



# Early-Career Reflections on College and Engineering

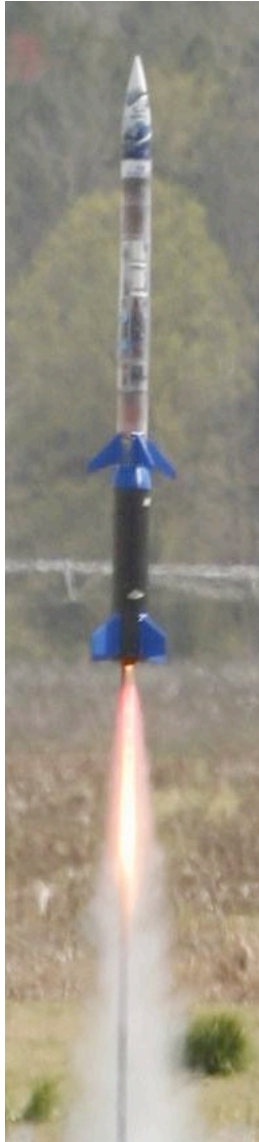
Matthew Denny  
Propulsion Engineer  
The Boeing Company



# Outline

- Background at UAH
- Space Launch System (SLS) at Boeing
  - Overview of development programs in general
  - Propulsion
  - Flight Termination System (FTS)
  - Separation Systems

# University Student Launch Initiative 2012-2013



Motor: J-355  
Apogee: 5360 ft  
Max Velocity: 700 ft/s  
Separation Altitude: 3000 ft  
Max Acceleration: 8.8 g's



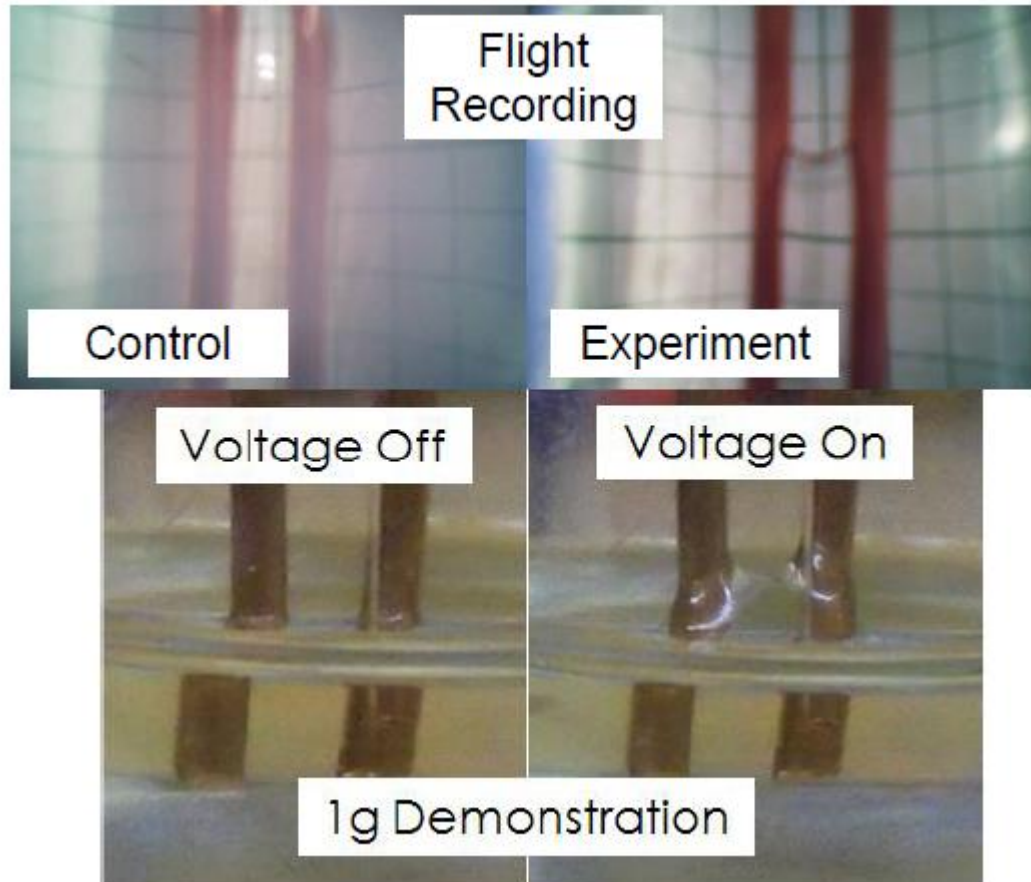
*Charger  
Rocket  
Works*



**UAHuntsville**  
THE UNIVERSITY OF ALABAMA IN HUNTSVILLE  
USLI 2012-2013  
sli.uah.edu

# USLI Payload Experiment: Dielectrophoresis

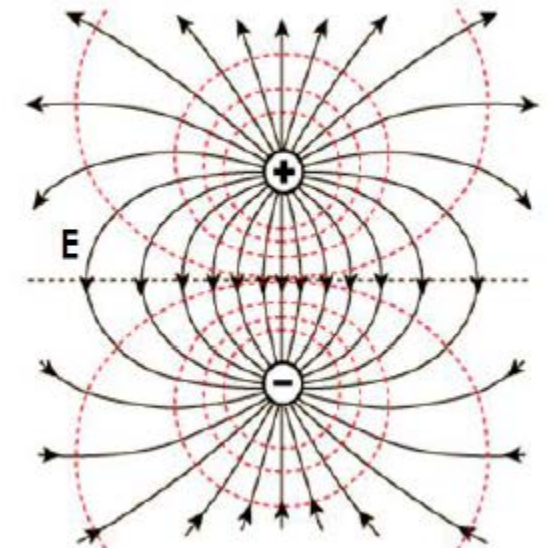
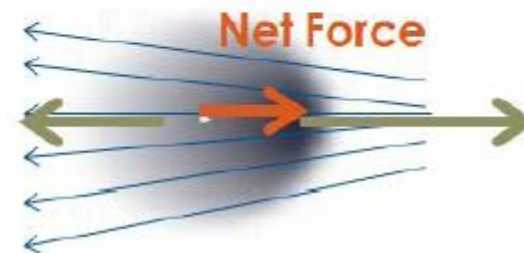
(Thanks Dr. Blackmon!)



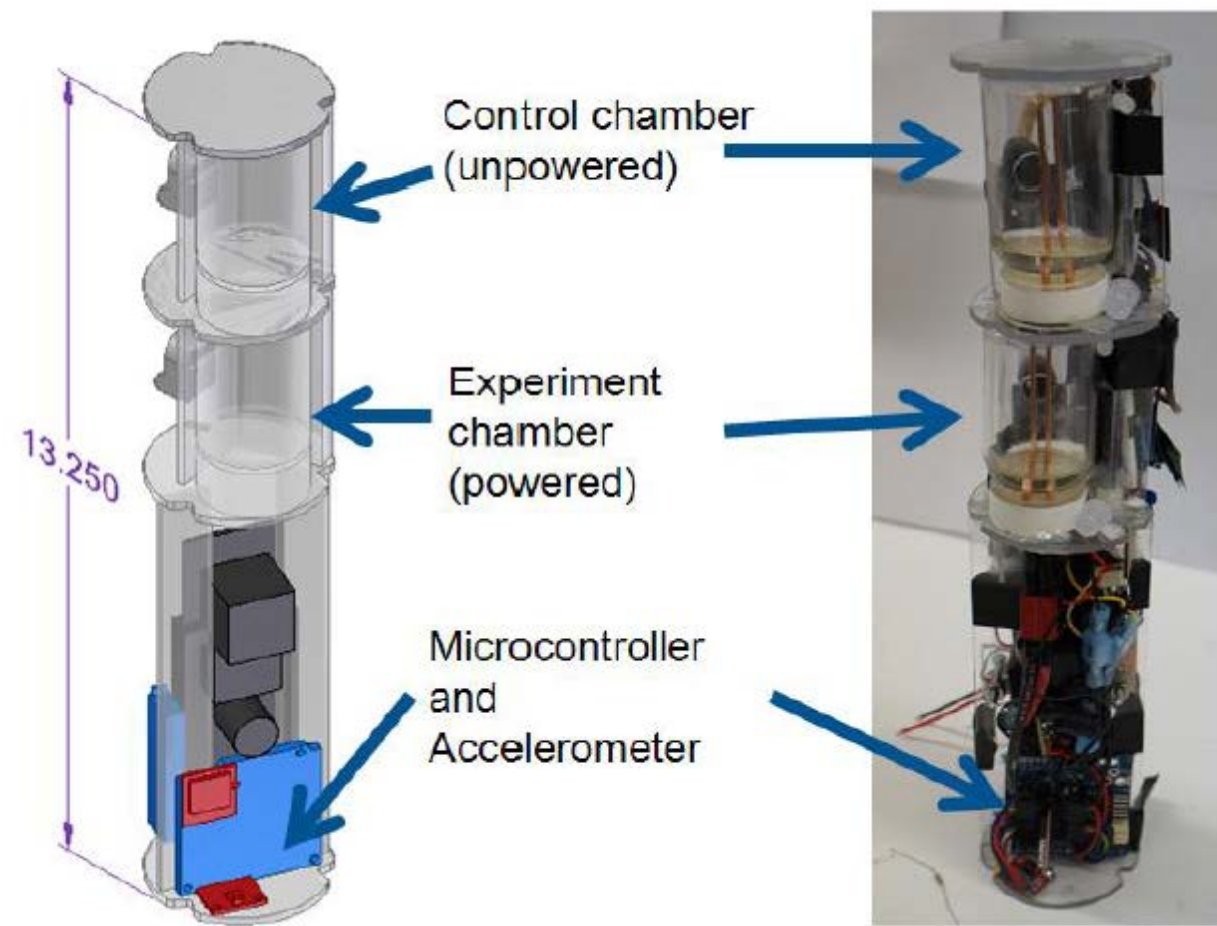
## Theory

- Dielectrophoresis: a force induced on an initially non-polar fluid particle in a non-uniform electric field
- Acts in the direction of the gradient of the electric field
- Electric field of parallel electrodes draws fluid to central location

