



NASA Langley Research Center

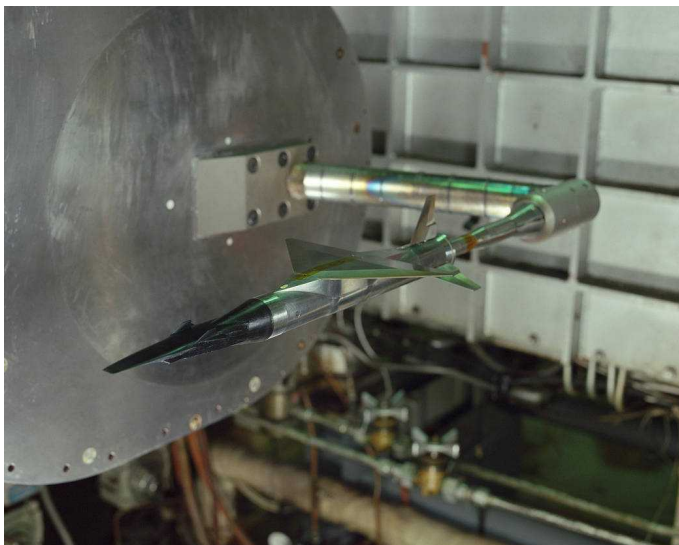


SUPERSONIC / HYPERSONIC GROUND TESTING CAPABILITIES
AND TEST TECHNIQUES



NASA Langley Research Center (LaRC)

Supersonic/Hypersonic Ground Testing



Aerothermodynamics Laboratory (LAL)

3% Hyper-X/Pegasus Launch Vehicle in Mach 6 and Mach 10 Tunnels

Unitary Plan Wind Tunnel (UPWT)

Space Launch System (SLS) – Stage Separation Test





NASA Langley Research Center (LaRC)

