Launch Abort Systems Overview

Space 2010 Panel Session

Launch Abort Systems: Applying Lessons Learned

David M. McGowan
Chief Engineer,
Orion Launch Abort System
NASA Langley Research Center

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Outline

- Why the Need for a LAS
- Brief Summary of Other Systems
- LAS Requirements
- Major Trades Conducted for Orion
- Orion LAS Configuration
- Lessons Learned

Orion Pad Abort-1

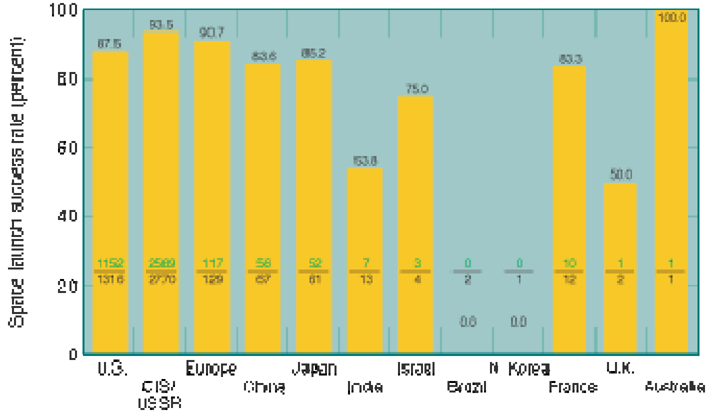
MLAS Abort-1

References

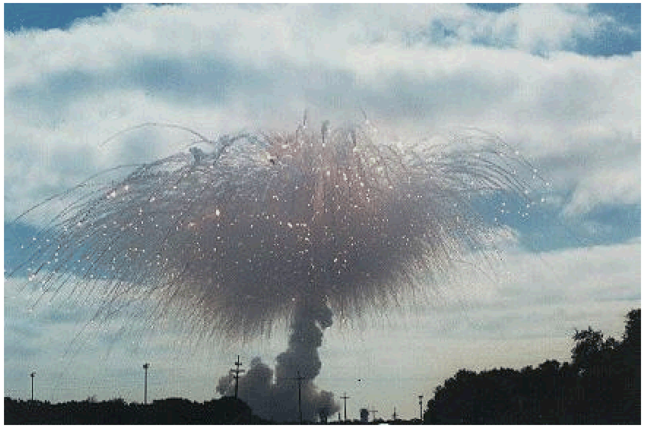
- **Summary information on previous systems relied upon the following sources:**
  - NASA Engineering and Safety Center:
    - Crew Exploration Vehicle "Smart Buyer" Design Team Final Report, Volume 2, Appendix I, May 2006
    - MLAS Overview Presentations
  - Shayler, David J.: *Space Rescue – Ensuring the Safety of Manned Spaceflight,* Springer, New York, NY; Praxis, Chichester, UK, 2009.
- **Summary information on the Orion LAS development relies upon the following source:**
  - Stadler, John.: Launch Abort System (LAS) Trades and Lessons Learned, Presentation at the NESC Launch Abort System Technical Interchange Meeting, Hampton, VA, May 11-12, 2010.

Need for Launch Abort Systems

- **Historical reliability of global launch vehicles is about 90%**
  - Asymptote at ~90%
- **Historical reliability of global human rated launch vehicles is about 99%**
  - Added redundancy and margin
  - More extensive quality/process control
- **Launch Abort Systems (LAS) have the potential to improve Loss of Crew (LOC) probability by almost another order of magnitude.**
  - Designed to prevent LOC 9 out of 10 ascent events



I-S. Chang, "Space Launch Vehicle Reliability" , Aerospace Corp. Crosslink Magazine, Winter 2001.



Mercury

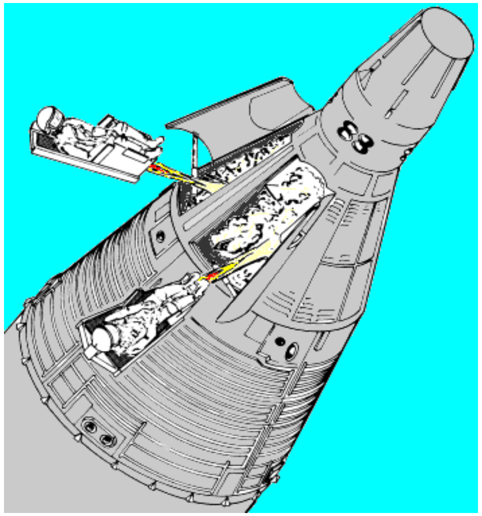
- **An escape tower, which utilized a solid rocket motor, was mounted on a truss above the spacecraft**
- **The entire assembly was jettisoned past its useful flight envelope, to save weight**
- **Abort Sensing Implementation System (ASIS) monitored:**
  - Liquid Oxygen tank pressure
  - Differential pressure across the intermediate bulkhead
  - Attitude rates on all axes
  - Engine injector manifold pressures
  - Sustainer engine hydraulic pressure
  - Primary electrical power
- **The abort sequence initiation:**
  - Automated abort via ASIS Booster Monitoring System
  - Manual initiation via:
    - Astronaut
    - Test Conductor or Flight Director (uplink command started the sequence)
    - Flight termination command from the Range Safety Officer (RSO)

Mercury/Redstone

Mercury/Atlas Lift-off

Gemini

- **Utilized ejection seats for emergency egress**
  - Most powerful rocket catapult ever developed in the US
  - Thrust sized based upon radius of the expected fireball should the TITAN explode
  - Seat required to outrun the fireball for a distance of about 800 feet to protect nylon parachutes
- **System tests included high-speed sled and launch orientation firing to demonstrate 800' seperation**
- **Mode I aborts with ejection seats covered pad to 15,000 ft**
- **Total of 5 abort modes defined**
- **Aborts relied on a fault-detection system coupled with manual initiation by the crew**
  - An abort command could be up-linked by Mission Control as well as the Range Safety Officer (independent system) prior to terminate actions
  - The ejection seat sequence was initiated by manually pulling the ejection handles located between the astronaut's legs

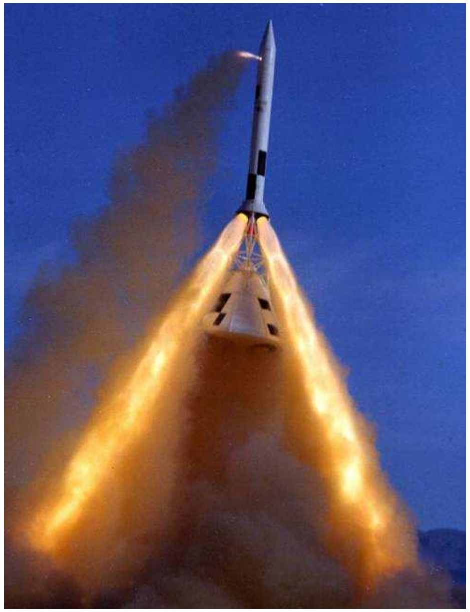


Gemini Launch Abort Seat Operation

Gemini/Titan II Lift-off

Apollo

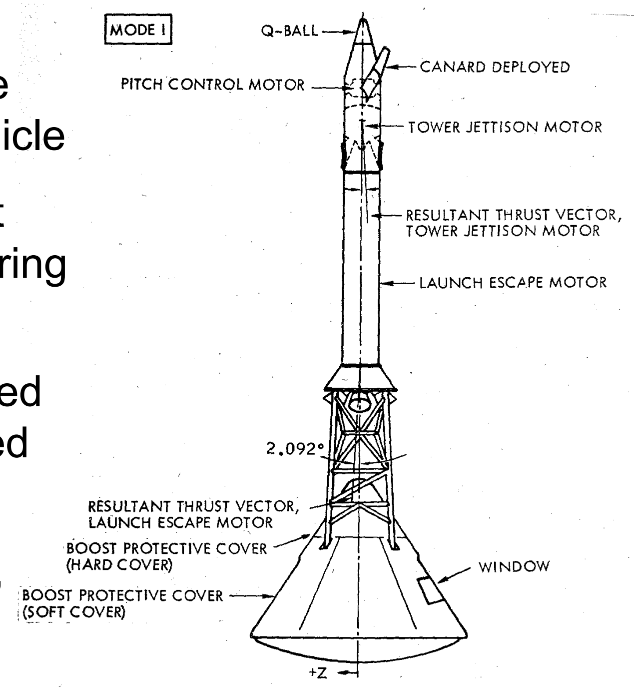
- **The launch escape system (LES) was a tower, which utilized a solid rocket motor mounted on a truss above the spacecraft – similar to Gemini**
- **Mode I aborts covered pad – end of atmospheric flight**
  - **Mode I Alpha** (low altitude mode) – pitch motor orients assembly to ensure the vehicle was directed downrange for water touchdown and to escape a launch vehicle explosion “fireball”
  - **Mode I Bravo** – Canards used to aerodynamically orient the CM (initiated a tumble in the pitch plane which reoriented the CM blunt end forward)
  - **Mode I Charlie** – CM RCS used to establish proper orientation following manual LES jettison. If the attitude platform was bad, then tumble was introduced via the RCS and aerodynamic forces resulted in a blunt end forward for attitude (like Mode 1B).
- **Total of 4 abort modes defined**
- **The Emergency Detection System (EDS) was used to detect launch vehicle conditions requiring an abort**
  - Manual and automatic aborts were possible
  - Manual aborts required two abort cues (EDS, verbal call from ground, “seat of the pants”)



Apollo LES Pad Abort Test

Apollo

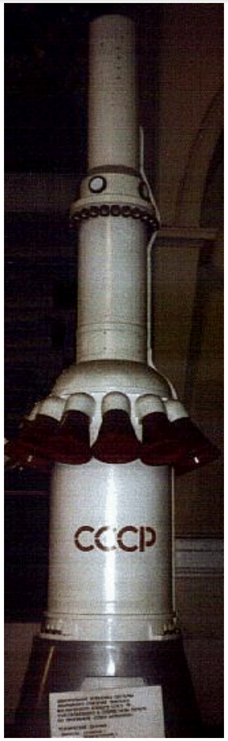
- **Major components of the Apollo Launch Escape System**
  - Nose Cone / "Q-Ball" - contained sensors that determined the angle of attack and attitude of the spacecraft and launch vehicle
  - Canard Assembly and Pitch Motor - worked together to direct the CM off a straight path to the side of the launch vehicle during an abort
  - Tower Jettison Motor - A smaller solid fuel motor that jettisoned the LES after it was no longer needed. Tower jettison occurred after second stage ignition.
  - Launch Escape Motor - The main solid fuel rocket motor that, when firing through four rocket nozzles, pulls the CM rapidly away from a launch emergency
  - Launch Escape Tower - Assembly that attaches the LES rocket motors to the CM
  - Boost Protective Cover - Hollow cone-shaped structure that fits over the CM during launch to protect its heatshield and windows during ascent through the atmosphere. It also protected the CM from rocket exhaust should the LES fire.