$$\vec{F}_v = \frac{\epsilon_0(K-1)(K+2)}{6} \nabla E^2$$



# USLI Payload Experiment Testing



**Testing at acceleration test facility**

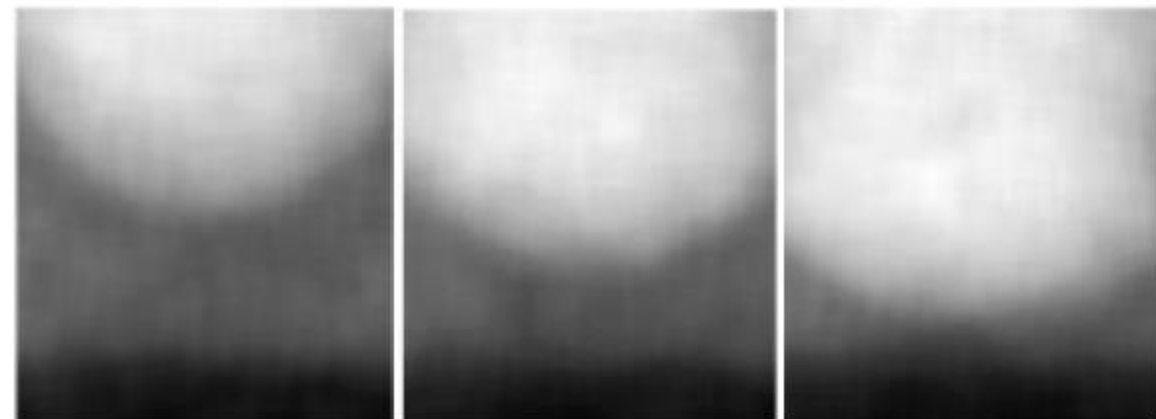
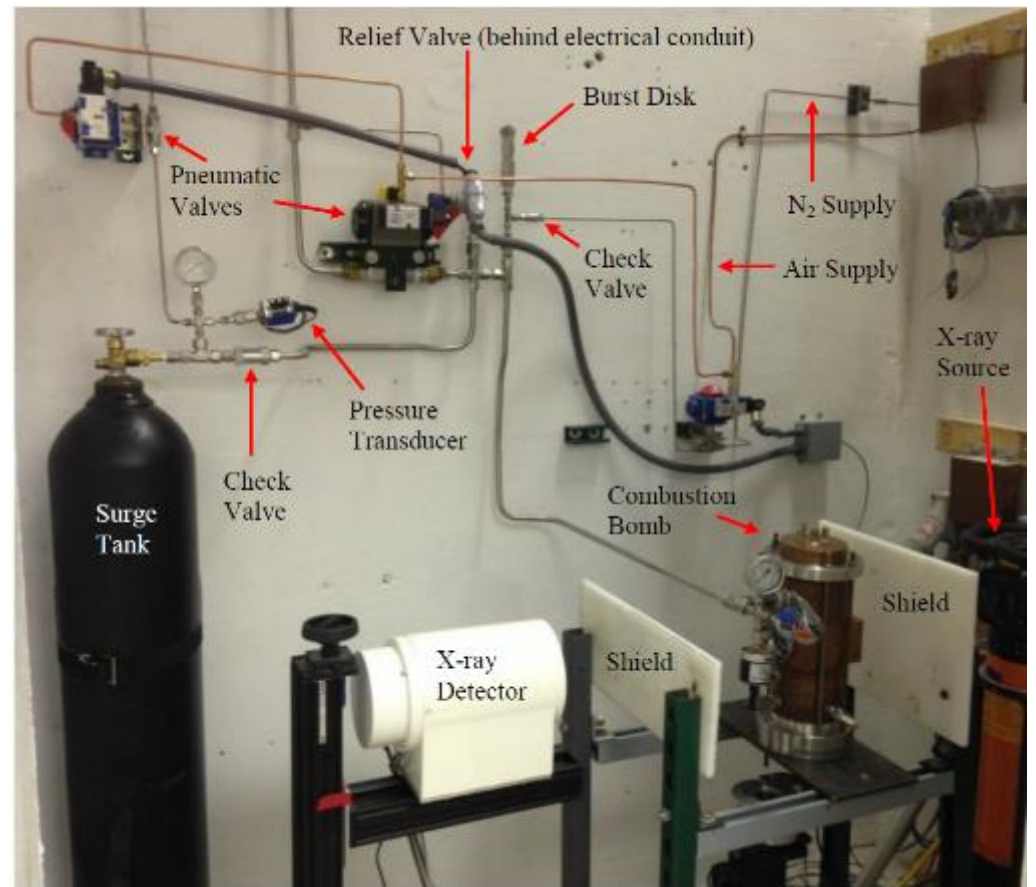
*Codename: Space Shot*



# High Pressure Lab

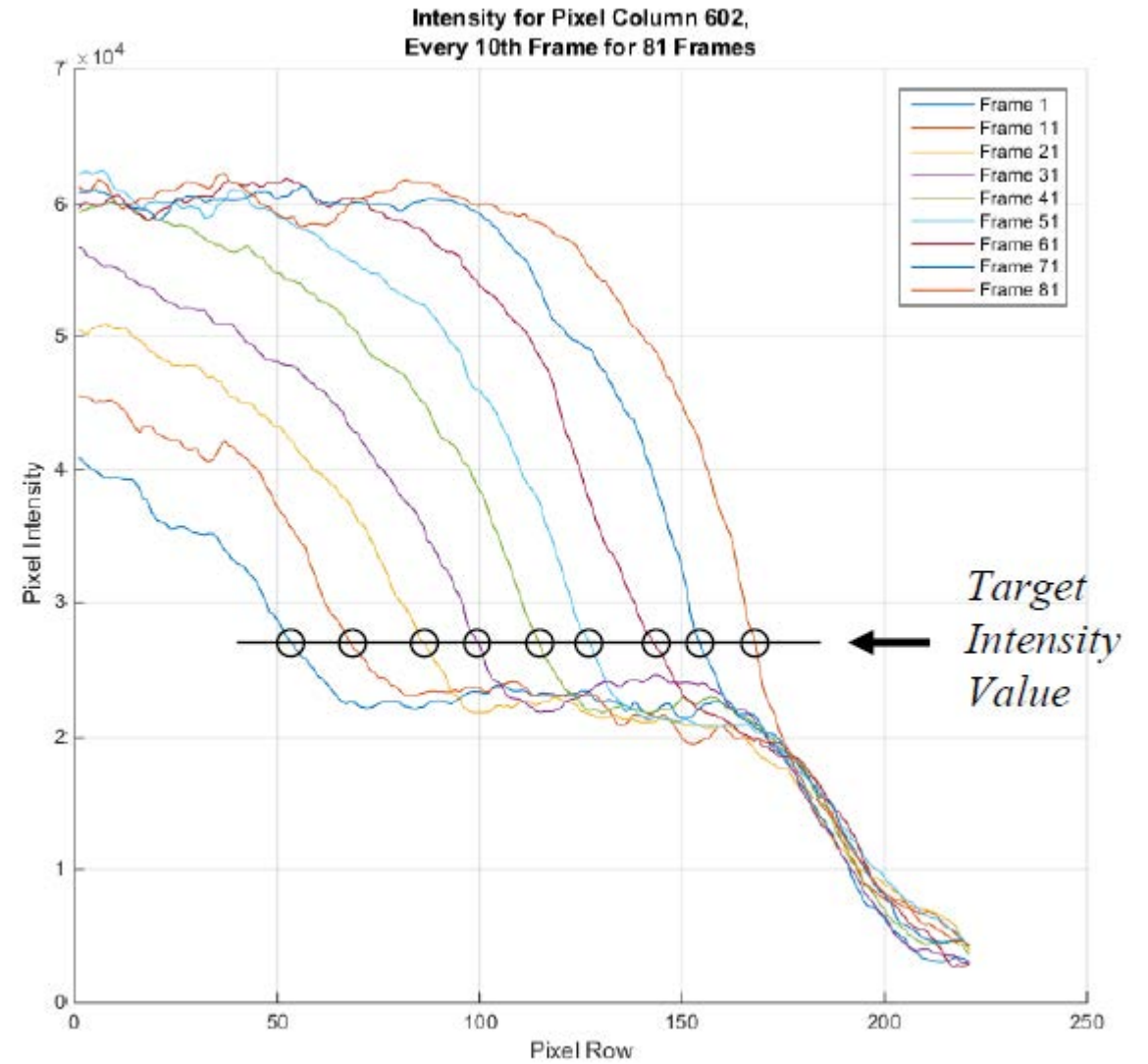
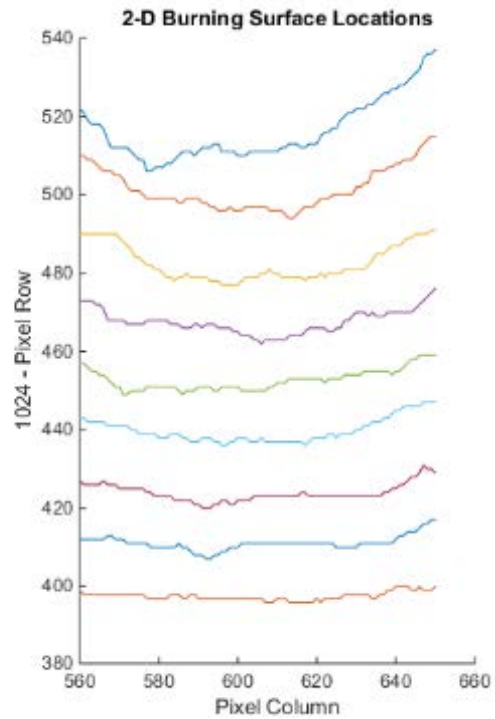