Supersonic/Hypersonic Ground Testing



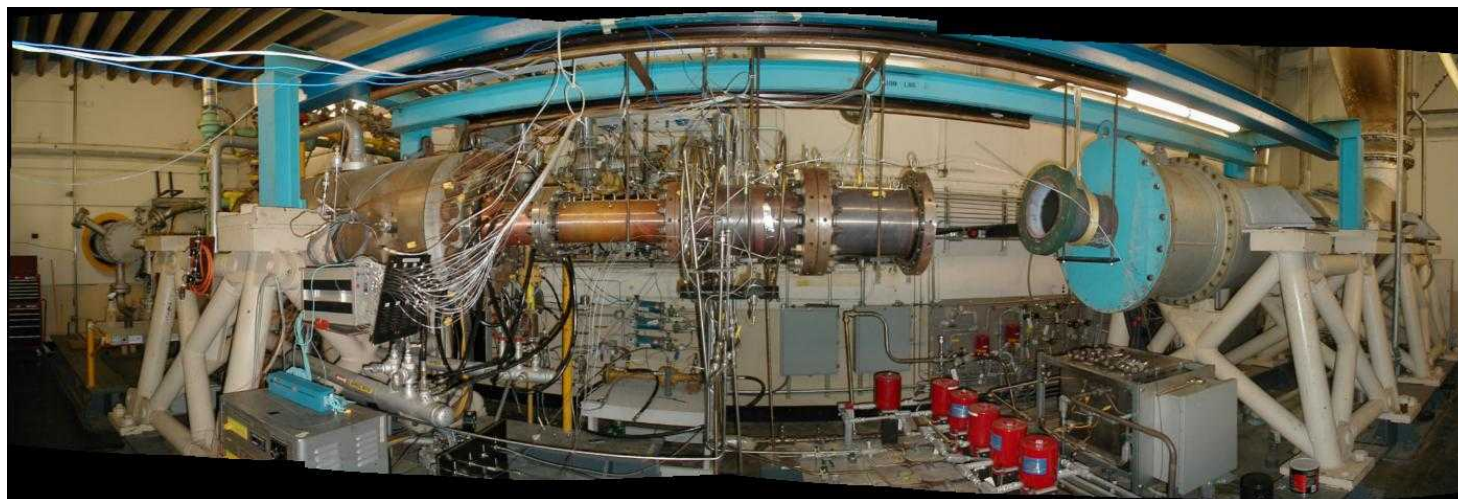
Arc-Heated Scramjet Test Facility

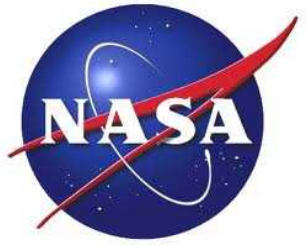
Flight Mach Enthalpy 4.7- 8



Direct-Connect Supersonic Combustion Test Facility

Flight Mach Enthalpy 4.5 - 7



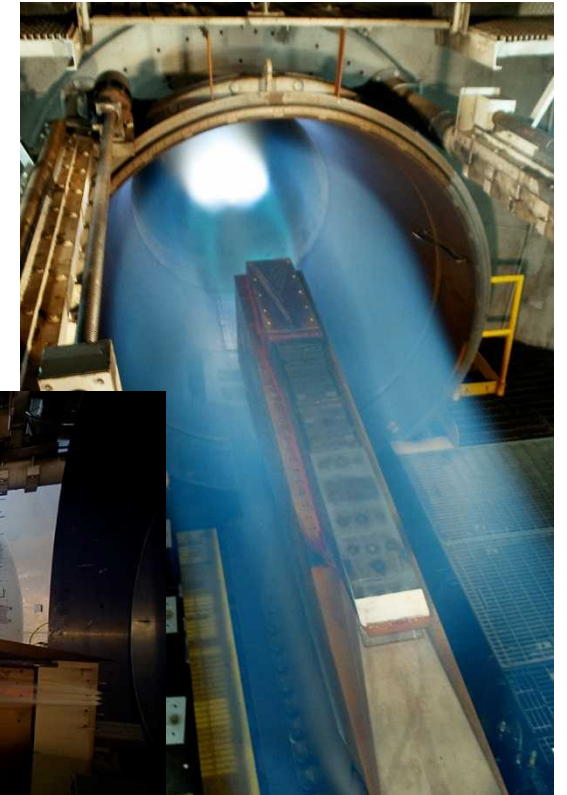
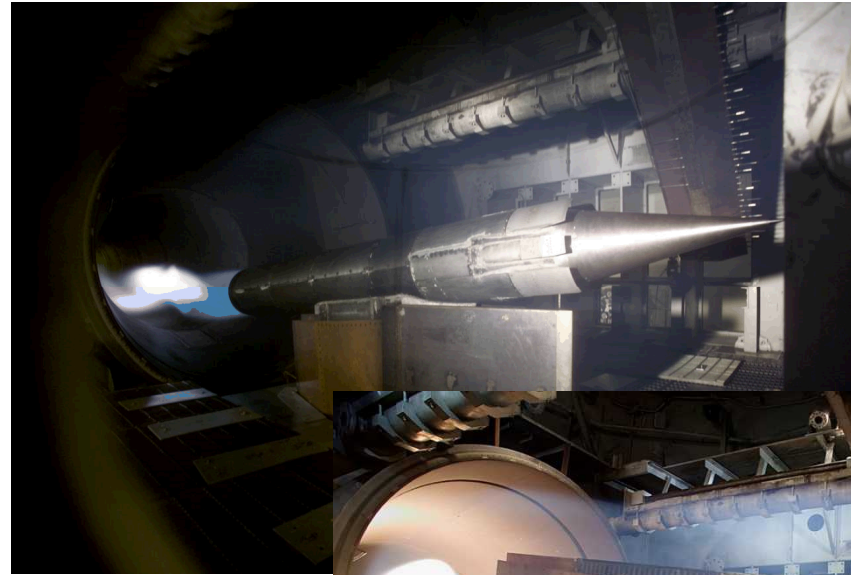


NASA Langley Research Center (LaRC)

Supersonic/Hypersonic Ground Testing



8-Foot High Temperature Tunnel (8'HTT)





NASA Langley Research Center (LaRC)

Supersonic/Hypersonic Ground Testing

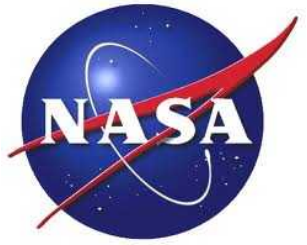


Condition Capability

- The NASA LaRC 8'HTT provides testing capability at Mach 3, 4, 5, and 6.5.
- Simulated altitude: up to 120k-ft
- Combustor stagnation pressure (up to 2000 psia)
- Combustor stagnation temperature (up to 3500°R)

The facility has been heavily utilized for hypersonic engine testing (last 4yrs).



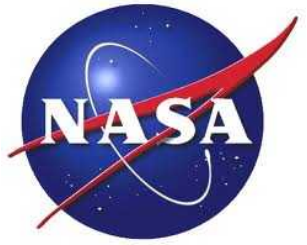


NASA Langley Research Center (LaRC)

Supersonic/Hypersonic Ground Testing



- National Aerospace Plane Concept Demonstration Engine (NASP)
- X43 Hyper-X engine
- Office of Naval Research HyFly Dual Combustor Ramjet Engine
- X43C program's Ground Demonstrator Engine No. 2
- Air Force Research Laboratory (AFRL) SJX61-1 and SJX61-2 engines
- NASA program for the Advancement of
- Program for Advanced Inflatable Decelerators for Atmospheric Entry thermal protection system test (PAI-DAE)
- Large Scramjet Engine Test Technology (LSETT)
- DARPA engine concepts