Apollo Launch Escape System

Soyuz/Shenzou

- **Very similar architecture consisting of**
  - Escape tower
  - Payload fairing (aerodynamic shroud)
  - Orbital and descent modules
  - Four aerodynamic flaps on the upper shroud to stabilize the escape vehicle during its high-speed flight
- **Propulsion system includes 6 solid-fuel motors:**
  - Four control motors
  - Low altitude separation motor
  - Low altitude escape motor
- **There are also six motors on the upper shroud:**
  - Two high altitude separation motors
  - Four high altitude escape motors
- **Two abort regions exist:**
  - Low altitude - ground to 39 Km – utilizes escape tower
  - High altitude - 39 Km – 110 Km – utilizes shroud-mounted propulsion
- **Emergency monitoring system is utilized**
  - Manual and automated aborts are possible



Soyuz

Shenzhou

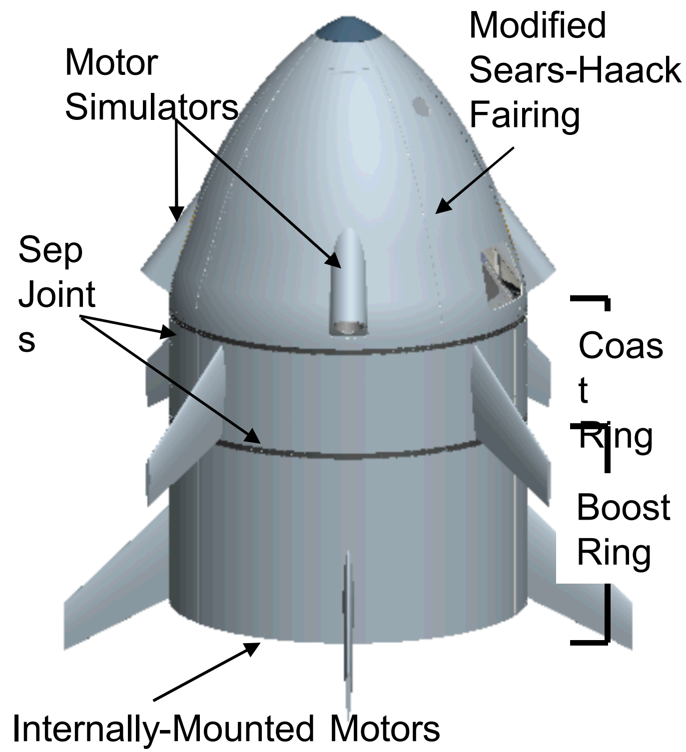
Soyuz T-10-1 Pad Abort September 26, 1983

- **The only use of a launch escape system was on the Soyuz T-10-1 on September 26, 1983**
  - Ninety seconds before lift-off, a fuel valve at the base of the rocket malfunctioned, opening and spilling fuel uncontrollably onto the launch pad
  - The fire had burned the system’s wiring, preventing it from being activated automatically
  - Cosmonaut attempts to fire the launch-escape system manually failed
  - Mission control initiated the abort 10 seconds after flames appeared with the vehicle leaning 20 degrees to the side

Soyuz T-10-1 Pad Abort
September 26, 1983

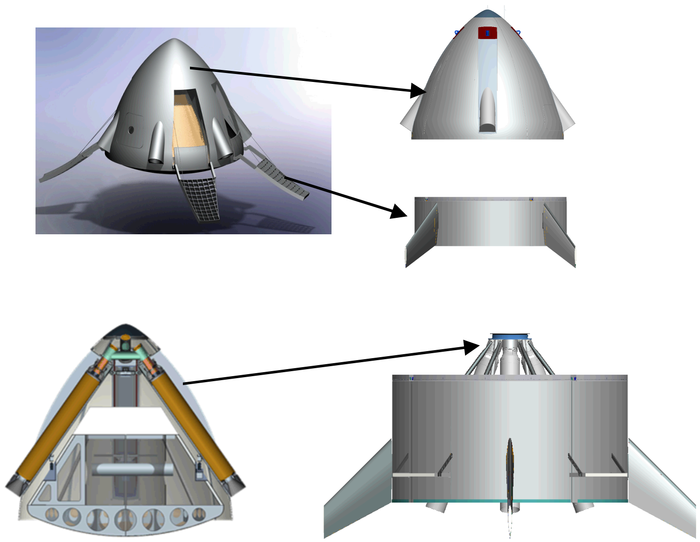
Max Launch Abort System (MLAS)

- **Developed by the NASA Engineering Safety Center as a risk mitigation for the baseline Orion LAS**
- **Named for Maxime "Max" Faget who developed the tractor (tower) escaper system concept**
- **Three MLAS objectives derived from project goals:**
  - Demonstrate a passively-stabilized LAS on a vehicle of Orion's size and weight class
  - Demonstrate separation of a fully-encapsulated CM from its fairing while capturing associated aerodynamic and orientation data
  - Conduct a flight test to gather data suitable for assessing FTA performance and validating design models and tools
- **The MLAS flight test demonstrated the basic "tower-less" LAS concept by simulating key elements of the aerodynamically controlled objective system**
  - Aft-mounted motors provided propulsion
  - Boost and coast flight stability provided by fixed fins



Max Launch Abort System (MLAS)

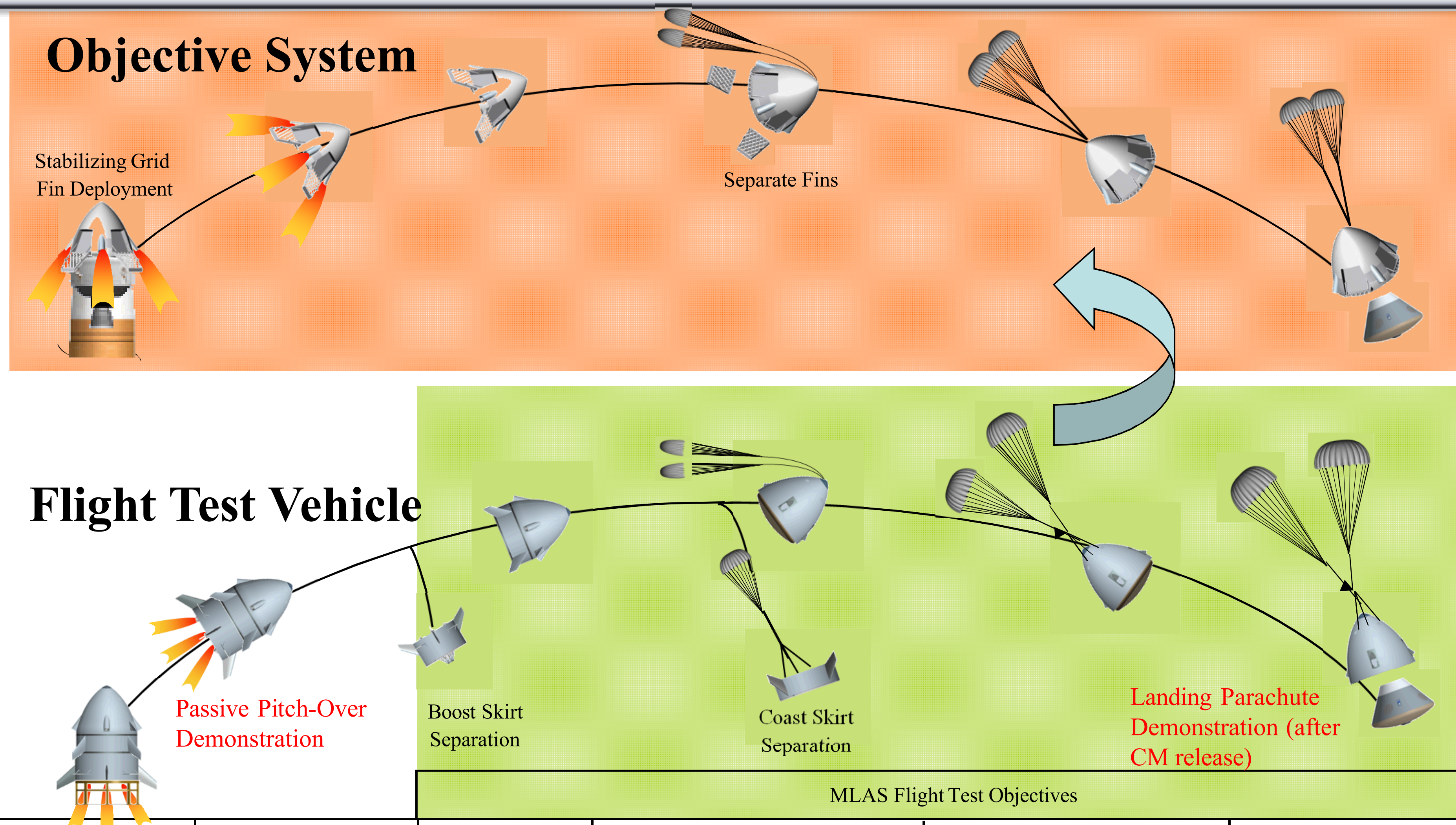
- **Conventional fins were used in lieu of active control or deployable drag fins to reduce project schedule and risk**
- **Existing Mk-70 (no active thrust vector control) were integrated into an boost stage to reduce project schedule and risk**
  - Motors moved aft & canted to minimize dispersions
  - Thrust alignment w.r.t. vehicle c.g. used to achieve abort pitch over



MLAS Upper Shell Assembly at NASA Wallops

MLAS on Pad at NASA Wallops

MLAS OS-Flight Test Con-Ops Relationship



		MLAS Flight Test Objectives			
Pad Abort Initiation	Powered Ascent	Stable Coast	Separate Stabilization Devices And Begin Reorientation	Reorientation And Stabilization	CM Delivery to Release Point Conditions