Solid Propellant Sample

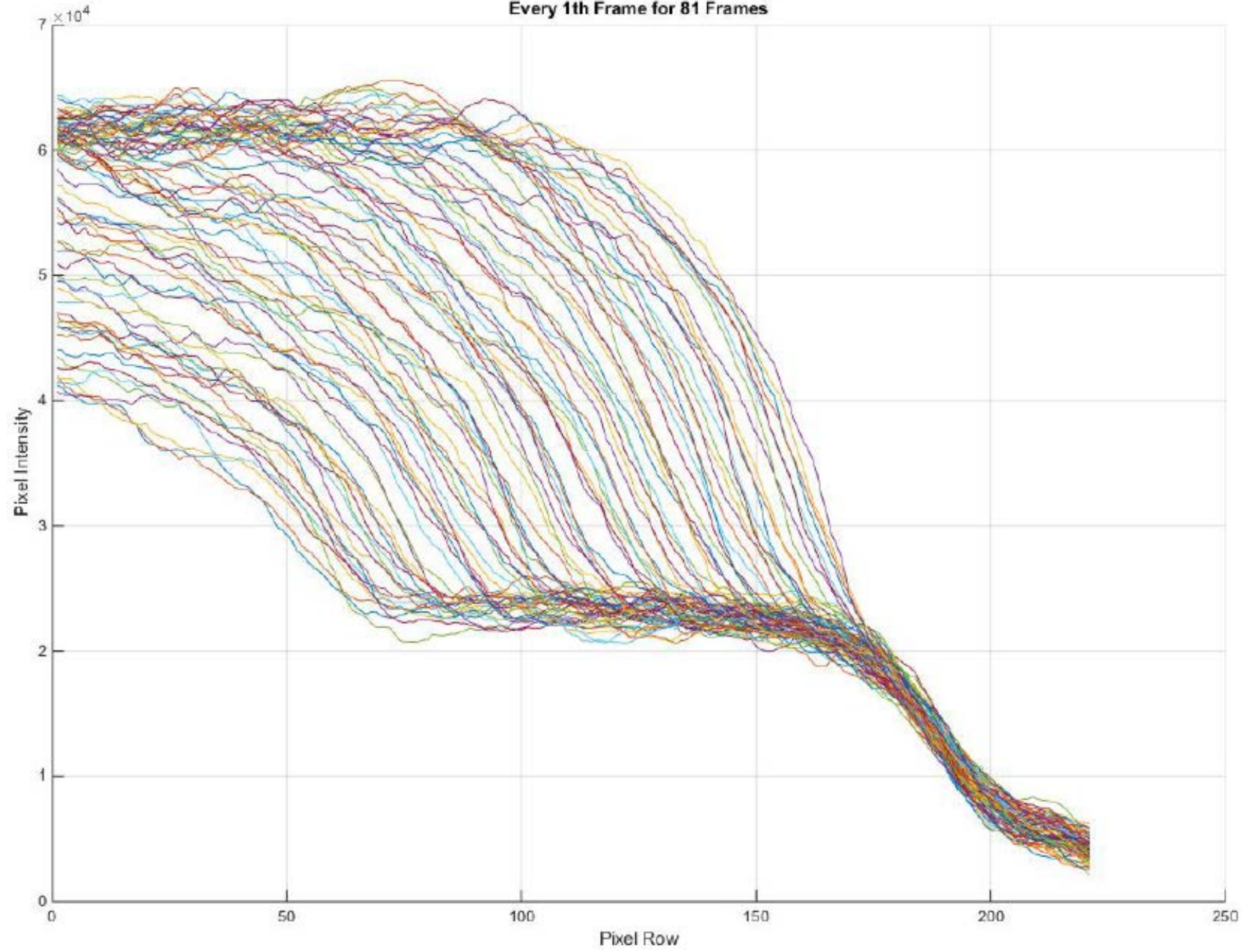


Burning surface regression in X-ray video frames

# “Measurement of Solid Rocket Propellant Burning Rate Using X-ray Imaging”

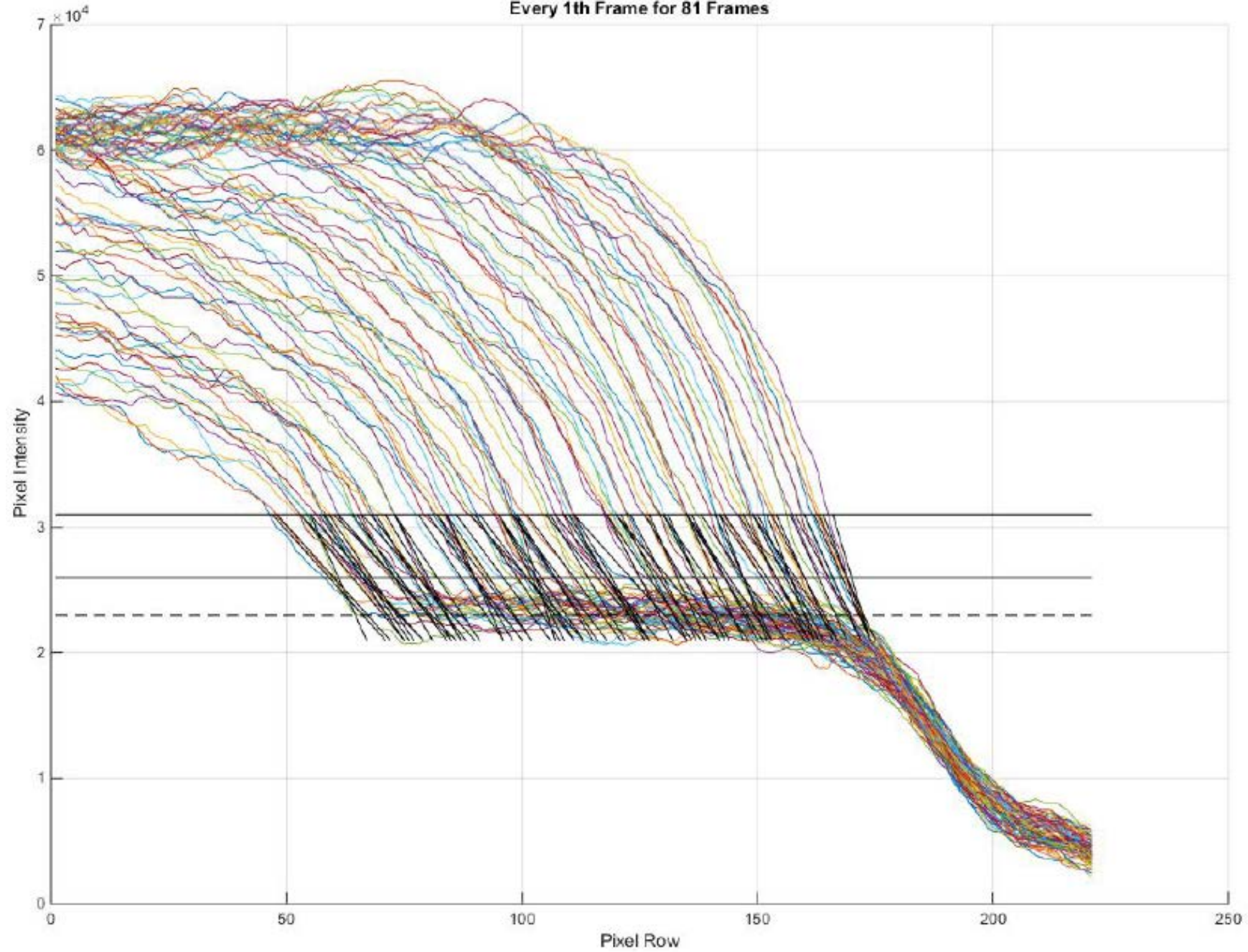


Intensity for Pixel Column 602,  
Every 1th Frame for 81 Frames



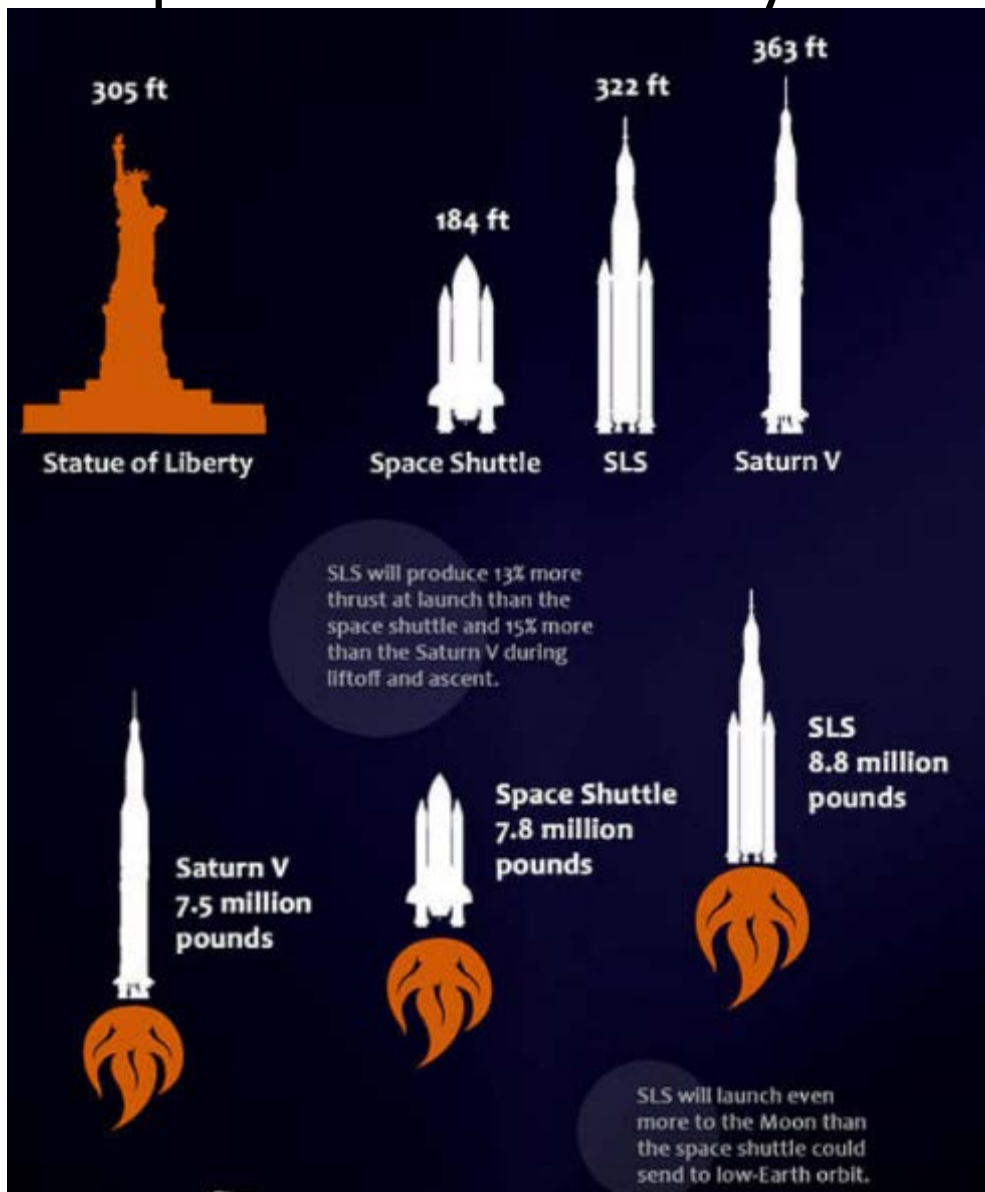


Intensity for Pixel Column 602,  
Every 1th Frame for 81 Frames

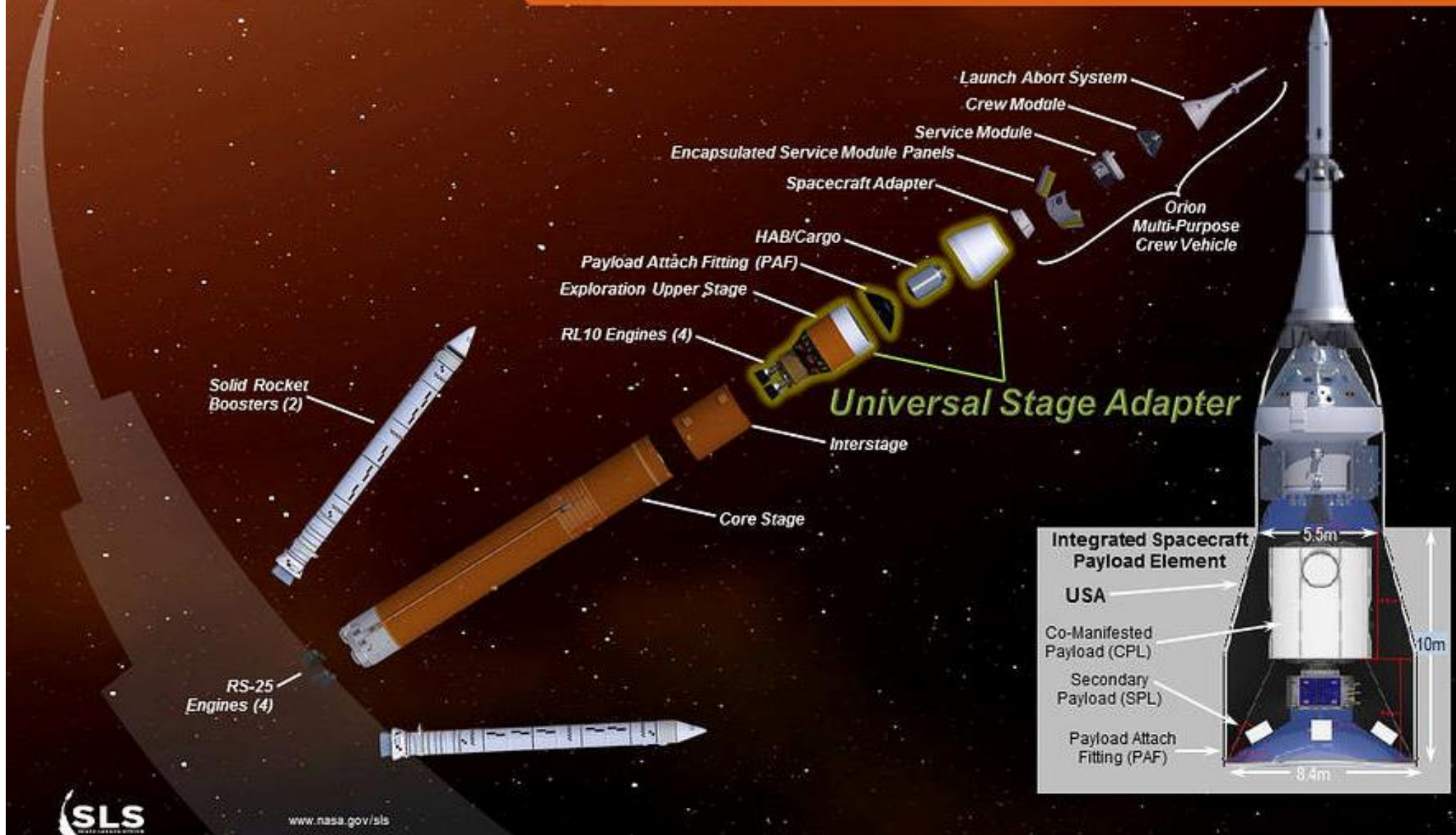




# Space Launch System (SLS)



# SPACE LAUNCH SYSTEM: THE NEXT STEP



www.nasa.gov/sls



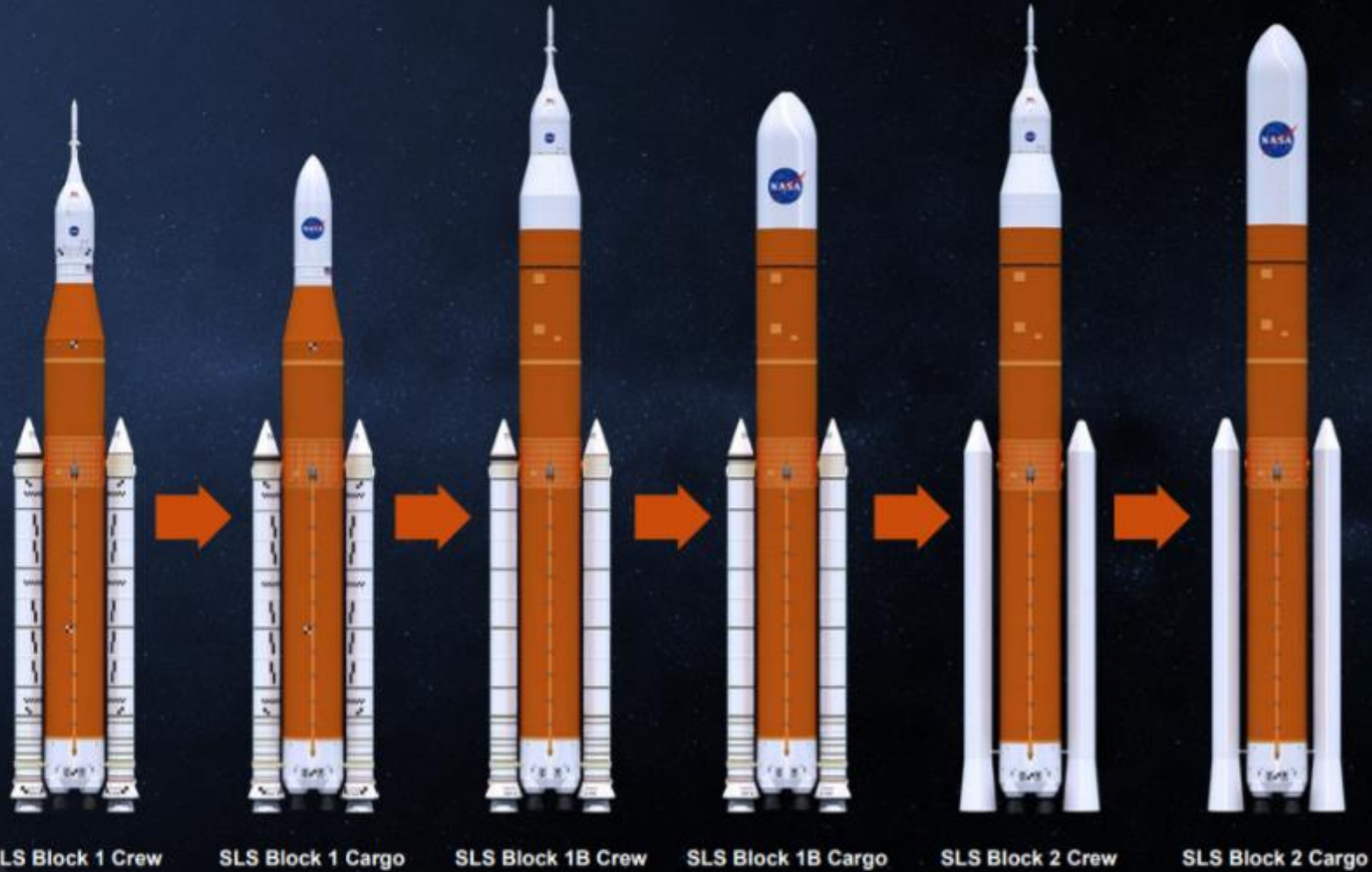
Payload to TLI/Moon > 26 t (57k lbs) > 26 t (57k lbs) 34–37 t (74k–81k lbs) 37–40 t (81k–88k lbs) > 45 t (99k lbs) > 45 t (99k lbs)

Payload Volume N/A\*\* 9,030 ft<sup>3</sup> (256m<sup>3</sup>) 10,100 ft<sup>3</sup> (286m<sup>3</sup>)\*\* 18,970 ft<sup>3</sup> (537 m<sup>3</sup>) 10,100 ft<sup>3</sup> (286m<sup>3</sup>)\*\* 34,910 ft<sup>3</sup> (988 m<sup>3</sup>)

**Trans-Lunar Injection (TLI)**

is a propulsive maneuver used to set a spacecraft on a trajectory that will cause it to arrive at the Moon. A spacecraft performs **TLI** to begin a lunar transfer from a low circular parking orbit around Earth.