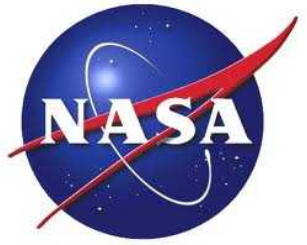
NASA Langley Research Center (LaRC)

Supersonic/Hypersonic Ground Testing



Hypersonic tunnel concepts:

- A means to move air
- A means to heat the air
- A means to accelerate the air

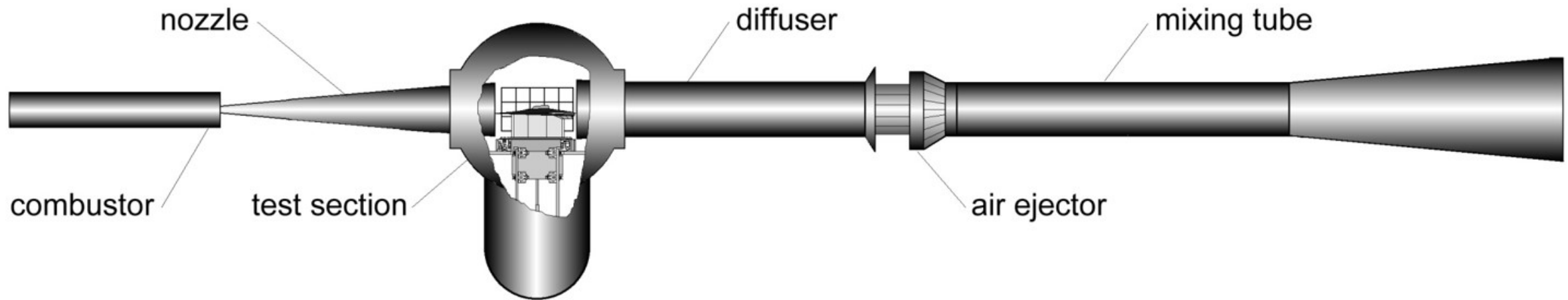


NASA Langley Research Center (LaRC)

Supersonic/Hypersonic Ground Testing



In Regards to ground testing, what is needed to achieve Hypersonic speeds?





NASA Langley Research Center (LaRC)

Supersonic/Hypersonic Ground Testing



How to move air?



UPWT drive line - compressors



8' HTT - Compressed air storage



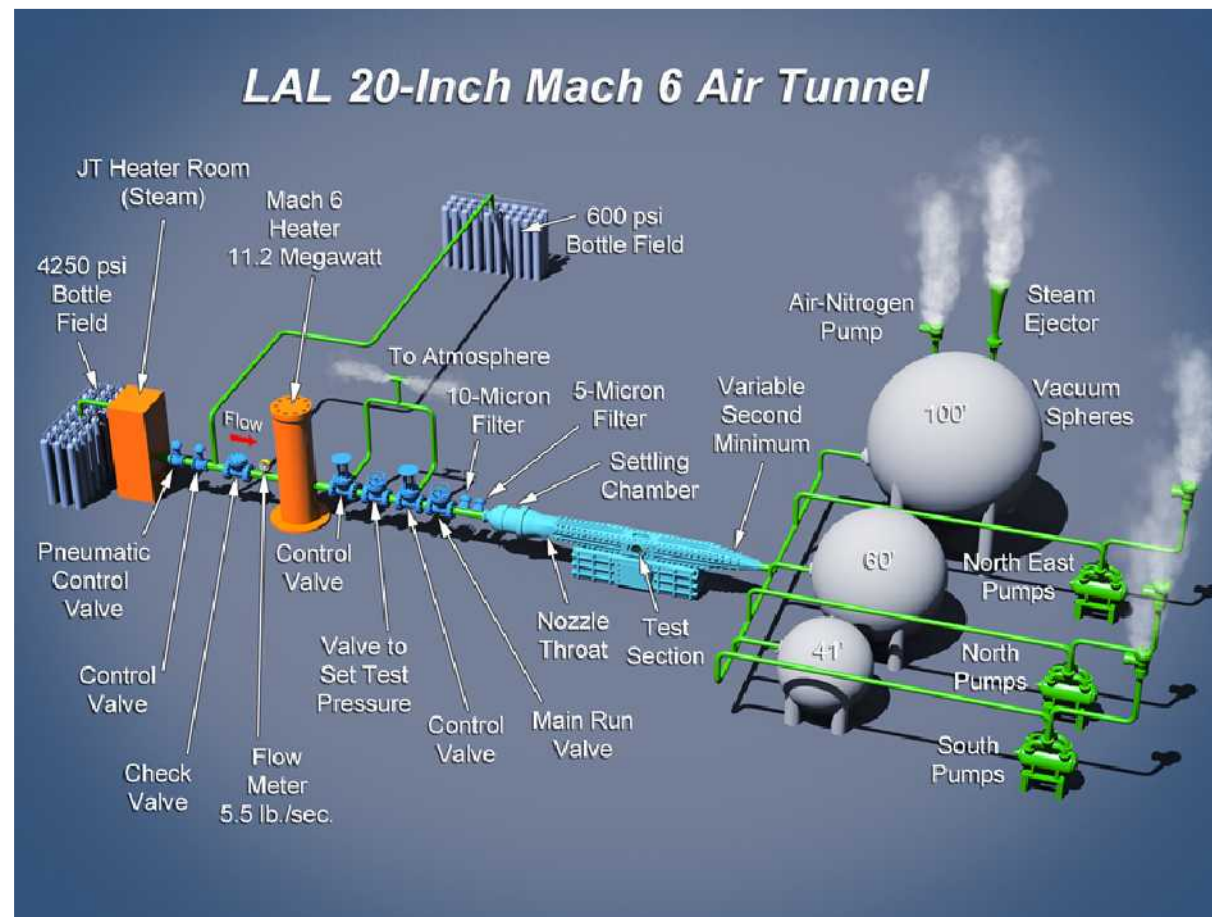
NASA Langley Research Center (LaRC)