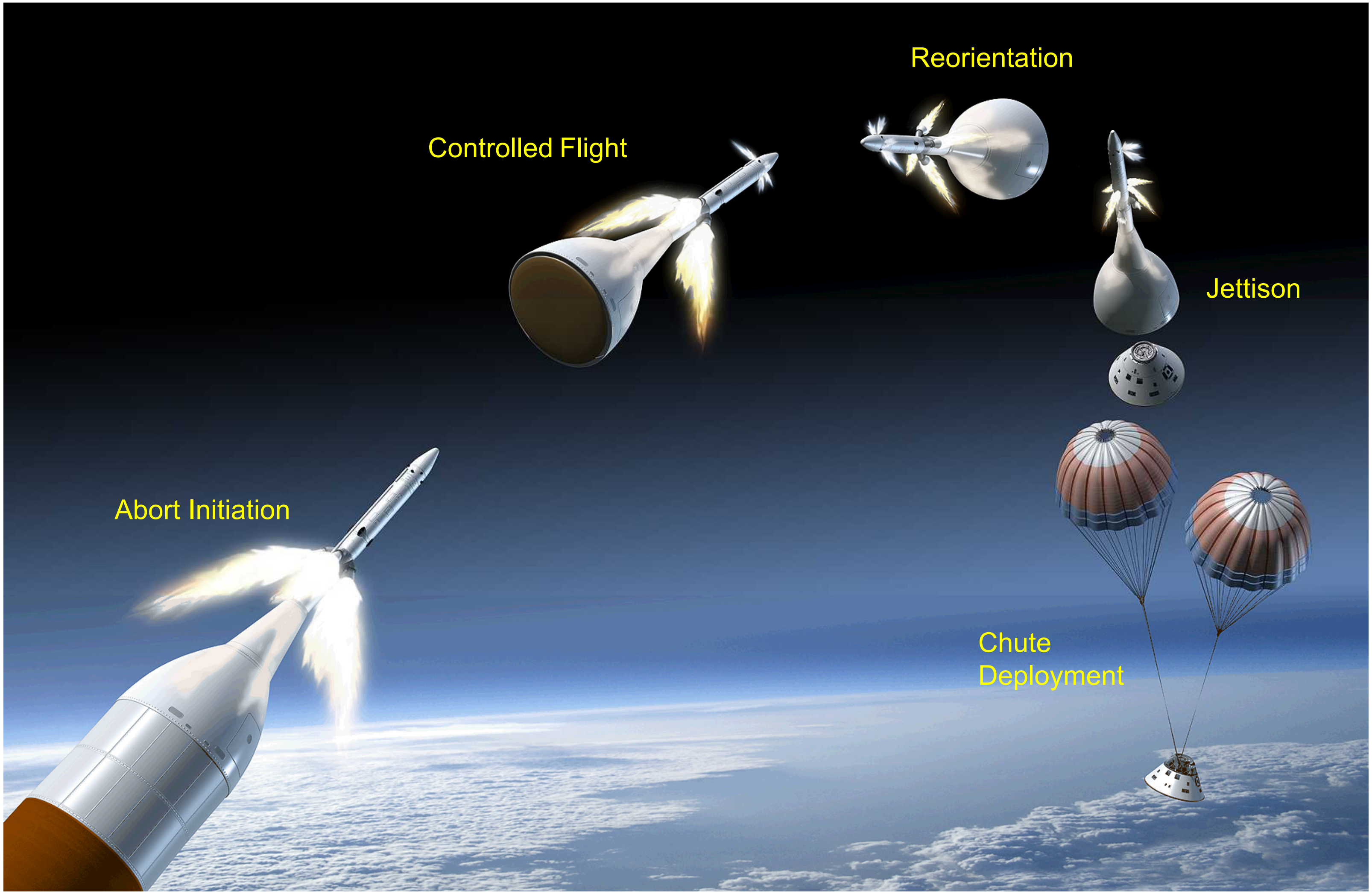
MLAS Flight Test

July 8, 2009, 6:30am

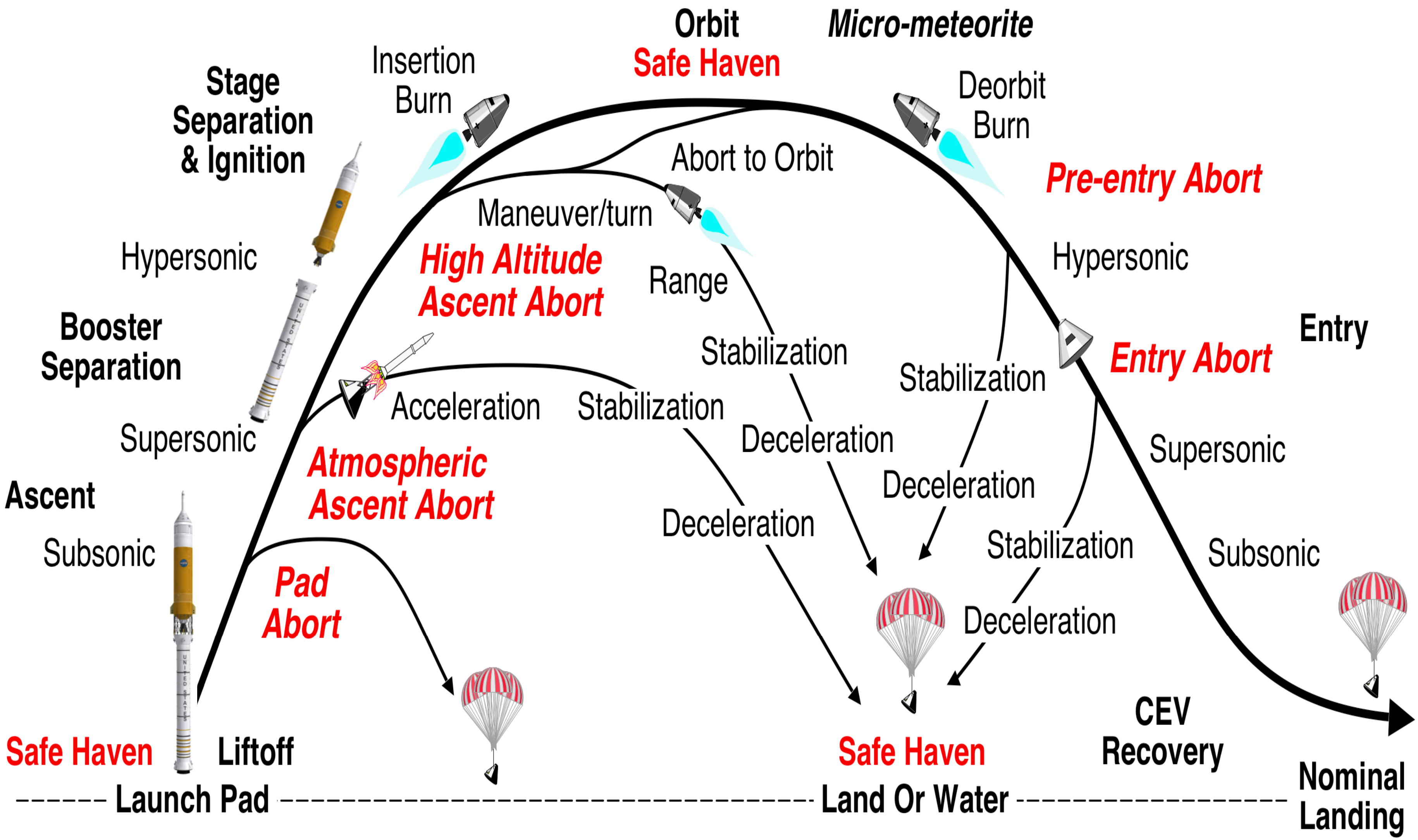
Key LAS Design Tenets

- **Know when you need to activate LAS**
  - Identify Launch Vehicle Failure Modes
  - Determine Methods of Detecting Failure
  - Implement Sensors
  - Define Trigger Thresholds
- **Determine most effective way to protect crew from the failure environment**
  - Abort Modes (LAS, ATA, ATO)
- **Determine best way to survive for each condition**
  - Abort Operations
- **Put crew capsule in safe recovery mode**
  - Remove from Hazardous Condition
  - Reorientation & Stabilize
  - Parachute Deployment

Abort Operations Concept



Orion Abort Scenarios

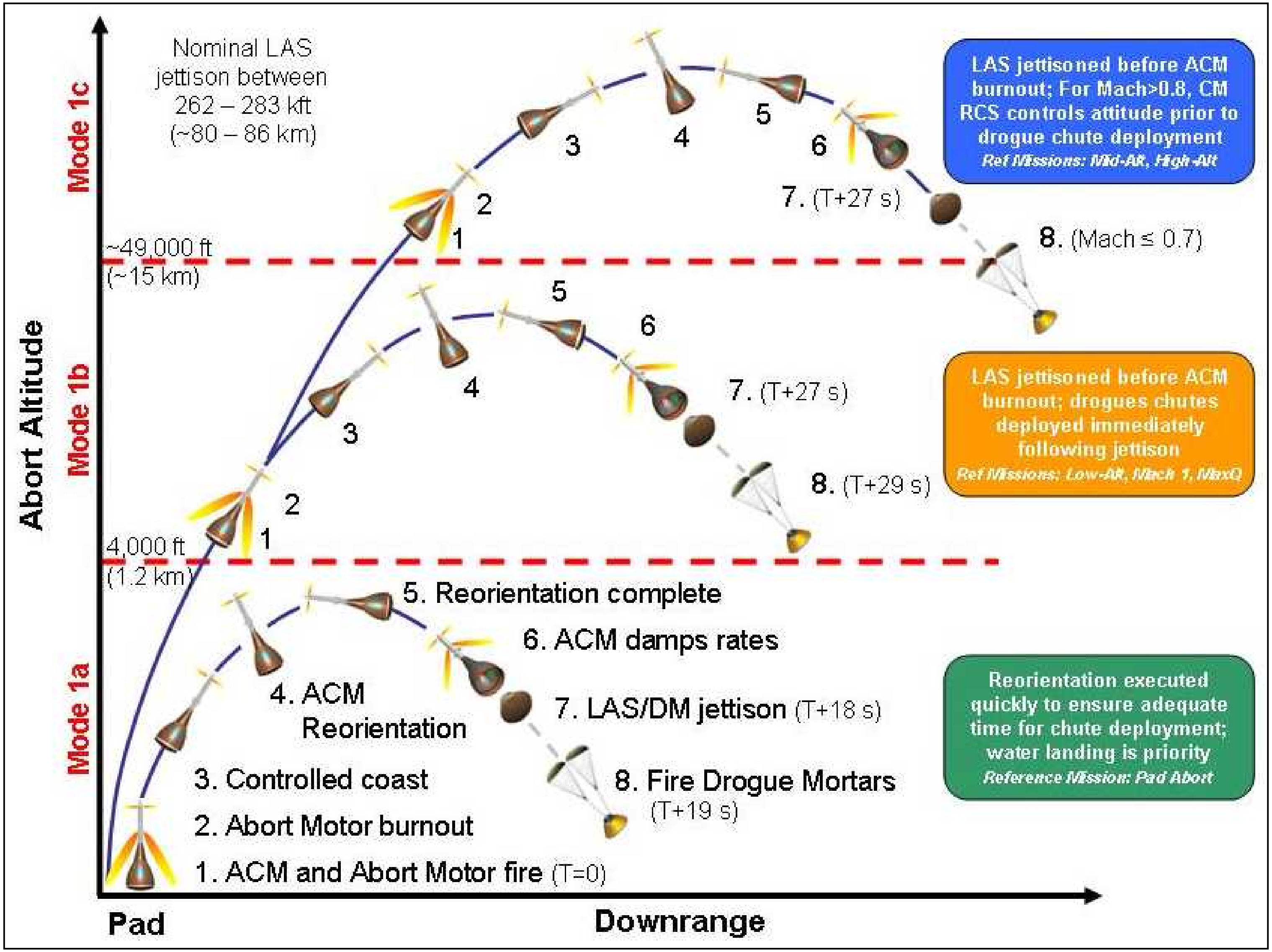


LAS Requirements

- **Provide Ascent Aborts from Pad to First Stage Separation**
  - From Pad through Transonic to Exo-Atmospheric
- **React as quickly as possible**
  - Declare abort and depart stack when outside of an “abort corridor”
  - If possible initiate the abort before breakup/explosion (i.e., “warning time” is required in many cases)
- **Provide for “absolute minimum” performance such as:**
  - Minimum downrange distance and altitude on a PAD abort
  - Ability to separate from the CLV under worst-case conditions (i.e., max drag)
- **Reorient Crew Module for Parachute Deployment**
- **Water Landing**

Orion LAS

LAS Abort Modes



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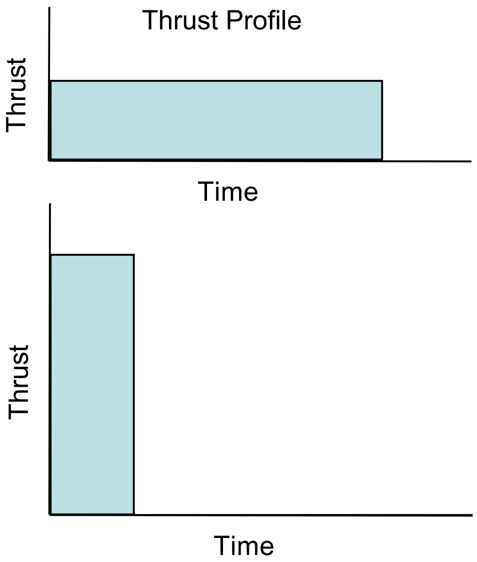
Key Design Considerations

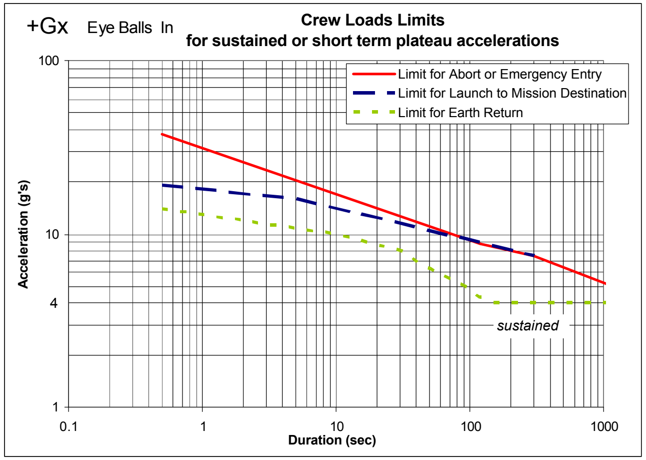
- **LAS is two vehicles in one**
  - Part of the Nominal Launch Vehicle Stack
    - Must Cleanly Jettison on Nominal Ascent
  - Abort Vehicle
- **The LAS is a complex Flight Vehicle**
  - Has to Fly Forwards and Backwards
  - Has to work on the Pad through Transonic and exoatmospheric Conditions