The numbers depicted here indicate the mass capability at the Trans-Lunar Injection point.



\*\* Not including Orion/Service Module volume



# RS-25 Engine – Aerojet Rocketdyne





# Stennis Space Center (SSC)



<https://www.nasa.gov/exploration/systems/sls/multimedia/hardware.html>



# THE HOW & WHY OF RS-25 TESTING

EVEN THOUGH THE RS-25 ENGINES FOR NASA'S SPACE LAUNCH SYSTEM (SLS) HAVE SUCCESSFULLY FLOWN DOZENS OF MISSIONS ON THE SPACE SHUTTLE, THEY NEED TO BE TEST-FIRED ON THE GROUND PRIOR TO THEIR USE ON SLS FOR A NUMBER OF COMPELLING REASONS.

## 1 ENGINE DEMANDS

RS-25 WILL BE OPERATING AT **109%** POWER VERSUS **104.5%** ROUTINELY FLOWN DURING THE SPACE SHUTTLE PROGRAM.



## 2 NEW CONDITIONS

PROPELLANT INLET PRESSURES WILL BE **HIGHER**, THE PROPELLANT WILL BE **COLDER**, AND THE NOZZLES WILL GET **HOTTER** AT LAUNCH DUE TO THEIR PROXIMITY TO THE BOOSTER NOZZLES.

## 3 NEW HARDWARE

ALONG WITH NEW DEMANDS ON THE ENGINE, THE RS-25 ALSO HAS A NEW ENGINE CONTROLLER AND OTHER COMPONENTS THAT HAVE NEVER FLOWN OR HAVE NEVER FLOWN TOGETHER THAT MUST BE TESTED.

## 4 NEW CORE STAGE

AFTER THE ENGINES AND ENGINE CONTROLLERS ARE INSTALLED, NASA NEEDS TO TEST THE FIRST SLS FLIGHT CORE STAGE TOGETHER WITH ALL FOUR ENGINES FOR THE FIRST TIME, KNOWN AS A "GREEN RUN."

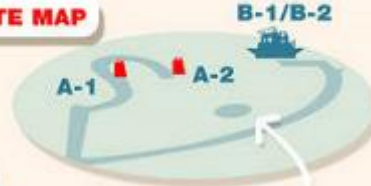
## 5 TESTING TESTERS

TESTING ALSO COMPARES ACTUAL TEST READINGS AGAINST PREDICTIONS MADE BY HUMANS AND COMPUTERS, THUS ENSURING THE ACCURACY AND RELIABILITY OF THE PREDICTIONS.

BUILT IN 1961, **STENNIS SPACE CENTER** IS NASA'S ROCKET ENGINE TEST CENTER. LOCATED IN HANCOCK COUNTY, MISSISSIPPI, IT HAS THE NATION'S **LARGEST** TEST STANDS.

OF THESE, THE **A-1** TEST STAND AND THE DUAL POSITION **B-1/B-2** TEST STAND WERE BUILT IN THE 1960s FOR NASA'S APOLLO PROGRAM. THEY WERE RE-USED FOR SPACE SHUTTLE PROPULSION TESTING AND NOW SUPPORT VARIOUS PROPULSION PROGRAMS.

### SITE MAP



### RESERVOIR

SINGLE RS-25 ENGINES WILL BE TESTED ON THE **A-1 TEST STAND**

THE FIRST TWO CORE STAGES WILL BE TESTED ON THE **B-2 TEST STAND**

IN THE 1960s AND '70s, WELL WATER WAS PUMPED TO THE B STAND. IN THE '80s, WATER WAS DIVERTED FROM A MANMADE CANAL SYSTEM INTO A **66 MILLION** GALLON RESERVOIR.



1 RS-25

6000°F  
120 dB

THE STANDS USE WATER TO KEEP THEMSELVES COOL. A FLAME DEFLECTOR HAS THOUSANDS OF HOLES THAT SPRAY WATER TO COOL THE HEAT AND DEADEN THE SOUND.



158' TALL

360' TALL

### FUN FACT:

RS-25 BURNS CLEAN. ITS EXHAUST IS **WATER VAPOR**. NOT SMOKE. THE EXHAUST IS SO DENSE THAT IT ACTUALLY CAN FALL LIKE RAIN.



A-1 SUPPORTS UP TO **1.1 MILLION** POUNDS OF THRUST (MAXIMUM DYNAMIC LOAD)

B-2 SUPPORTS UP TO **3 MILLION** POUNDS OF THRUST (MAXIMUM DYNAMIC LOAD)

NASA'S A-1 TEST STAND WAS DESIGNATED A NATIONAL HISTORIC LANDMARK IN **1984**



# CORE STAGE

# 101\*

\* Or: What you need to know about the Space Launch System Core Stage, the backbone of the rocket.

## INSIDE THE CORE STAGE



## HOW BIG IS THE SLS CORE STAGE?

- **212'** tall and **27.6'** in diameter
- **~2.3M POUNDS** with propellant
- The largest rocket stage ever built
- Fuels the world's most powerful rocket



### A FAST RIDE!

SLS reaches **MACH 23** (faster than **17,000 MPH**) in just **8.5 MINUTES**.



1	2	3	4	5
<b>ENGINE SECTION</b>	<b>LH2 TANK</b>	<b>INTERTANK</b>	<b>LOX TANK</b>	<b>FORWARD SKIRT</b>
<ul style="list-style-type: none"> <li>• Delivers propellants from the LH2 and LOX tanks to <b>4 RS-25 ENGINES</b></li> <li>• Avionics to steer engines</li> <li>• Aft booster attach point</li> </ul>	<ul style="list-style-type: none"> <li>• Holds <b>537,000 GALLONS</b> of liquid hydrogen cooled to <b>-423°F</b></li> </ul>	<ul style="list-style-type: none"> <li>• Joins <b>LH2</b> and <b>LOX</b> tanks</li> <li>• Houses avionics and electronics</li> <li>• Forward booster attach point</li> </ul>	<ul style="list-style-type: none"> <li>• Holds <b>196,000 GALLONS</b> of liquid oxygen cooled to <b>-297°F</b></li> </ul>	<ul style="list-style-type: none"> <li>• Houses flight computers, cameras, and avionics — the <b>"BRAINS"</b> of the rocket</li> </ul>



Fuels 4 engines to produce a total **2 MILLION POUNDS** of thrust



**733,000 GALLONS** of propellant fill the **LH2** and **LOX** tanks together, enough to fill **63** large tanker trucks.

[www.nasa.gov/sls](http://www.nasa.gov/sls)

**BIGGER TANKS. BOLDER MISSIONS.**

**#NASASLS**





# Michoud Assembly Facility (MAF)



Engine Section  
at  
Michoud  
Assembly  
Facility (MAF)



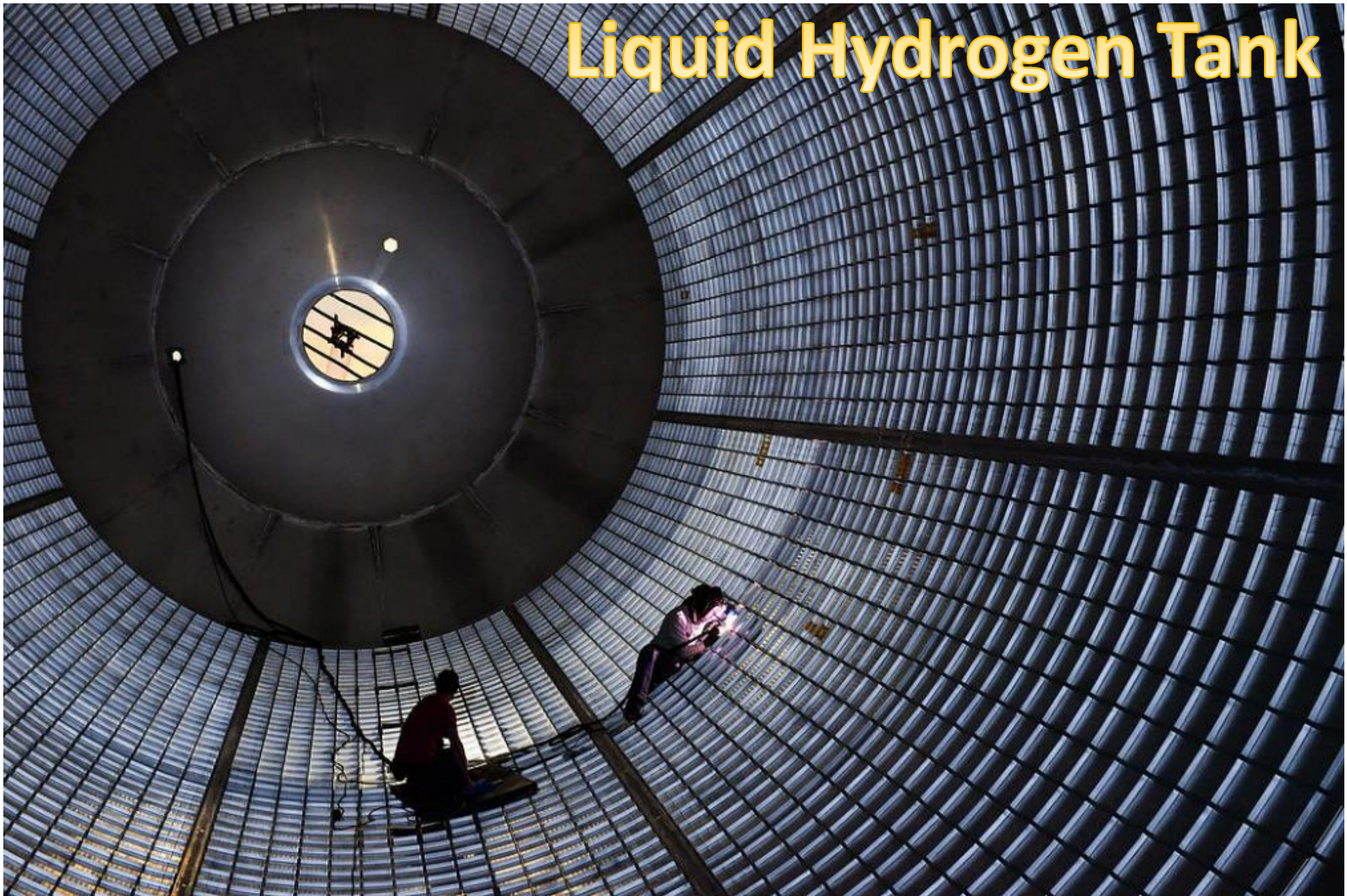
# Qualification Liquid Hydrogen Tank at MAF



