>
<tr>
<td>Sweep Angle (deg)</td>
<td>53</td>
<td>60</td>
<td>30</td>
</tr>
<tr>
<td>Root Chord (ft)</td>
<td>33</td>
<td>13</td>
<td>10</td>
</tr>
<tr>
<td>Tip Chord (ft)</td>
<td>3.7</td>
<td>3</td>
<td>8.0</td>
</tr>
<tr>
<td>Sref (ft²)</td>
<td>1,010</td>
<td>290</td>
<td>216</td>
</tr>
</tbody>
</table>
Utilized SEI’s Sentry code to determine approximate surface temperatures for *Hybrid-OS* booster

Convective heat transfer rates provided by S/HABP

Analysis conducted at each grid node was 1-D, thus significant airframe conduction not accounted for

- High temperatures on windward side likely worst-case and low temperatures on leeward side likely under-predicting maximum reached

Results

- Wing, tail, and canard leading edges will require some TPS due to small local radii
- Remainder of airframe appears to be within limits of metallic (Aluminum) skin material
Approx. Booster Surface Temp. Distribution: Integrated Ascent and Flyback Trajectory
Summary Conclusions and Observations
Summary
- An all-rocket, LOX/RP-1 version of a Hybrid-OS concept design has been created as part of an independent assessment
- Hybrid-OS employs a reusable booster and two-stage expendable upperstage in an effort to enhance affordability and responsiveness
- SEI’s approach leverages existing systems and technologies through the use of SpaceX Falcon-derived upperstages and propulsion systems

Conclusions
- Trajectory simulation and aeroheating analysis results have increased confidence in ability to avoid extensive TPS on the booster airframe (limited TPS is required on leading edges and nose)
- Although the Hybrid-OS trajectory is sub-optimal in terms of performance (gross mass, etc.), the operational benefits of this approach enable the objectives of affordability and responsiveness

Observations and Recommendations
- The design characteristics of the booster flyback system are significant drivers in the design of the overall system
  ▶ Difficult to achieve optimal performance matching when using existing turbine engines
- While SEI examined jet engine propulsion for flyback, future studies should consider rocket boost-back as an alternative

ARES Hybrid-OS Concept Remarks
## ARES Hybrid-OS All-Rocket Concept Summary

<table>
<thead>
<tr>
<th>Item</th>
<th>Characteristics</th>
</tr>
</thead>
</table>
| **Concept**   | Autonomous, uncrewed TSTO VTHL Launch Vehicle  
Winged-body booster with ascent (rocket) and flyback (turbofan) propulsion systems  
Two-stage expendable Upperstage to provide final orbital insertion boost for payload  
Utilizes number of advanced propulsion systems to enable mission flexibility and operationally responsive space lift |
| **Reference Mission** | Payload: 15,000 lbs.  
Delivery to 100 nmi. @ 28.5 degrees inclination from Cape Canaveral                                                                 |
| **Propulsion** | Booster:  
(3) LOX/RP-1 Liquid Rocket Engines (Tsls, each=308Klbs.), (2) Subsonic turbine engines  
Upperstage:  
Stage 1: (2) Merlin engines (Tvac=77kbs, T/W=96:1)  
Stage 2: (1) Kestrel engine (Tvac=7klbs, T/W=42:1) |
| **Sizing**    | GLOW: 710,750 lbs, Upperstage Gross Weight (2nd+3rd): 141,760 lbs  
Booster Dry Wt.: 78,870 lbs, Upperstage Dry Wt.(2nd+3rd): 6,820 lbs  
Overall Length: 105 ft, T/W @ liftoff: 1.3 |