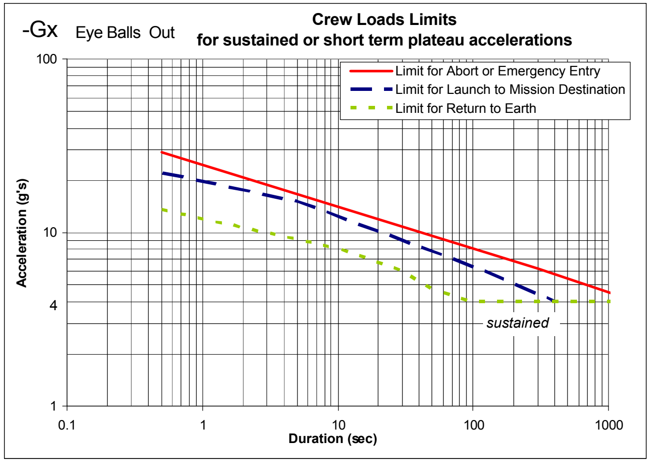
Design Drivers

- **Pad Abort Drives Total Impulse**
  - Relatively low thrust to pitch over and achieve necessary down range for water landing



- **Maximum Drag (Transonic) Drives Initial Thrust Magnitude**
  - High Initial Thrust to overcome Free Stream and Aero Proximity effects
- **Crew Acceleration Limits**
  - Deceleration during Pad Aborts can drive design

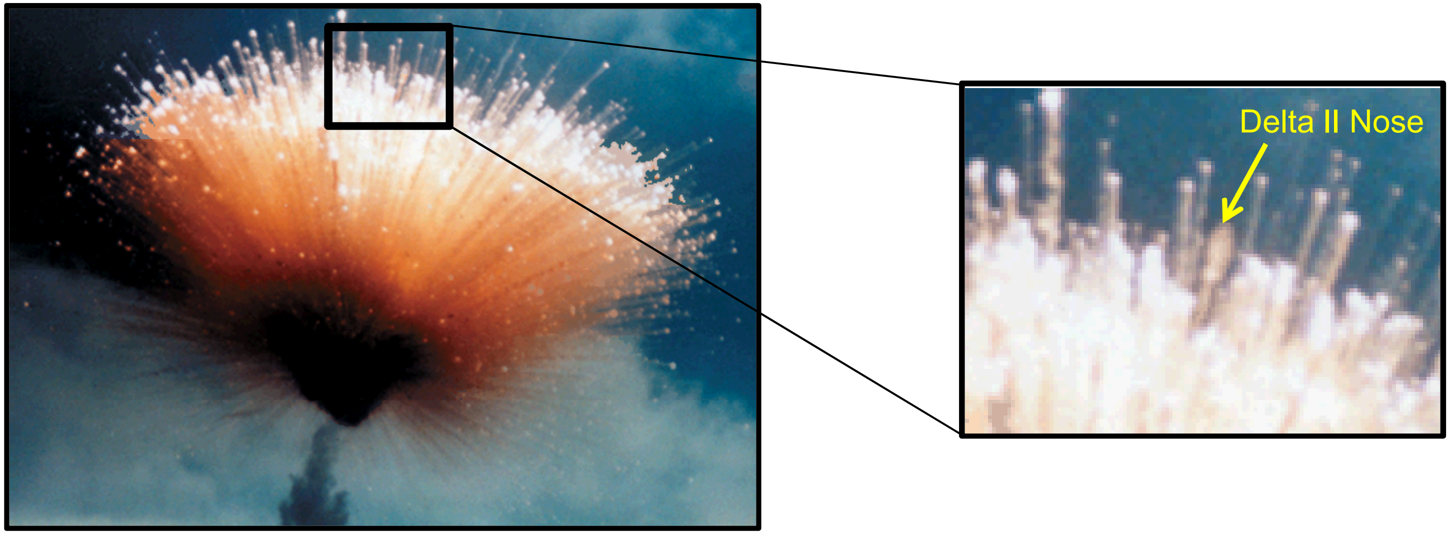




Not Design Drivers

- **Blast Overpressure – Ability to Survive Insensitive to LAS Design**
  - Above Mach 1 – Outrun Blast Overpressure Wave
  - Below Mach 1 – Higher Thrust LAS does *not* decrease required warning time
    - Minimum 1 Second Warning Time to Ensure
- **Debris Field**
  - Difficult to quantify – Random Debris Velocity and Ballistic Coefficients
  - Second Stage & Service Module will tend to protect departing CM

Delta II Debris Field



Parallel Trade Teams

- **Mainline Orion Program Design**
  - Phase 1
  - Phase 2
- **NESC Team Design**
  - Smart Buyer
  - Revisit Side Mount
  - Side Mount in Shroud
  - Ogive Fairing
  - MLAS

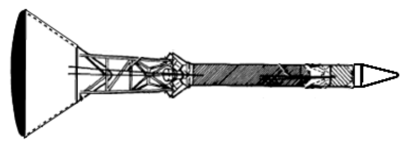
Key LAS Trade Studies

- **LAS Configuration: Pusher/Tractor, Tower/Non-Tower**
- **Thrust Profile: Multiple/Single Motor, Thrust/Weight, Time**
- **Control Approach: Active/Passive, Thrust Offset, c.g./Cp**
- **LAS Ascent Assist: Yes/No, Approach, Level of Redundancy**
- **Outer Mold Line Trades: Drag/Mass/Stability**
- **Motor Type: Solid/Hybrid/Liquid**
- **Level of Human Intervention: Warning Time/Sensors/Algorithms**

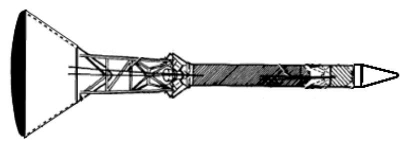
Trades are Interdependent and Must be Considered from a <u>Systems</u> Perspective including Launch Stack and Abort Vehicle Configurations

LAS Design Configurations Evaluated

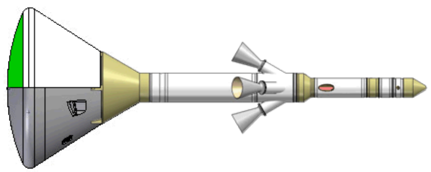
LAS 0: Tower	LAS 1: Crew Module	LAS 2: Service Module



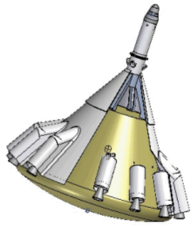
LAS 0-A - Tower (Passive)



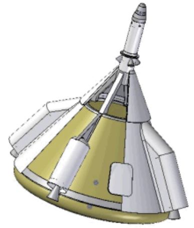
LAS 0-B - Tower (Active)



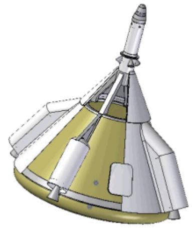
LAS 0-C - Tower (Reverse Flow)



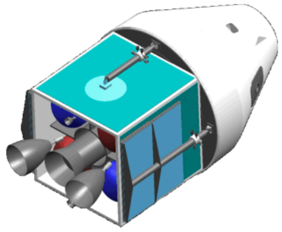
LAS 1-A1 - Crew Module Strap on Motors (12)



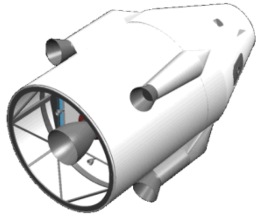
LAS 1-A2 - Crew Module Strap on Motors (4)



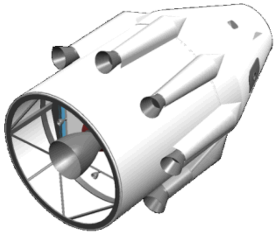
LAS 1-B - Integrated Strap-On CM Motor



LAS 2-A - Single Internal SM Abort Motor



LAS 2-B - Multiple External (4) SM Abort Motors



LAS 2-C - Multiple External (8) SM Abort Motors

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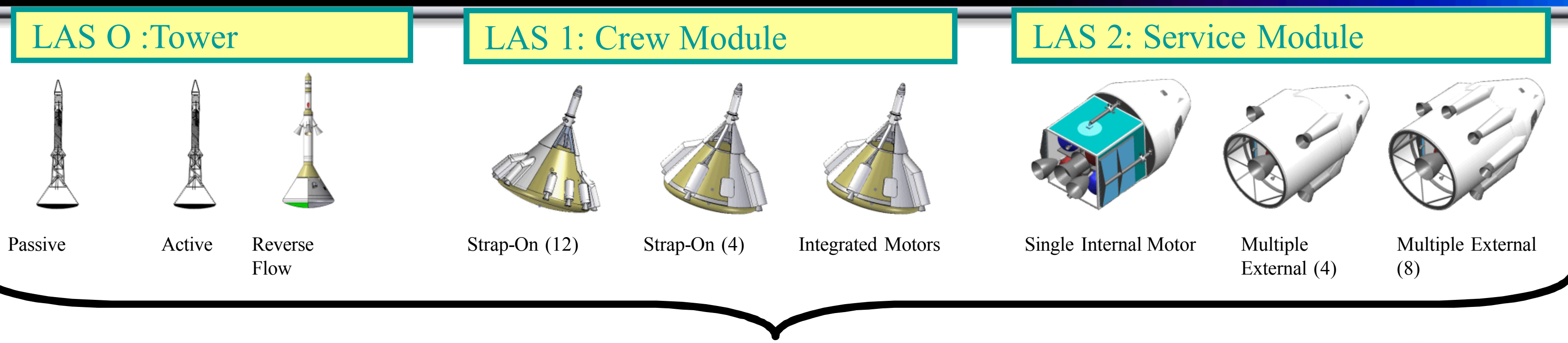
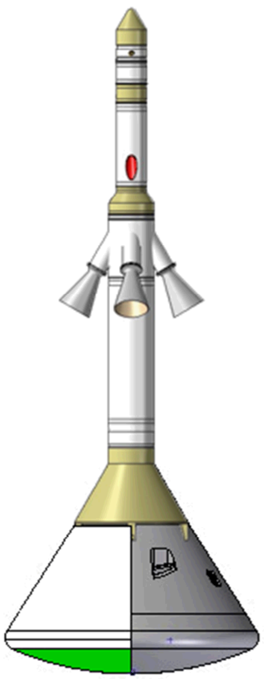
Trade Studies Results



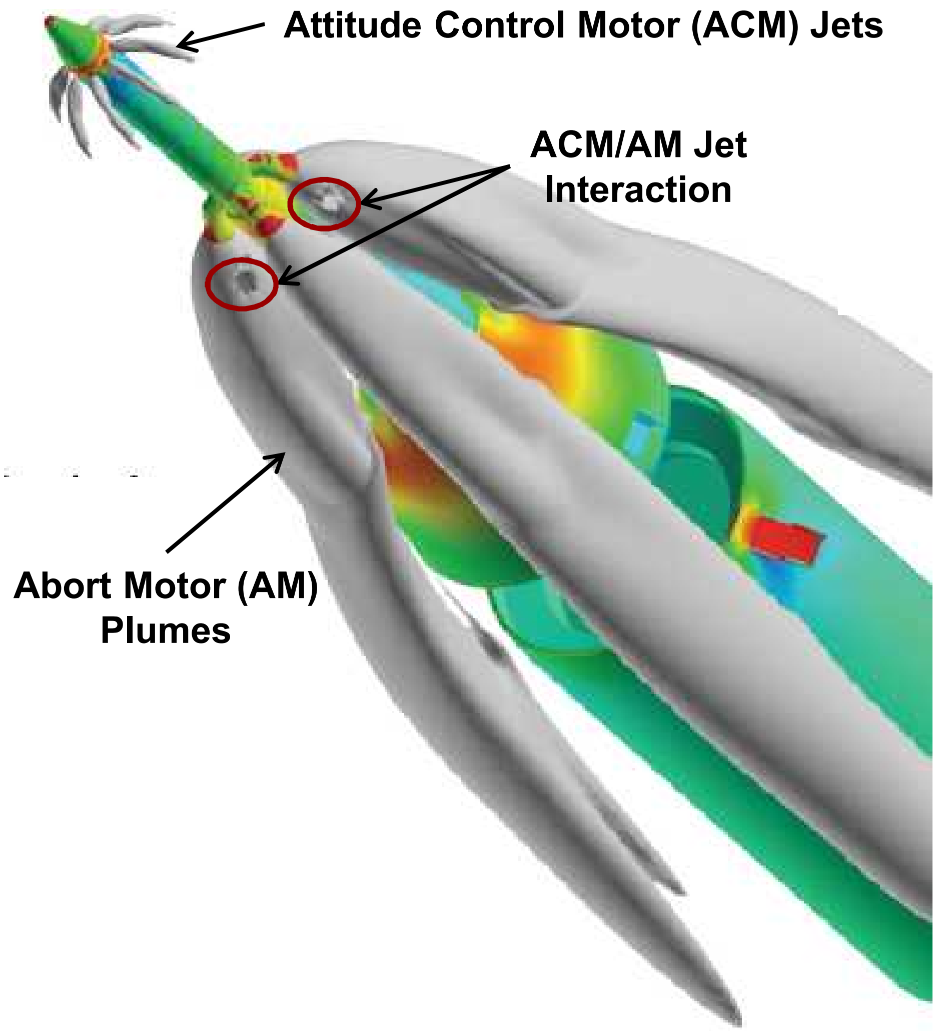
- **Tower Configuration**
- **Single Reverse Flow Abort Motor with Customized Grain**
- **Active Control**
- **Attitude Control Motor – Solid Motor with Pintle Valves Design**