Supersonic/Hypersonic Ground Testing



How to move air?

Compressed air storage with
vacuum sphere





NASA Langley Research Center (LaRC)

Supersonic/Hypersonic Ground Testing



How to move air?

Compressed air storage with vacuum sphere





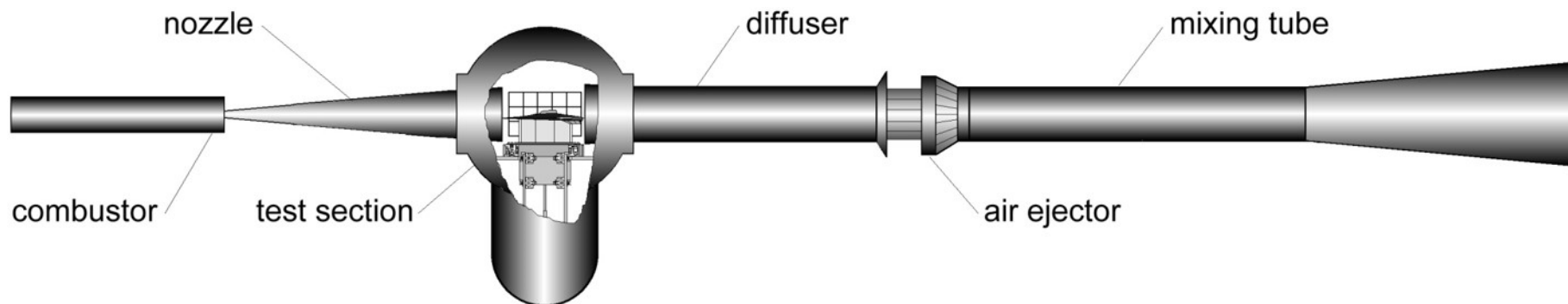
NASA Langley Research Center (LaRC)

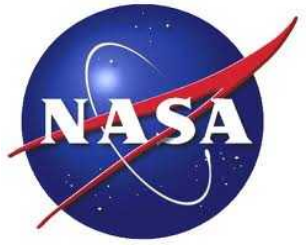
Supersonic/Hypersonic Ground Testing



Air ejector in place of vacuum spheres

- Up to 1,100 lbs/sec





NASA Langley Research Center (LaRC)

Supersonic/Hypersonic Ground Testing



How to reach flight enthalpy (temperature)? Means of heating

- Electrical heating
 - Arc heated facilities
 - Electrical resistance bundles heaters
- Combustion heating (Hydrogen, Methane, etc.)