# Qualification Liquid Hydrogen Tank at MSFC



# Liquid Hydrogen Tank



# Liquid Oxygen Tank at MAF



# Solid Rocket Booster (SRB) – ATK / Northrop Grumman

## Solid Rocket Booster Details

Length: 177 feet

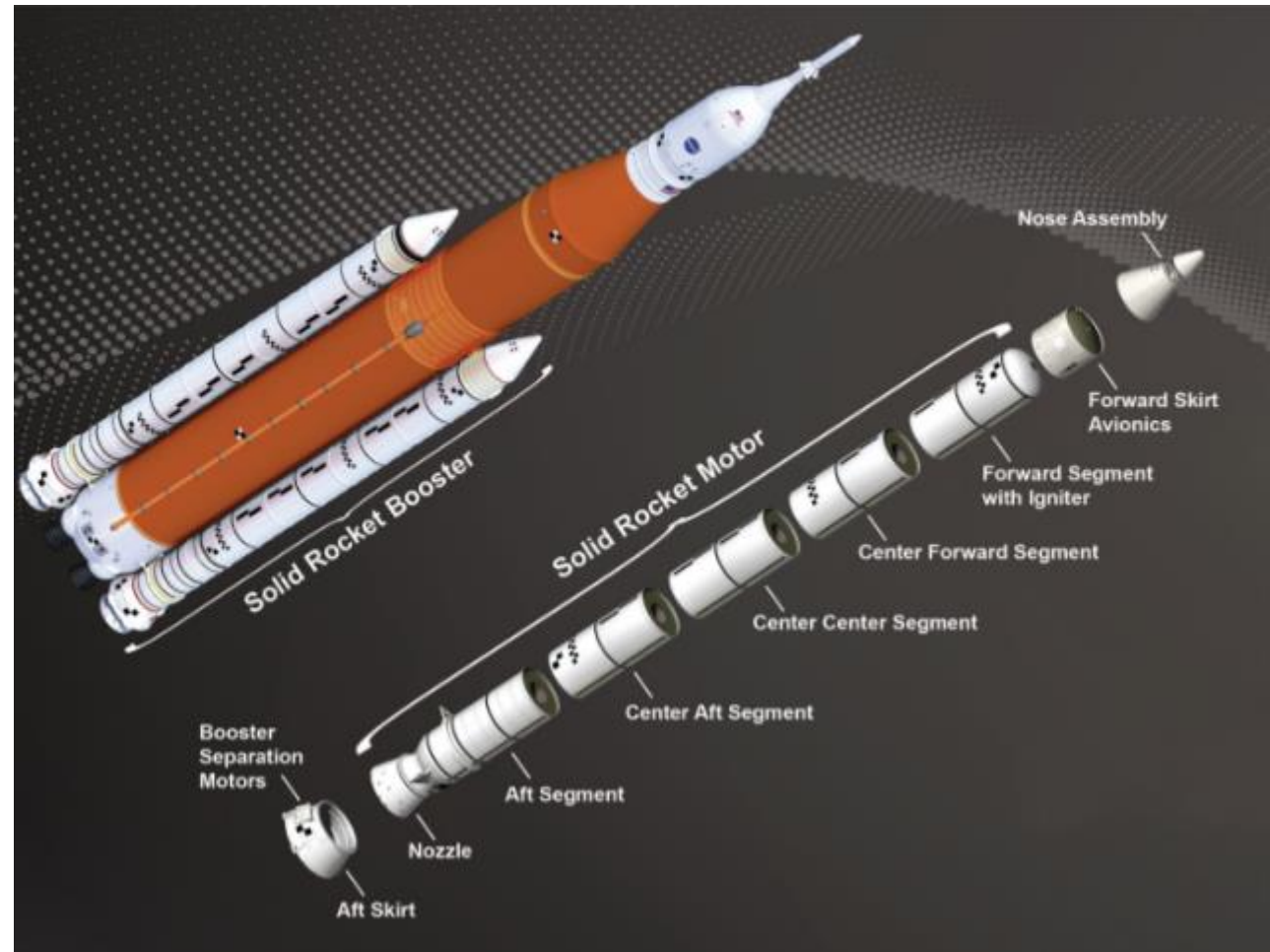
Diameter: 12 feet

Weight: 1.6 million pounds each

Propellant: polybutadiene acrylonitrile (PBAN)

Thrust: 3.6 million pounds each

Operational time: 126 seconds



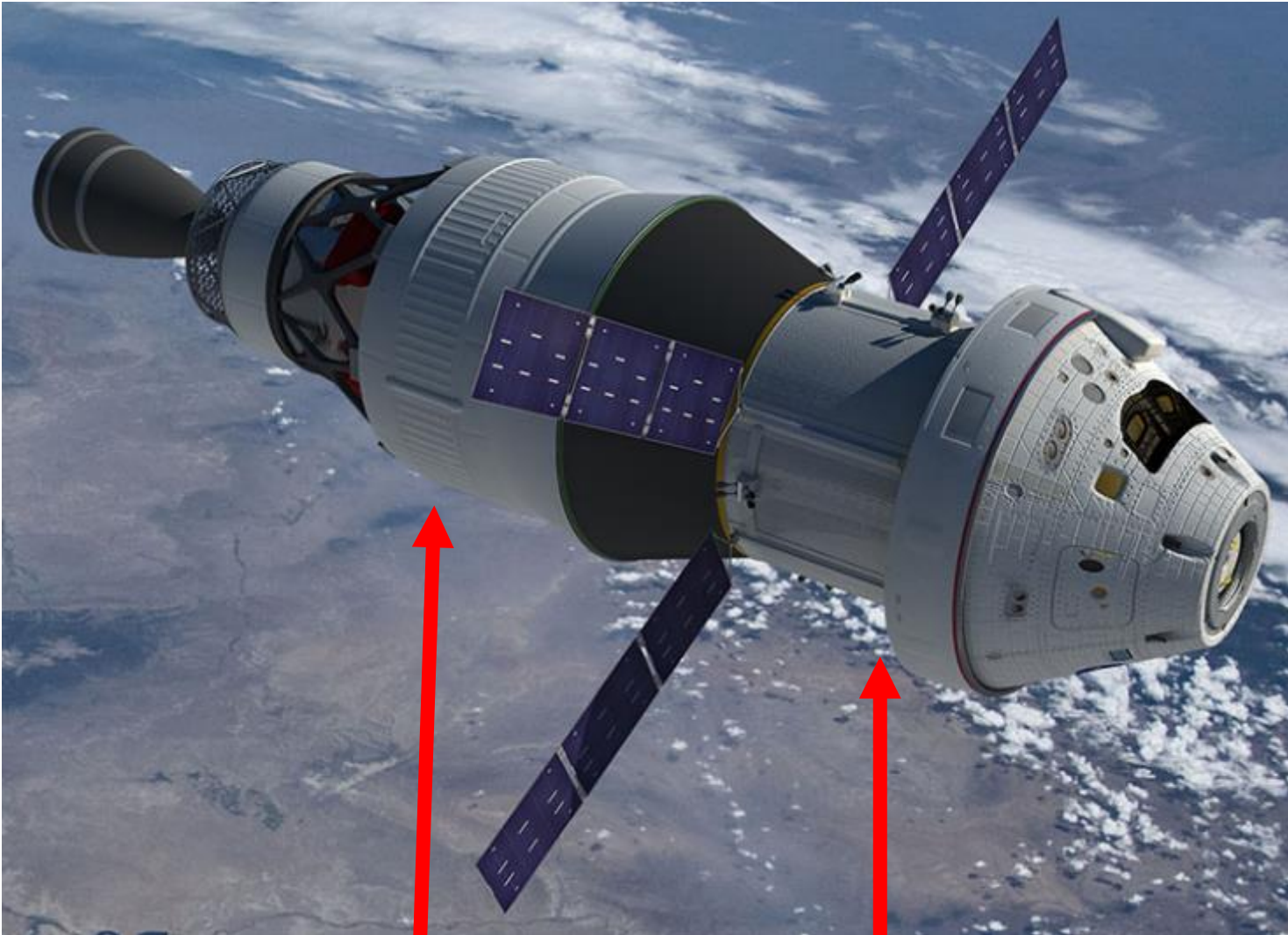
# Upper Stage for First Launches (SLS Block 1) Interim Cryogenic Propulsion Stage (ICPS) – Boeing/ULA



RL-10 Engine made by Aerojet Rocketdyne  
(formerly Pratt & Whitney Rocketdyne)