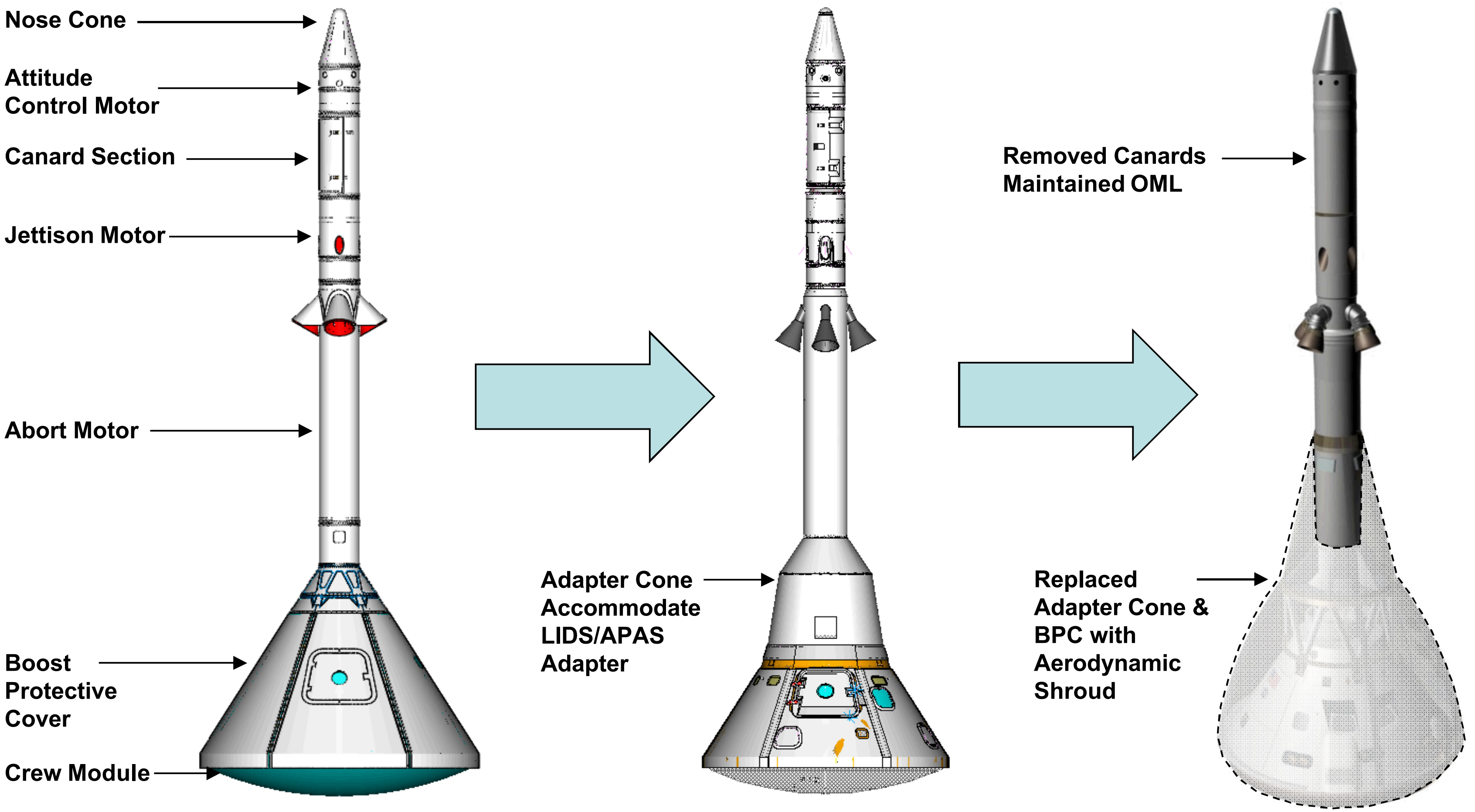
Lower Mass, Less Drag, and Reduced CLV Instability

Challenges

- **Attitude Control Motor TRL**
- **Attitude Control Motor Jet Interactions**
  - ACM nozzles can be Individually adjusted produce pitch and yaw
  - Moments generated by ACM nozzles cannot be approximated simply by the ACM thrust operating on a moment arm.
  - ACM jets interact with Free Stream and AM plume nonlinearly to reduce/enhance the control authority of the ACM.
  - Transonic flight regime is particularly problematic.
- **Abort Motor Plume Acoustic Loads**
  - Drives many of the Secondary Structure Designs



Orion LAS Evolution

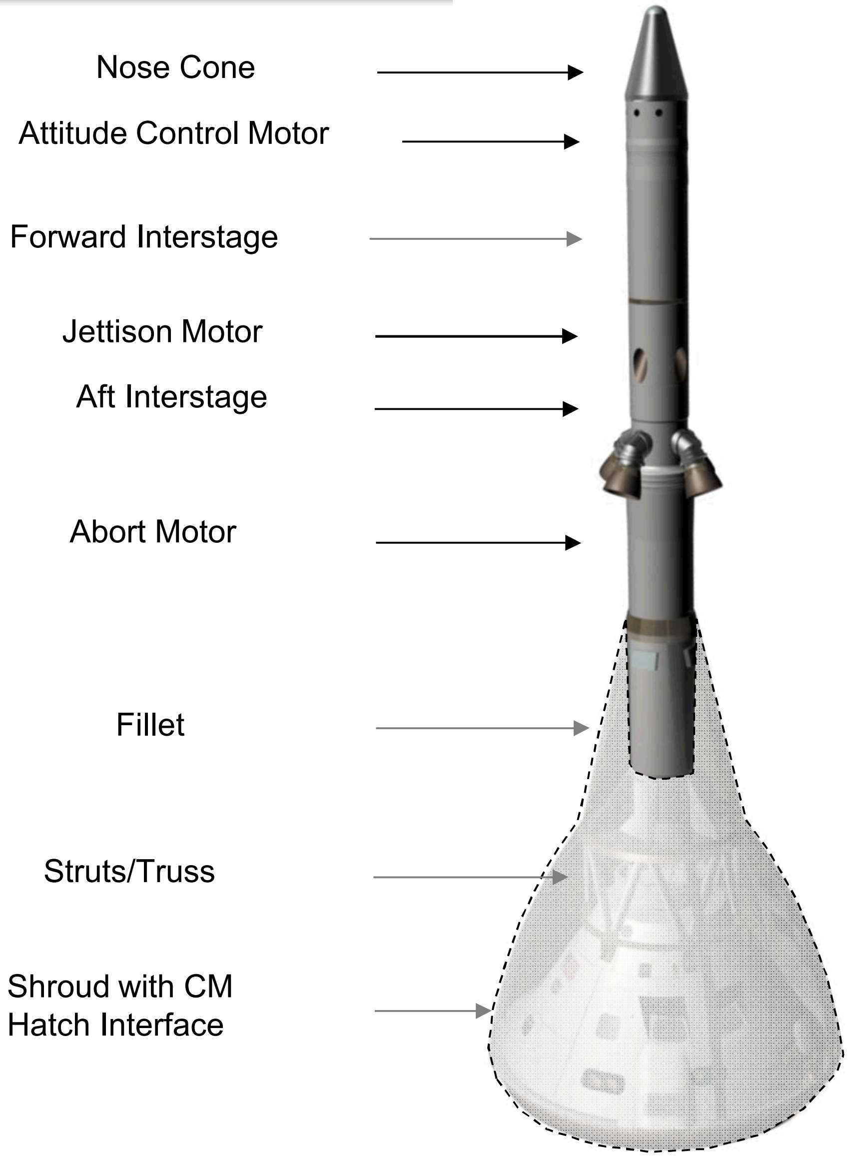


Original Configuration
Passively Stable
Canards provided Graceful Degradation Re-orientation Mode

Interim Configuration
Added Adapter Cone
Neutrally Stable
Canards provided Graceful Degradation Re-orientation Mode

Current Configuration
Added Aerodynamic Shroud to Reduced Drag and Acoustic Noise
Aerodynamically Unstable
Removed Canards

ORION LAS Design



- **Nominal Ascent Functions:**
  - Jettisons at First Stage Separation + 30 sec
  - Shroud Reduces CM Acoustic Levels
- **Abort Functions:**
  - Propels Crew Module to Safety
  - Reorients for to enable Parachute Deployment
  - Jettisons to allow Parachute Deployment
- **Provides Aborts from Pad to first stage Separation**
- **Features Three Solid Rocket Motors**
  - Reverse Flow Abort Motor
  - Jettison Motor
  - Active Pintle Valve Attitude Control Motor
- **Actively Controlled**

Lessons Learned (1/3)

- **Nonlinearities are inherent in full-coverage LAS design**
  - Cannot rely on performance predictions based on linear assumptions in developing LAS concepts
  - Vehicle capability and response changes drastically over flight envelope.
    - Vehicle concepts tailored for atmospheric aborts (pad, transonic, max q) may not be optimal, or even operational at high altitudes.
      - e.g. conventional aerodynamic effectors such as fins and other aerodynamic lifting surfaces.
    - Concepts tailored to high-altitude operations can introduce strong nonlinearities and aerodynamic couplings at lower altitudes.
      - e.g. thrust vectoring and reaction control systems.