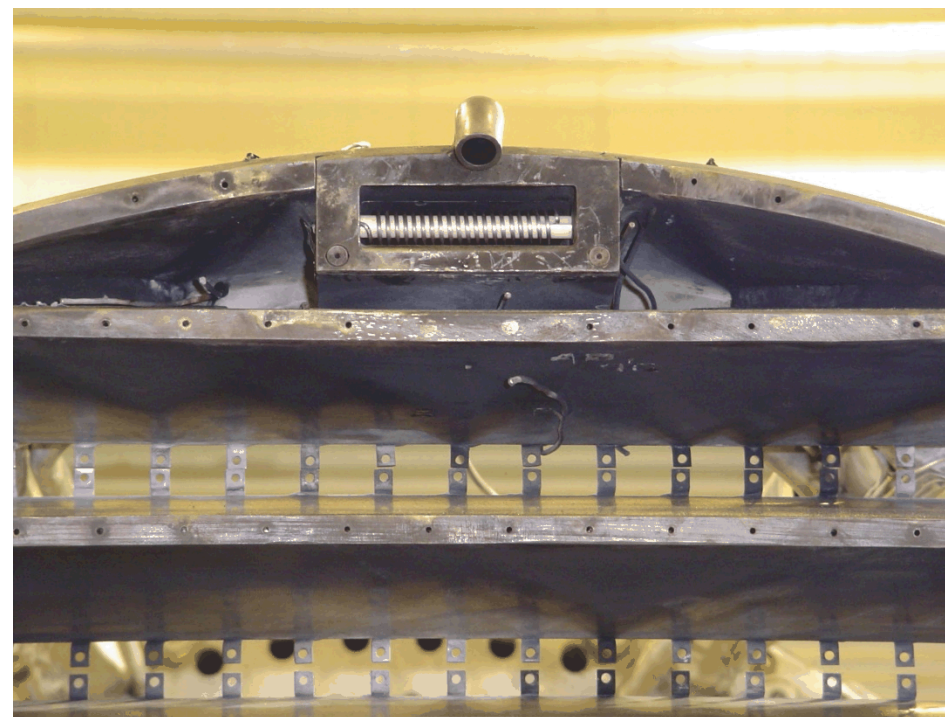


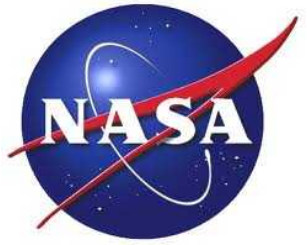
NASA Langley Research Center (LaRC)

Supersonic/Hypersonic Ground Testing



8'HTT Combustor Burner



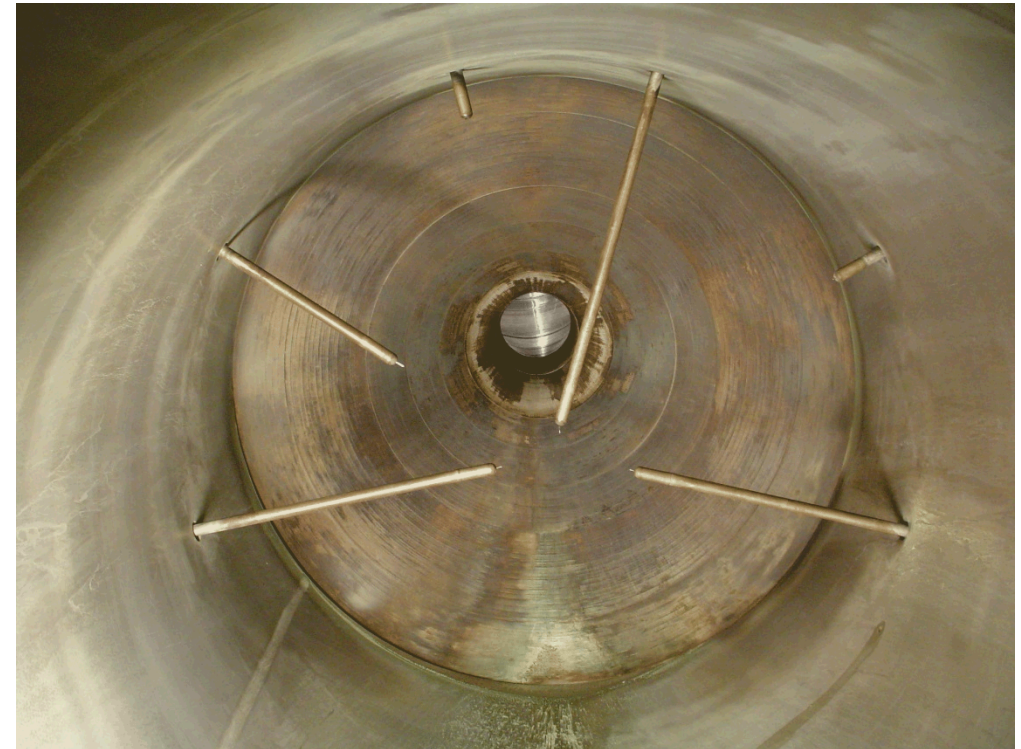


NASA Langley Research Center (LaRC)

Supersonic/Hypersonic Ground Testing



- Combustor temperature can reach $\sim 4000^{\circ}\text{R}$
- Measured with 6 thermocouples
- Custom wires
 - Iridium 40% Rhodium / Platinum 40% Rhodium