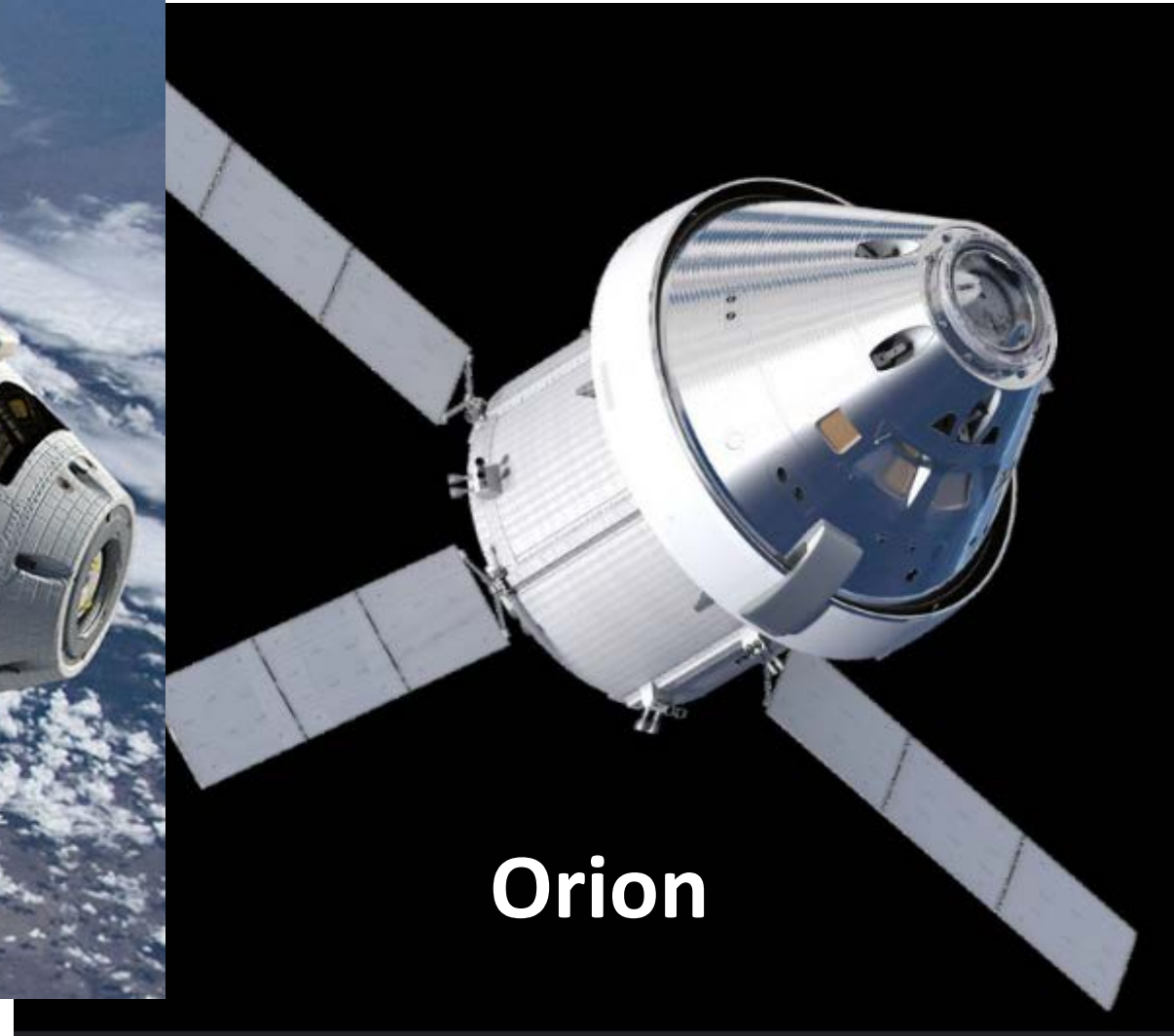


# Orion – Lockheed Martin



ICPS

Orion



Orion

# Final Integration and Launch from Kennedy Space Center



# Flight Termination System (FTS)

## Ground-controlled FTS



Ref 1  
RF Antenna



Ref 2  
Receiver/Decoder



Ref 5  
Safe & Arm  
Device containing  
an Initiator



Ref 6  
Flexible Confined  
Detonating Cord  
Assembly (FCDCA)



Ref 4  
Time Delay



Ref 6  
Flexible Confined  
Detonating Cord  
Assembly (FCDCA)



Ref 7  
Destruct  
Charge

## Autonomous FTS



Ref 3  
Sensors



Ref 2  
Logic Controller



Ref 5  
Safe & Arm  
Device containing  
an Initiator



Ref 6  
Flexible Confined Detonating  
Cord Assembly (FCDCA)



Ref 7  
Destruct Charge

## References:

1. [https://www.google.com/search?biw=1536&bih=754&tbm=isch&sa=1&ei=W\\_OmXMbDC6iwjwTx3Bk&q=rf+antenna&oq=rf+antenna&gs\\_l=img.3..35i39j0i67i2j0i2j0i67j0i3.3790.3985..4247...0.0..0.75.148.2.....1....1..gws-wiz-img.C88or3i47tk](https://www.google.com/search?biw=1536&bih=754&tbm=isch&sa=1&ei=W_OmXMbDC6iwjwTx3Bk&q=rf+antenna&oq=rf+antenna&gs_l=img.3..35i39j0i67i2j0i2j0i67j0i3.3790.3985..4247...0.0..0.75.148.2.....1....1..gws-wiz-img.C88or3i47tk)
2. [https://www.google.com/search?biw=1536&bih=754&tbm=isch&sa=1&ei=8POMXLQfi\\_uPBLzujMgN&q=avionics+box&oq=avionics+box&gs\\_l=img.3..28030.29472..29572...0.0..0.0.0.....1....1..gws-wiz-img.u0\\_s7hVDcll](https://www.google.com/search?biw=1536&bih=754&tbm=isch&sa=1&ei=8POMXLQfi_uPBLzujMgN&q=avionics+box&oq=avionics+box&gs_l=img.3..28030.29472..29572...0.0..0.0.0.....1....1..gws-wiz-img.u0_s7hVDcll)
3. [https://www.google.com/search?ei=rvWmXlvEJuzljwSShbDACg&q=accelerometers&oq=accelerometers&gs\\_l=psy-ab.3..0j0i20i263j0i8.3147.4625..4757...0.0..0.97.1137.14....2..0....1..gws-wiz.....0i71j35i39j0i67j0i228j0i131i67j0i131.TZQnBxBh1h8](https://www.google.com/search?ei=rvWmXlvEJuzljwSShbDACg&q=accelerometers&oq=accelerometers&gs_l=psy-ab.3..0j0i20i263j0i8.3147.4625..4757...0.0..0.97.1137.14....2..0....1..gws-wiz.....0i71j35i39j0i67j0i228j0i131i67j0i131.TZQnBxBh1h8)
4. <https://www.eba-d.com/products/time-delay-assembly/>
5. <https://psemc.com/products/electromechanical-safe-and-arm-device-esad/>
6. <https://www.eba-d.com/products/flexible-confined-detonating-cord-assembly-fcdca/>
7. <https://psemc.com/products/destruct-charge/>

# Destruct Charges

LINEAR SHAPED CHARGE  
CONFIGURATIONS RANGE  
(IN LENGTH)  
6 INCHES TO 10 FEET



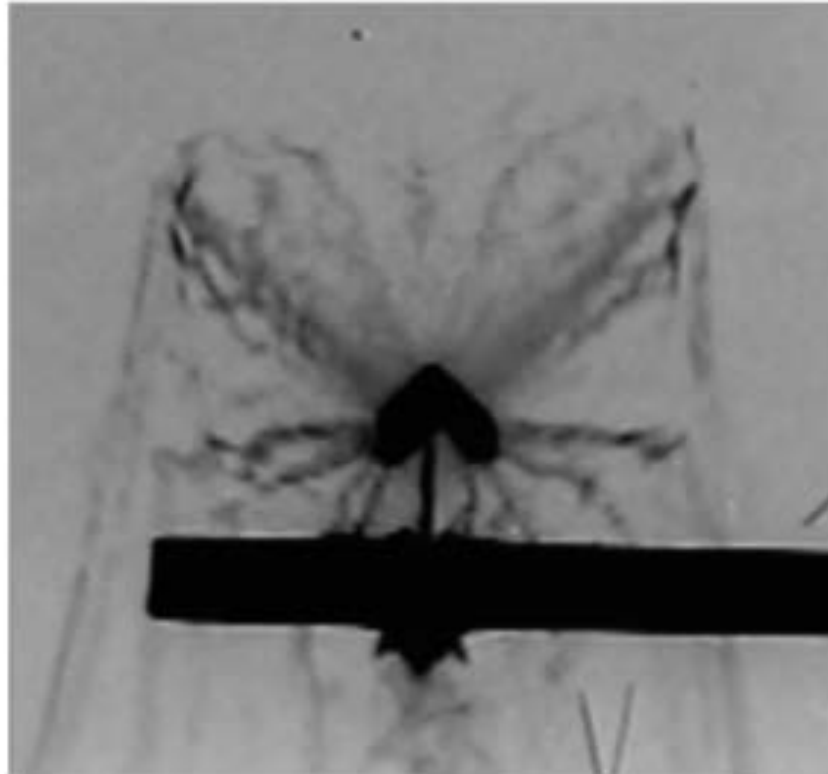
DESTRUCT CHARGE  
CONFIGURATIONS RANGE  
(IN DIAMETER)  
1 INCHES TO 12+ INCHES



<https://psemc.com/products/destruct-charge/>

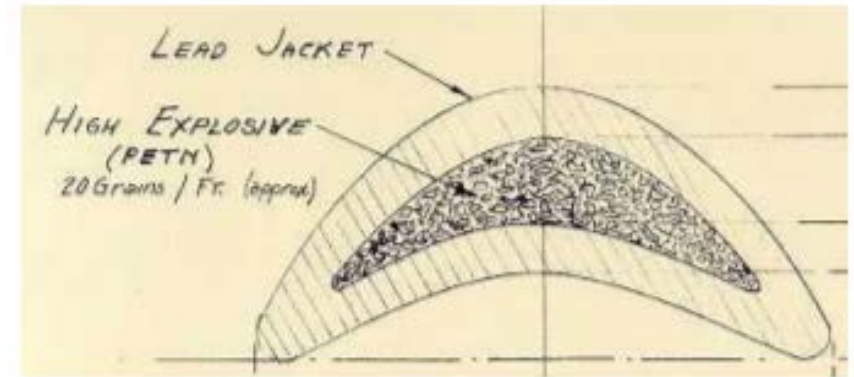
# Linear Shaped Charge (LSC)

- Can be used for Flight Termination (destruct)
- Can be used for separation of stages, fairings, vent ports, etc.