Lessons Learned (2/3)

- **Launch Abort System must maintain minimal impact to nominal Launch operations**
- **LAS Design Solution Driven by Launch Vehicle Characteristics**
  - Launch Vehicle Stability/Instability
  - Launch Maximum q, q-Alpha, Acceleration, and Acoustic Loads
  - Launch Site, Inclination, Proximity to Viable Landing Site
  - Available Mass Margin
  - Explosive Potential (TNT Equivalency) and Fragmentation Characteristics

LAS <u>Must</u> Be Designed as a System with the Launch Vehicle

Lessons Learned (3/3)

- **LAS Design Pushed the State of the Art of several tools:**
  - CFD Aerodynamic ACM and Abort Motor Jet Interactions
  - Integrated coupled aerodynamic, vibro-acoustics and structural loads performance predictions

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    - MLAS Overview Presentations
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Back-Up Charts

Launch Abort Systems

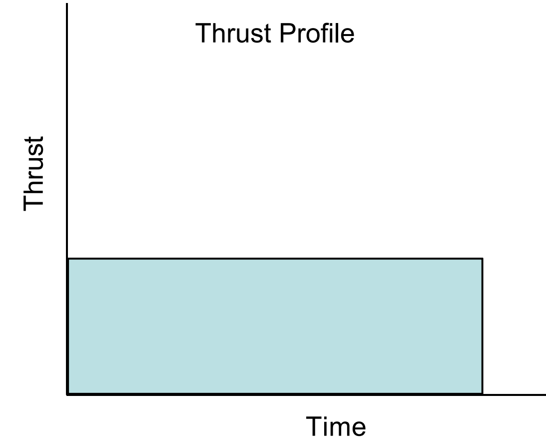
Forward Tractor
(e.g. Orion, Apollo)

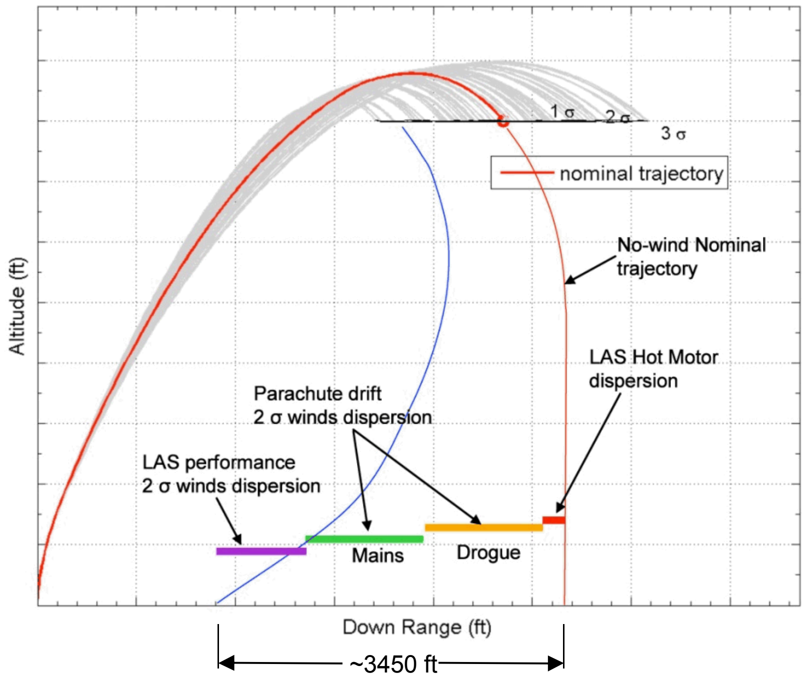
Side-Mount Pusher
(e.g., MLAS)

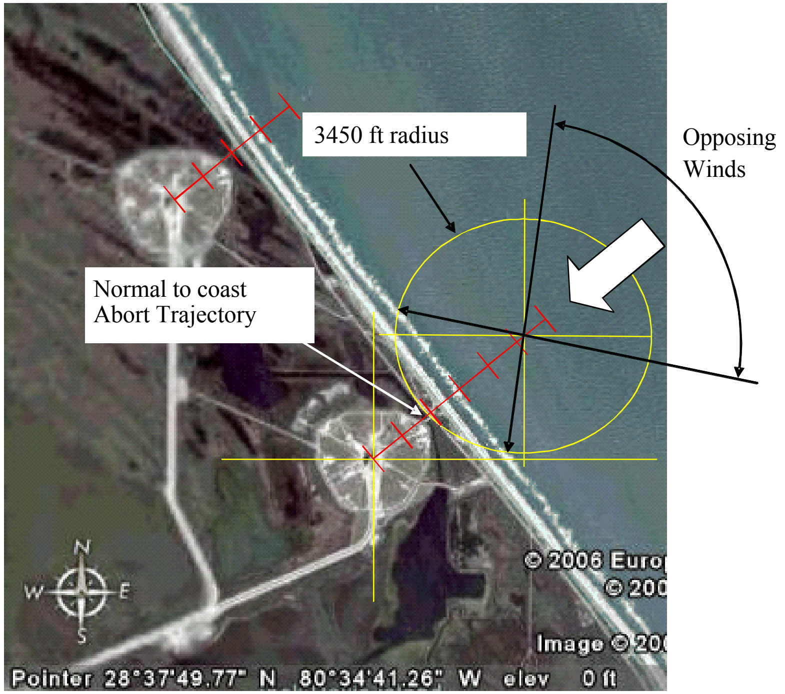
Aft-Mount Pusher
(e.g., HL-20)

Design Drivers (1/3)

- **Pad Abort Drives Total Impulse**
  - Relatively low thrust to pitch over and achieve necessary down range for water landing

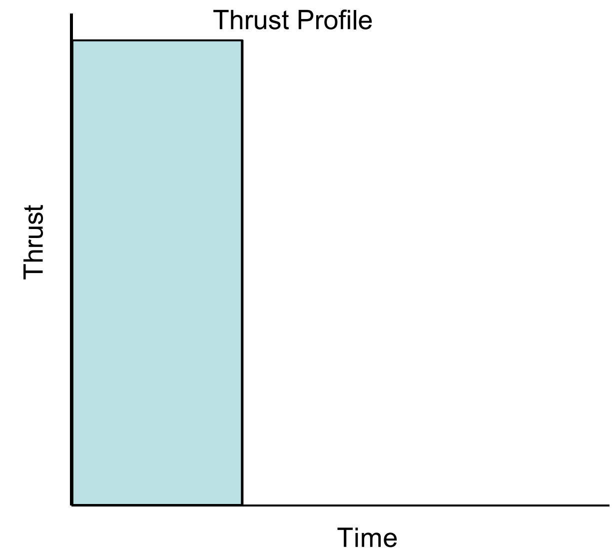


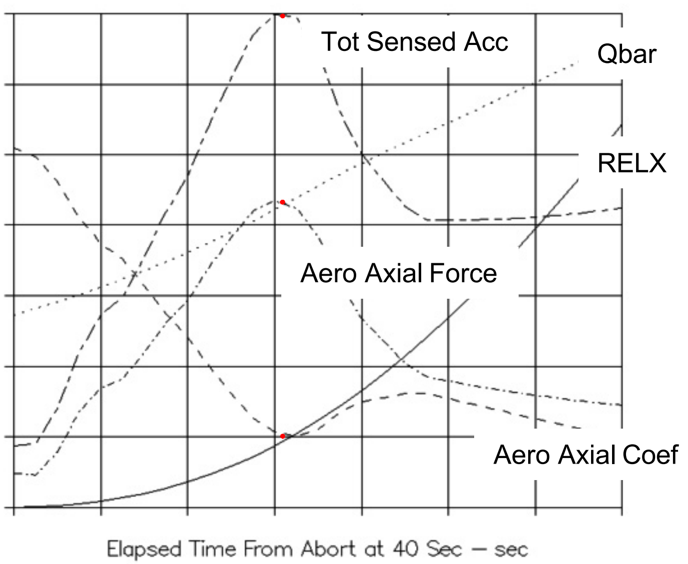


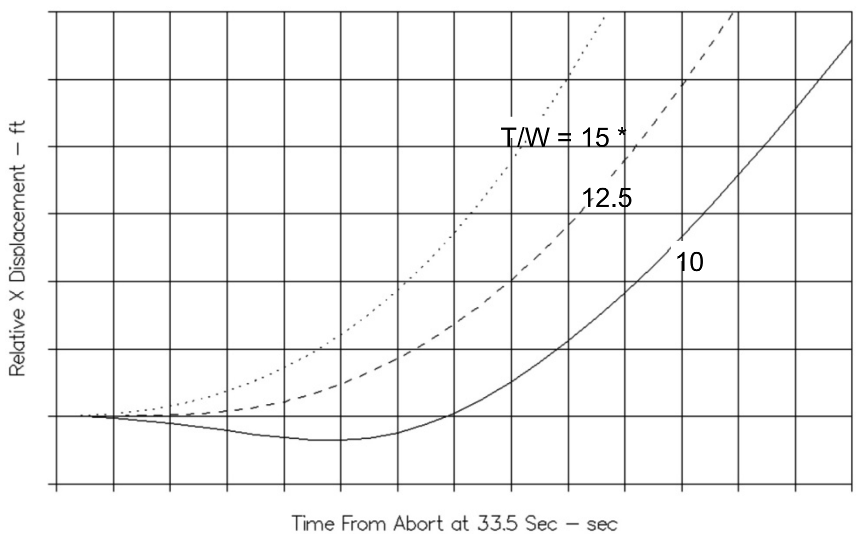


Design Drivers (2/3)

- **Maximum Drag (Transonic) Drives Initial Thrust Magnitude**
  - High Initial Thrust to overcome Free Stream and Aero Proximity effects

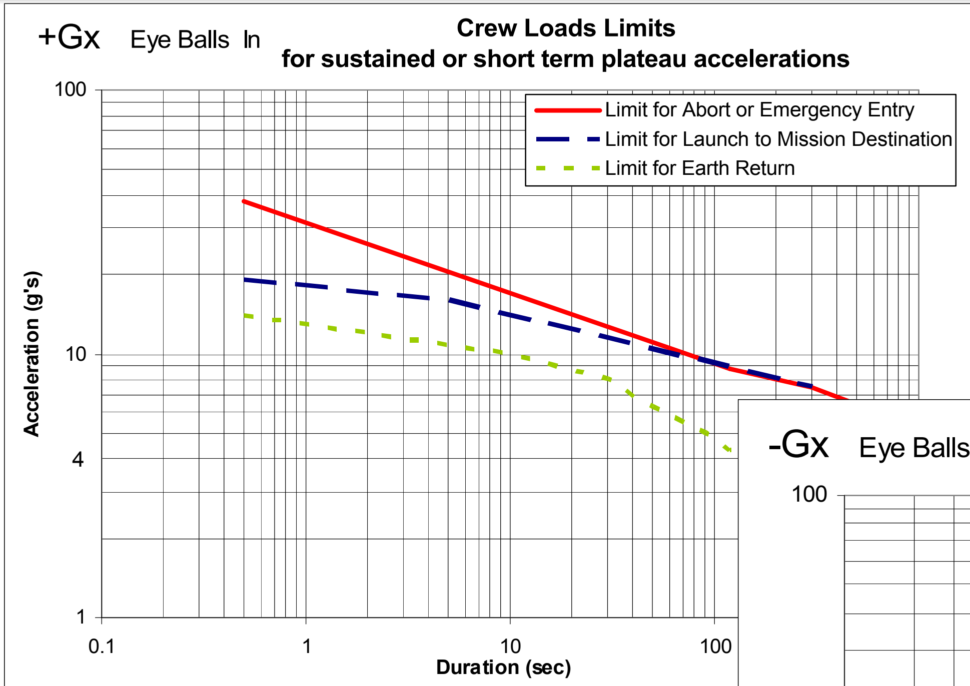


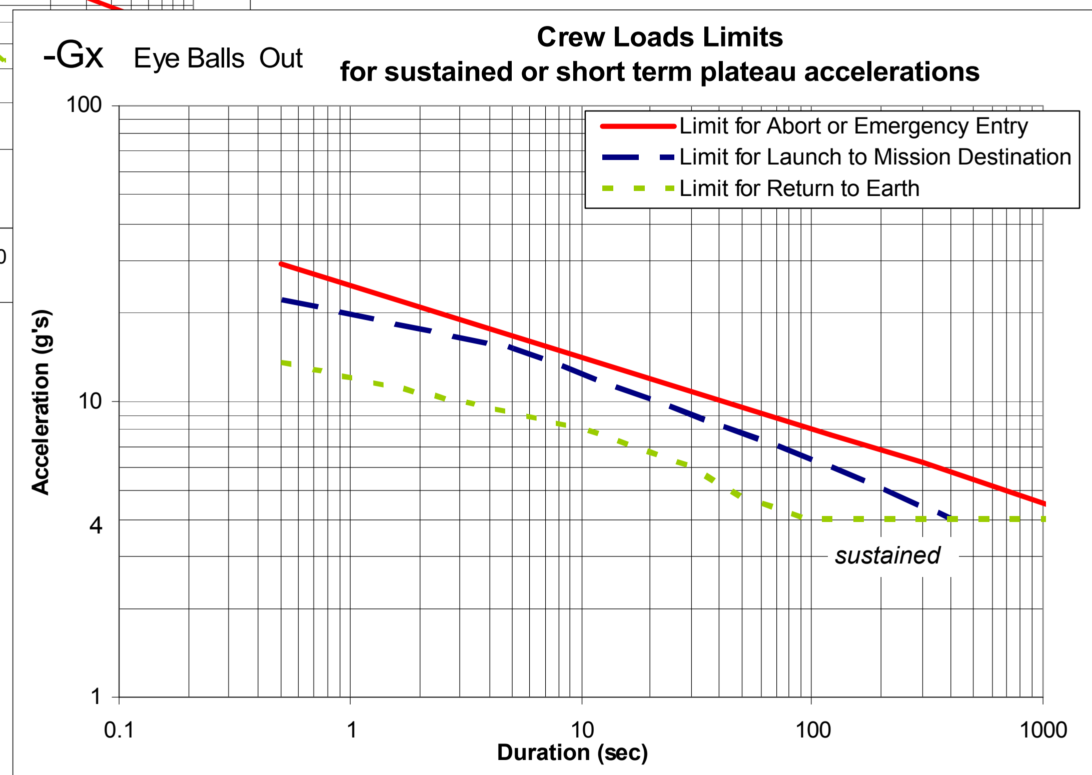




Design Drivers (3/3)