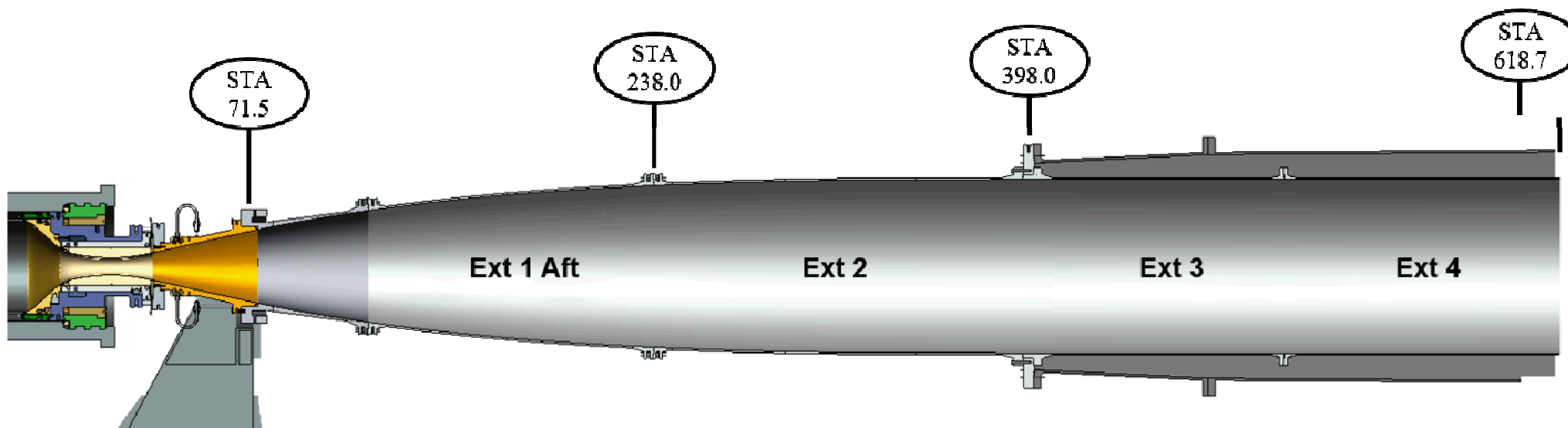


NASA Langley Research Center (LaRC)

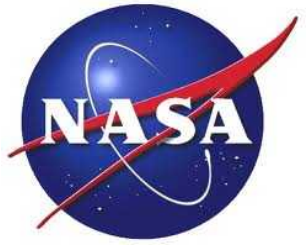
Supersonic/Hypersonic Ground Testing



How to accelerate the air?



Converging/Diverging Nozzles



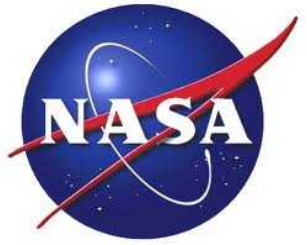
NASA Langley Research Center (LaRC)

Supersonic/Hypersonic Ground Testing



- 8'HTT's Mach 7 Transpiration Cooled Nozzle (Air cooled)
- Converging/diverging sections made of approx. 4500 plates
 - Acid etched
 - Vacuum brazed together





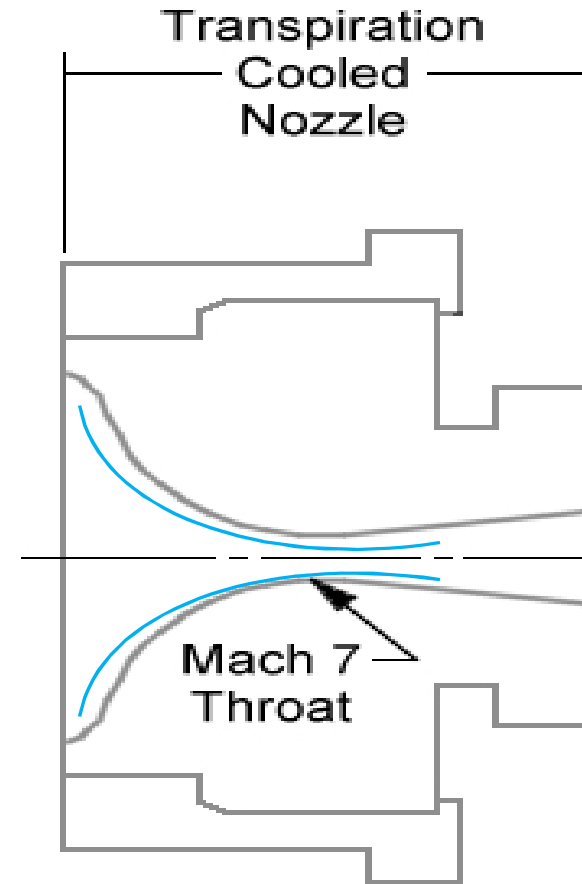
NASA Langley Research Center (LaRC)

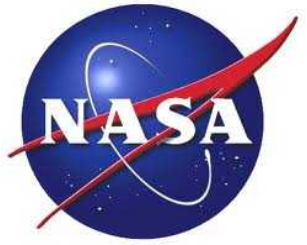
Supersonic/Hypersonic Ground Testing



8'HTT Transpiration Cooled Nozzle:

- Active air cooling
- Only fixed part of the tunnel
- Used for all test conditions





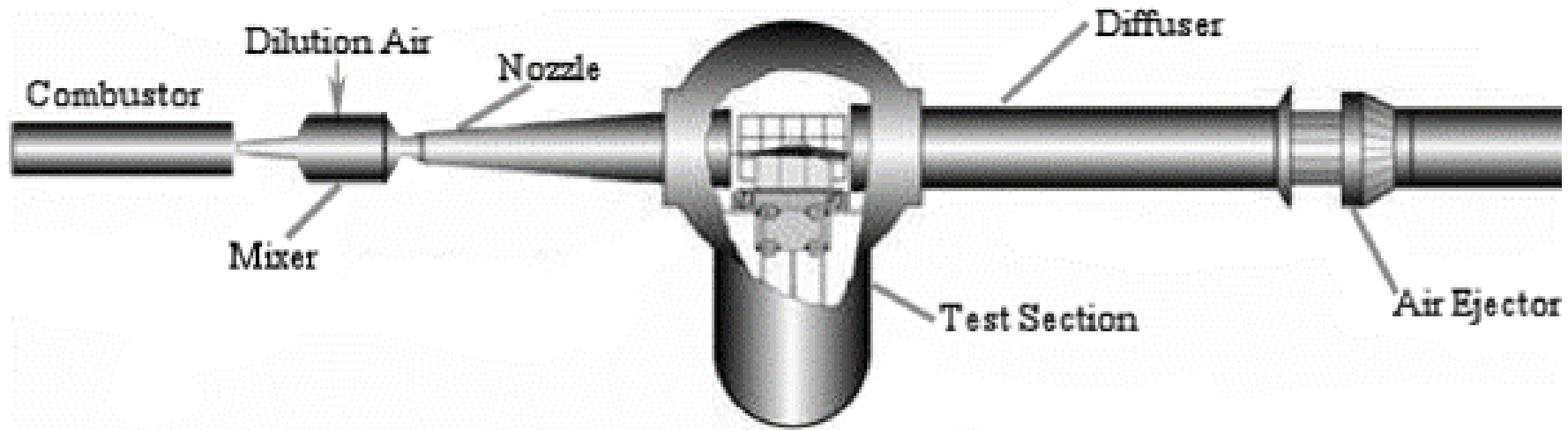
NASA Langley Research Center (LaRC)

Supersonic/Hypersonic Ground Testing



Multiple nozzles

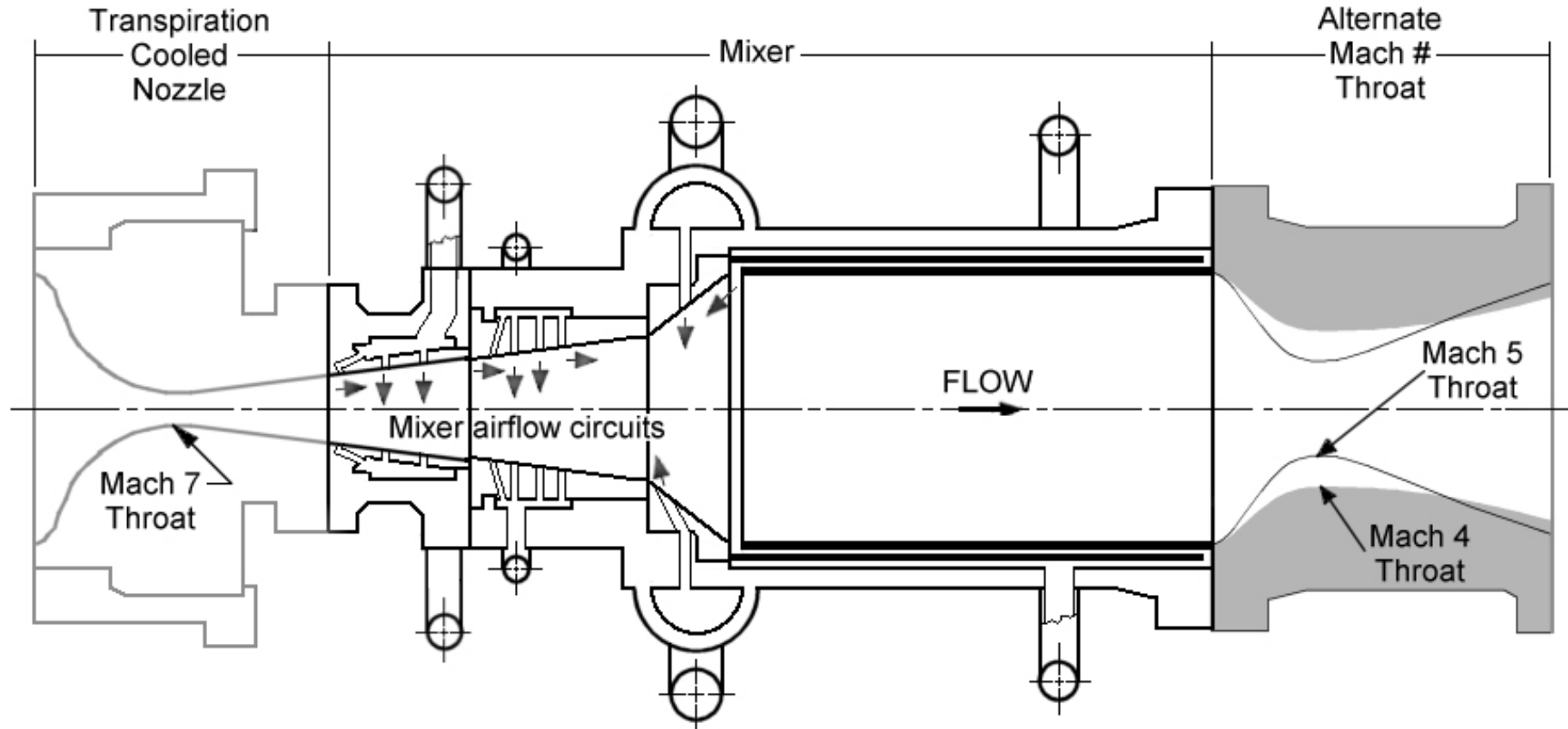
- Mach 7 transpiration cooled nozzle (built in)
- Mach 3, Mach 4, Mach 5 by use of the Mixer