*Figure 16 – Flash X-Ray of detonating LSC. High velocity fragments can be created by the detonation event. (Source: Reference 6)*

<https://www.eba-d.com/assets/Uploads/AIAA-2003-4436-Separation-Joint-Tech.pdf>

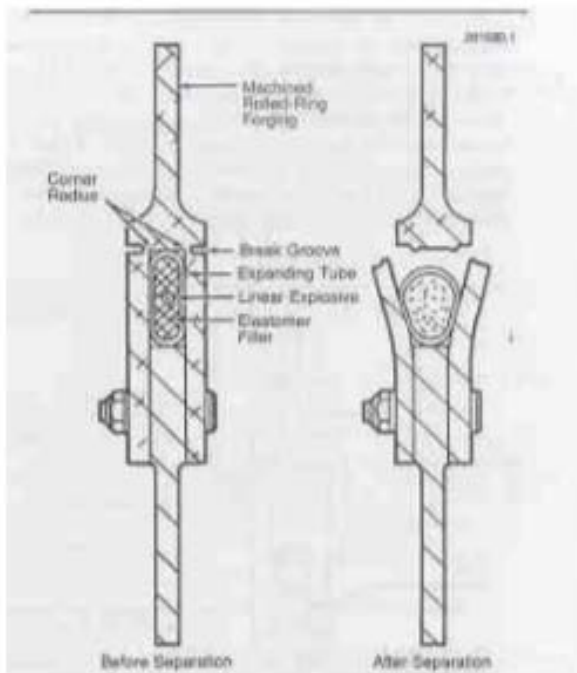


*Figure 10. Early LSC cross section, circa 1957 (Source: Reference 11)*

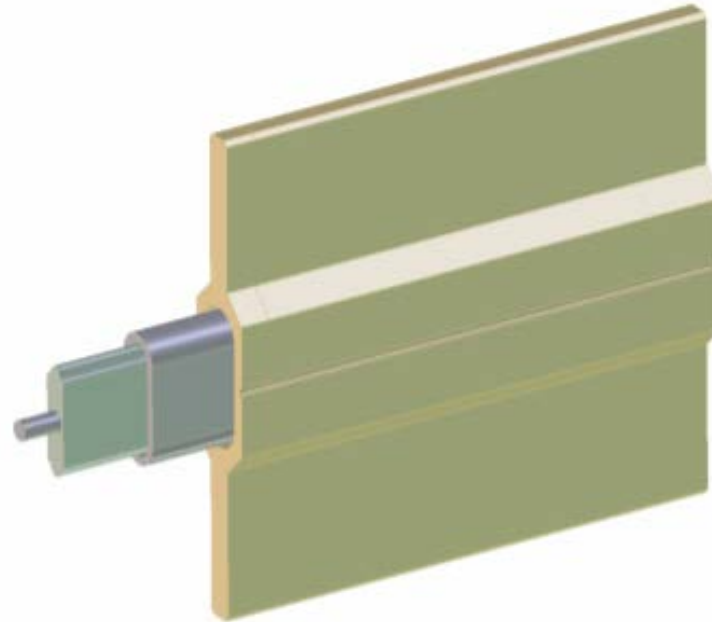


*Figure 12. Some examples of current production Linear Shaped Charges (Source: EBA&D)*

# Frangible Joint with Expanding Tube



*Figure 5. "Sure-Sep" Frangible Joint Configuration (Source: Reference 14)*



*Figure 6. Solid model of hollow form extrusion frangible joint (Source: EBA&D)*



*Figure 7. Confined Detonating Cord Separation Joint Assembly (Source: EBA&D)*

# Separation System Comparison

Linear Shaped Charge	Expanding Tube
More debris	Less debris
More source shock	Less source shock
More simple	Less simple

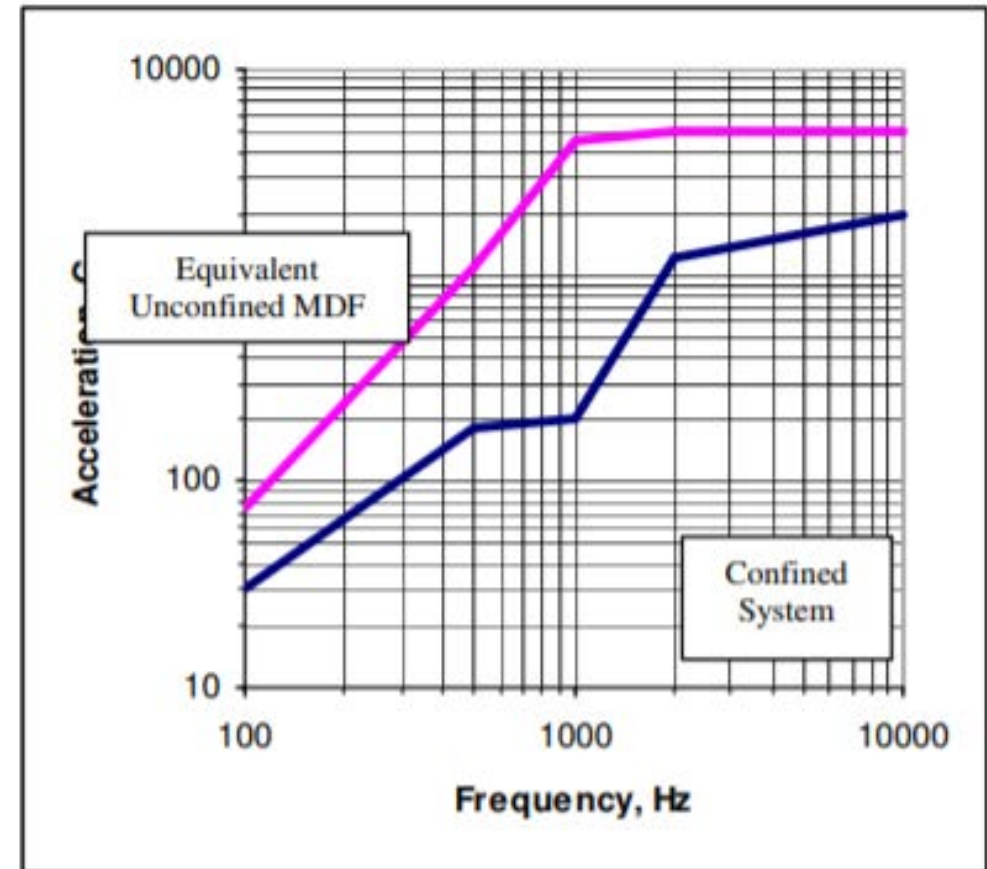


Figure 17. Comparative Data, Application of an Unconfined MDF system vs. a Confined Separation System (Source: EBA&D)

# Overview of Component Development

- Understand the subsystem that uses the components
- Write component specification, Statement of Work (SOW), Test plans if needed
- Send Request for Proposal (RFP) package: 60 days for suppliers' responses
- Evaluate proposals using predetermined evaluation criteria: 30 days
- Issue contract award to best supplier
- Design Reviews and Testing (iterative as design matures and hardware is built)
- Delivery to Boeing
- Support subsystem testing
- Support integration onto the vehicle
- Support vehicle testing
- Support the mission



# Component Specification

## Types:

- Envelope Drawing (ED)
- Source Control Drawing (SCD)
- Build-to-print Drawing with notes and parts list

## Requirements with Verifications:

- Functionality
- Environments: temperature, loads, pressure, vibration, shock, humidity, salt fog, electrostatic discharge, etc.
- Reliability
- Safety
- Dimensional Envelope (often includes a preliminary drawing)

# Governing Specifications for SLS Ordnance



## DoD Requirements and Standards

DoDD 3200.11	Major Range and Test Facility Base (MRTFB)
RCC Standard 313-01	Test Standards for Flight Termination Receivers/Decoders
RCC Standard 321-16	Common Risk Criteria Standards for National Test Ranges
RCC Standard 323-99	Range Safety Criteria for Unmanned Air Vehicles
EWR 127-1	Range User Handbook
AFSPCMAN 91-710V1	Range Safety User Requirements Manual Volume 1 - Air Force Space Command Range Safety Policies and Procedures
AFSPCMAN 91-710V2	Range Safety User Requirements Manual Volume 2 - Flight Safety Requirements
AFSPCMAN 91-710V3	Range Safety User Requirements Manual Volume 3 - Launch Vehicles, Payloads, and Ground Support Systems Requirements
AFSPCMAN 91-710V4	Range Safety User Requirements Manual Volume 4 - Airborne Flight Safety System Design, Test, and Documentation Requirements
AFSPCMAN 91-710V5	Range Safety User Requirements Manual Volume 5 - Facilities and Structures
AFSPCMAN 91-710V6	Range Safety User Requirements Manual Volume 6 - Ground and Launch Personnel, Equipment, Systems, and Material Operations Safety Requirements
AFSPCMAN 91-710V7	Range Safety User Requirements Manual Volume 7 - Glossary of References, Abbreviations, and Acronyms, and Terms.

<https://kscsma.ksc.nasa.gov/RangeSafety/reqDocs/DoDlinks>



MEASUREMENT  
SYSTEM  
INCH-POUND

National Aeronautics and  
Space Administration

MSFC-SPEC-3635  
REVISION C  
EFFECTIVE DATE: JUNE 25, 2018

George C. Marshall Space Flight Center  
Marshall Space Flight Center, Alabama 35812

EV30

MSFC TECHNICAL STANDARDS

## PYROTECHNIC SYSTEM SPECIFICATION

Approved for Public Release; Distribution is Unlimited

CHECK THE MASTER LIST - VERIFY THAT THIS IS THE CORRECT VERSION BEFORE USE

<https://standards.nasa.gov/standard/msfc/msfc-spec-3635>

# Component Testing

- Development Testing
- Qualification Testing
- Acceptance Testing

# Component Reviews

- Pre-Contract Requirements Review
- System Requirements Verification Review
- Preliminary Design Review (PDR)
- Critical Design Review (CDR)
- Test Readiness Review (TRR)
- Acceptance Review (AR) or Hardware Acceptance Review (HAR)

Questions?