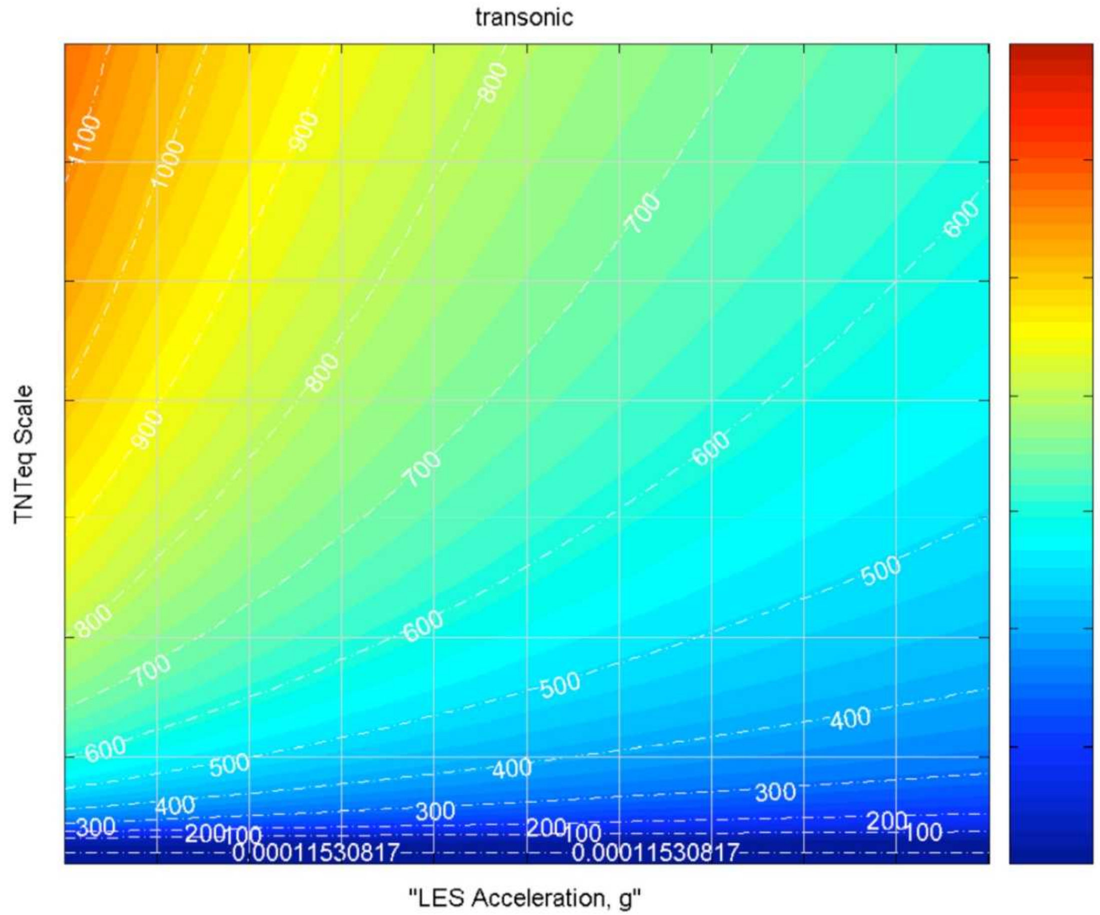
- **Crew Acceleration Limits**
- **Deceleration during Pad Aborts can drive design**





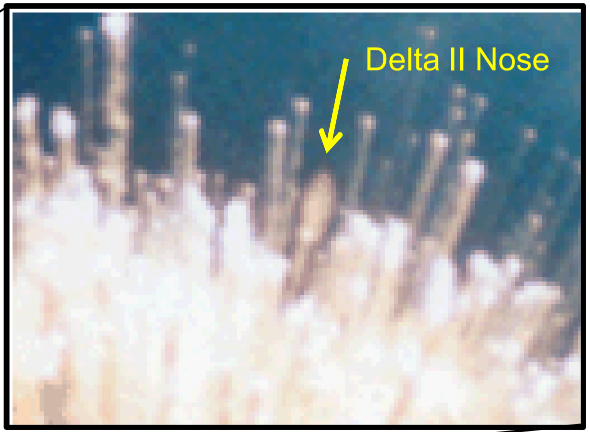
Not Design Drivers (1/2)

- **Blast Overpressure – Ability to Survive Insensitive to LAS Design**
  - Above Mach 1 – Outrun Blast Overpressure Wave
  - Below Mach 1 – Higher Thrust LAS does *not* decrease required warning time
    - Minimum 1 Second Warning Time to Ensure

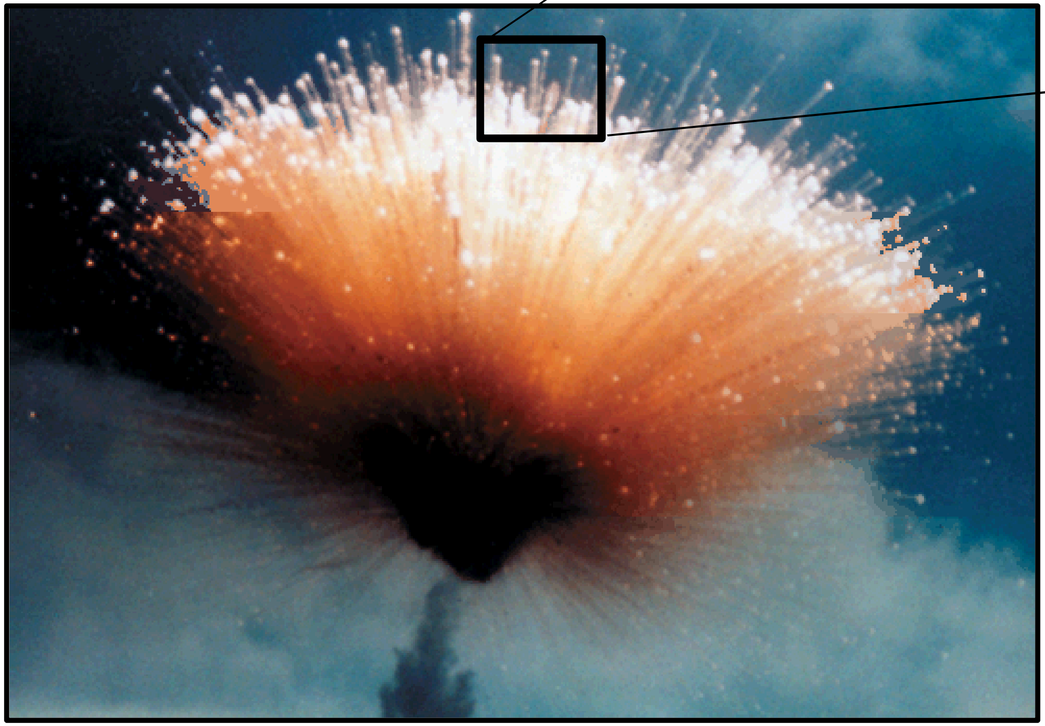


Not Design Drivers (2/2)

- **Debris Field**
  - Difficult to quantify – Random Debris Velocity and Ballistic Coefficients
  - Second Stage & Service Module will tend to protect departing CM

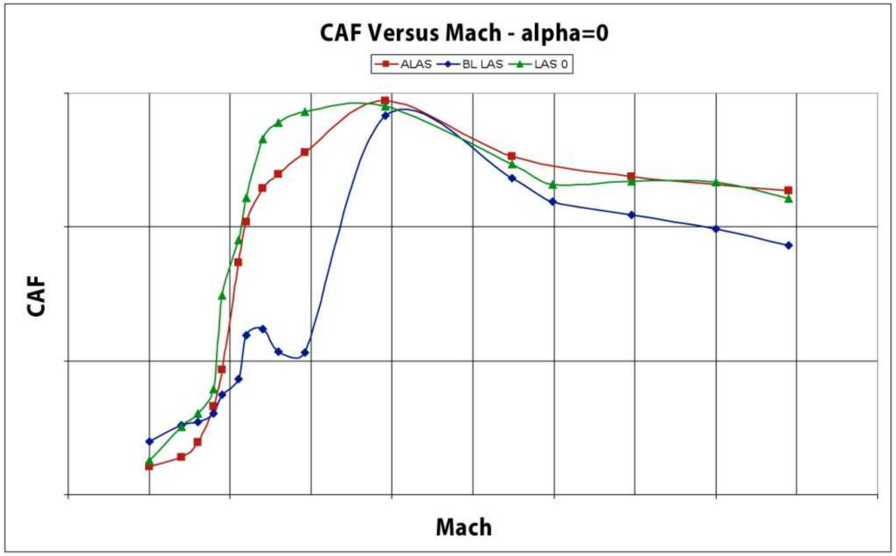


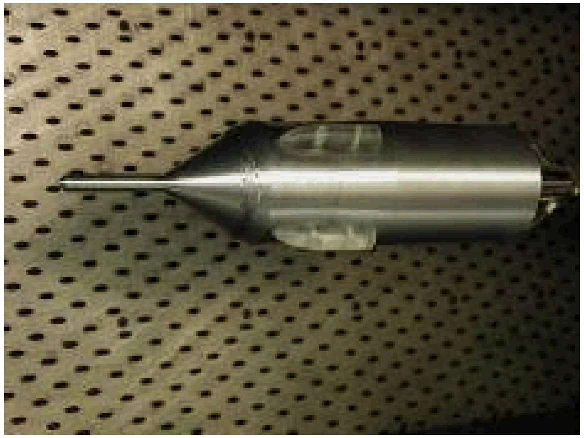
Delta II Debris Field



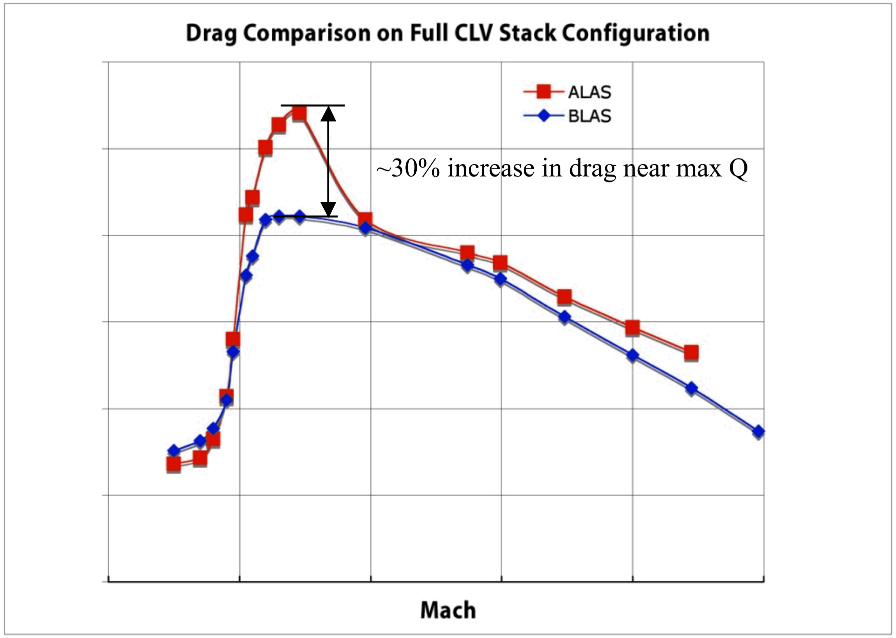
Side Mounted LAS Wind Tunnel Results

Baseline LAS (BL LAS)



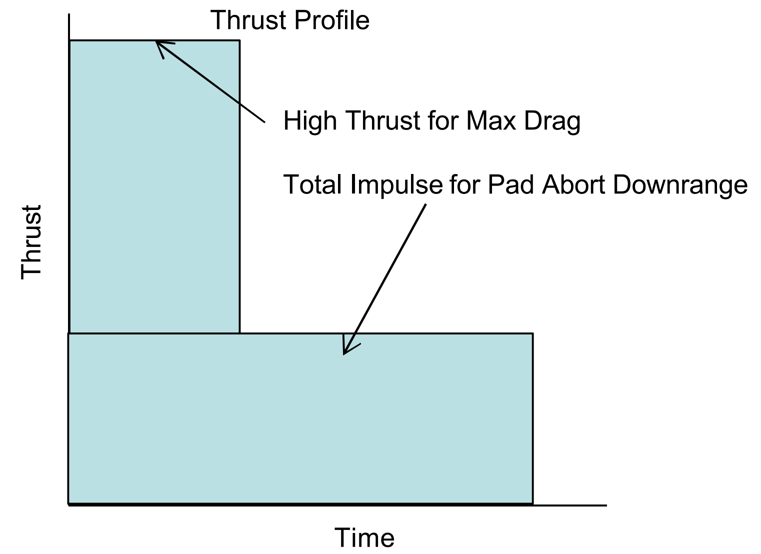


Alternative LAS (ALAS)

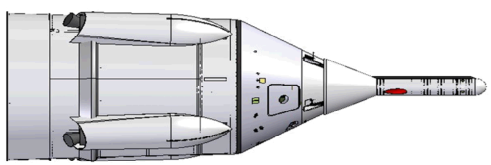


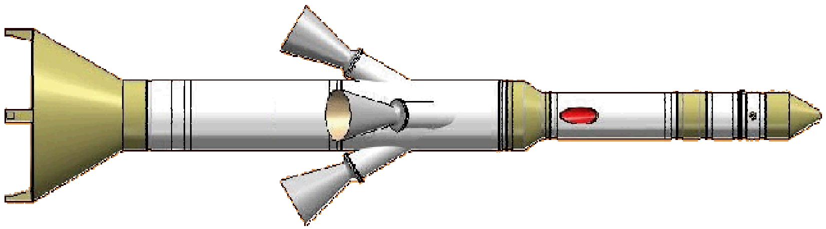
Thrust Profile Trade

- **Thrust Profile Dimensioned by Two Cases:**
  - Pad Abort - Drives total impulse (to achieve required down range)
  - Max Drag (Transonic) - Drives Initial Acceleration
- **Multiple ways to achieve desired thrust profile**
  - Multiple Engines fired in Parallel and/or Serial
  - Single Motor with Customized Solid Grain Profile



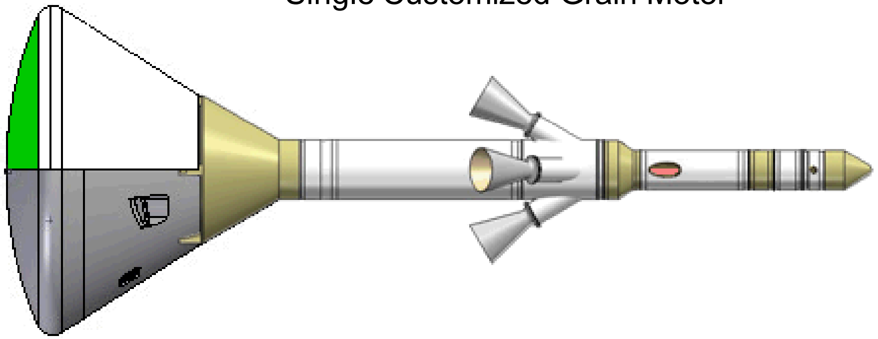
Multiple Motors





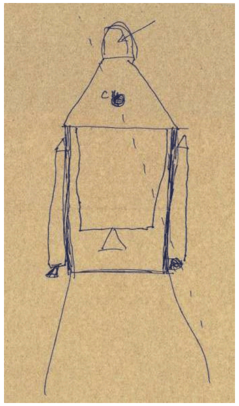
Tandem Tractor
Axial Motor mounted on top of Reverse Flow Motor

Single Customized Grain Motor

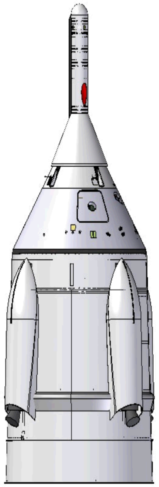


Tower vs. Pusher LAS Trade

- **Pusher Multi-Stage LAS Pros:**
  - Additional Operation Options (Activate Motors in Parallel or Serial)
  - Ascent Assist (Fire pairs of motors in series)
  - Reduces ACM Requirements
- **Pusher Multi-Stage LAS Cons:**
  - Increased Atmospheric Drag - Reduces Mass-to-Orbit (350 lbs)
  - Reduces CLV longitudinal aerodynamic stability
    - Aerodynamic center of pressure moves forward during max Q
  - LAS Control Challenging due to Asymmetric Thrust
    - Motor-to-motor variability
    - Motor temperature differentials (sun/shade)
    - Motor tail off



SM Concept Sketch
(Mike Griffin, 3/22/06)



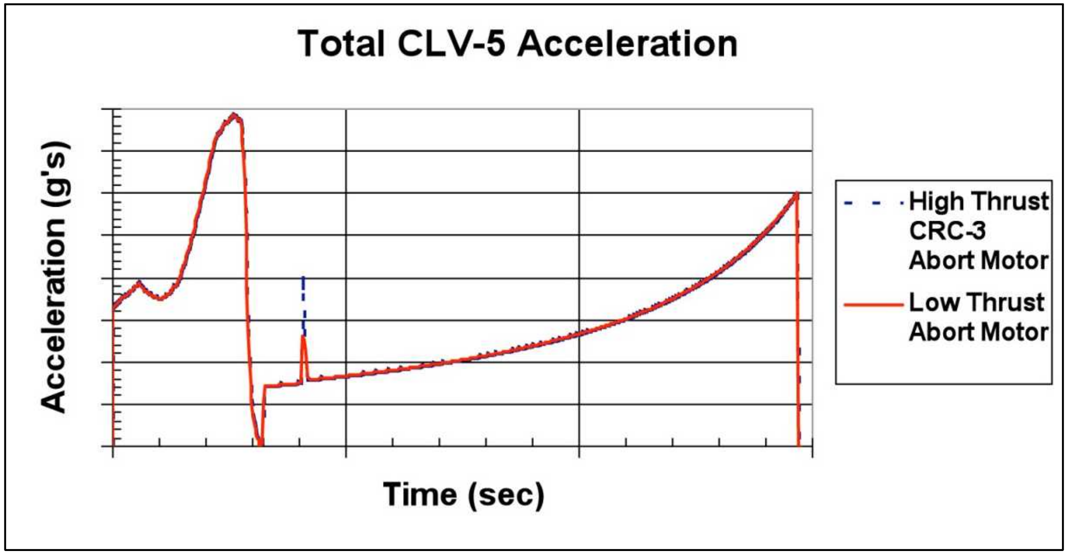
Multiple External (4)
SM Abort Motors

Active vs. Passive Control

- **Passive System requires Aerodynamically Stable LAS**
  - Center of Mass Forward of Center of Pressure
  - Ballast forward or drag area aft
- **Active LAS**
  - Pros: Greater Survivability Envelope; Lower Mass and/or Drag
  - Cons: ACM Development & recurring costs; GNC complexity; Reliability
- **Passive LAS**
  - Pros: Simple and Robust; Lower DDT&E and Operational Costs
  - Cons: Greater Mass or Drag Area; Potential Black-Out Zones
- **Highly Desirable to have a Passive System with Active Attitude System**
  - Graceful Degradation

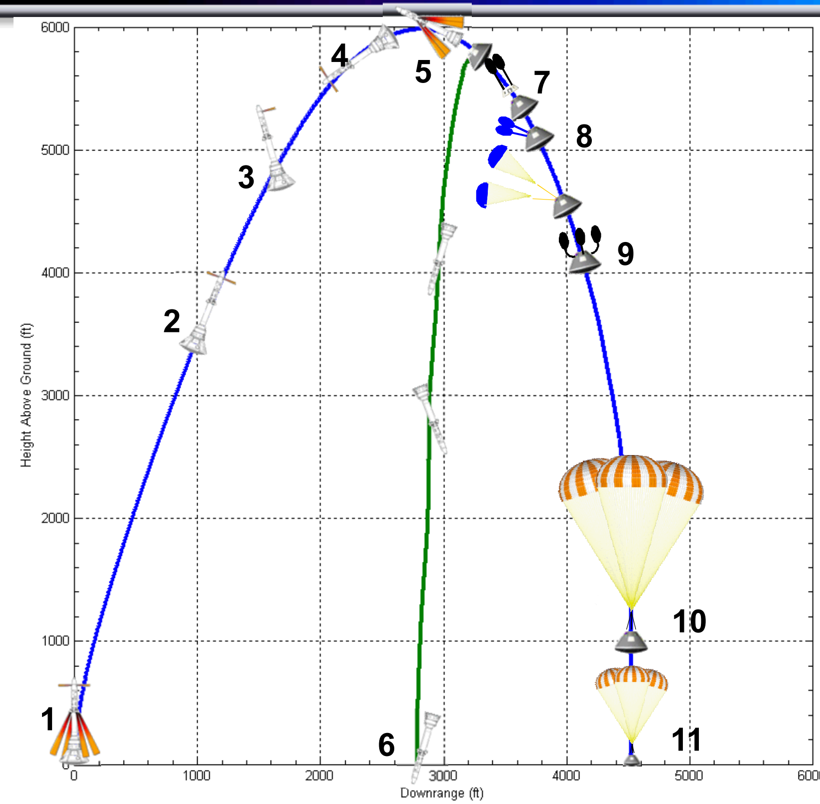
LAS Ascent Assist

- **Single Motor LAS**
  - Theoretically can increase mass to orbit by 1000 lb
  - However, additional tension loading on the Command Module requires additional structure that leads to overall decrease in mass to orbit
- **Multi-Motor LAS**
  - Fire motors in Series - Reduced Thrust, Increases burn time
  - Relieves Command Module Compressive load – no tension loads
  - Increases Mass-to-Orbit by ~650 lb
- **Cons**
  - Second Stage Motor Ullage Pressure and Cavitations Concerns



Orion LAS PA-1 Flight Tests

- **Full End-to-End Test**
  - Full Active Control
  - Achieve Altitude and Downrange Performance
  - Reorient for Parachute Deployment
  - Jettison LAS
  - Parachute Deployment
  - Touch Down



Event	Time (s)
1. Ignition	0.00
2. AM Burnout	6.45
3. Begin Re-Orientation	10.05
4. End Re-Orientation	15.77
5. LAS Jettison	21.03
6. LAS Touchdown	49.32
7. FBC Jettison	22.02
8. Drogue Mortar Fire	24.56
9. Pilot Mortar Fire	30.56
10. Reach 33 ft/sec	52.54
11. CM Touchdown	96.83

Orion PA-1 Movie

PA-1 Photos