NASA Langley Research Center (LaRC)

Supersonic/Hypersonic Ground Testing





NASA Langley Research Center (LaRC)

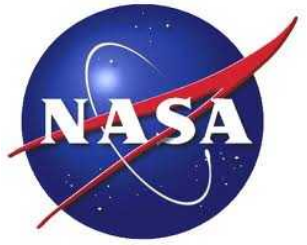
Supersonic/Hypersonic Ground Testing



← Mach 7 configuration

Mach 5 configuration →





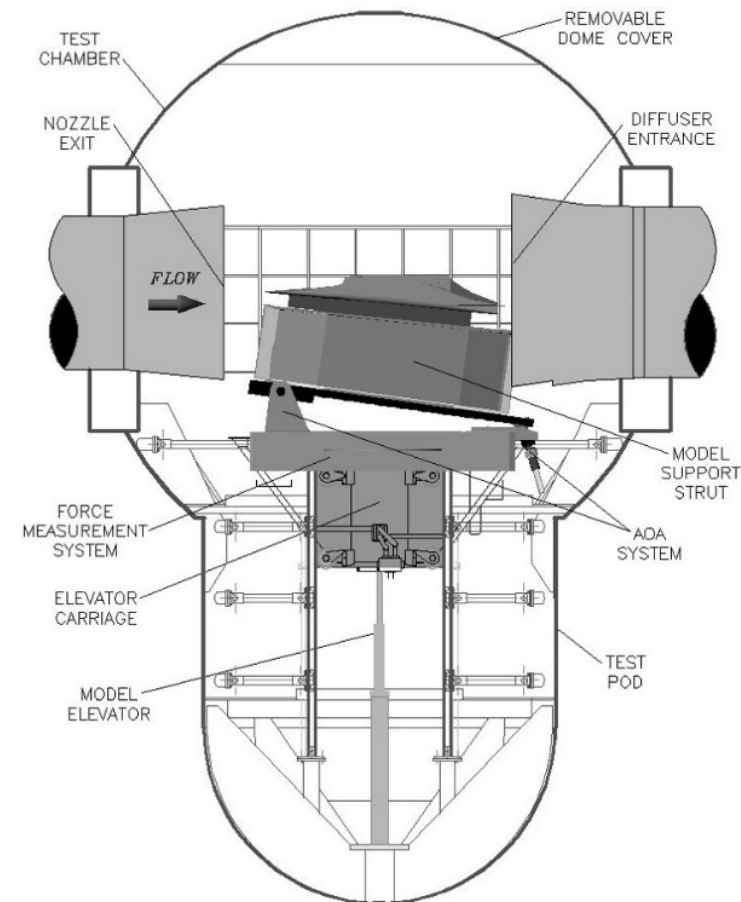
NASA Langley Research Center (LaRC)

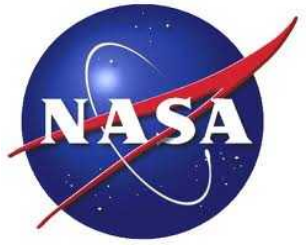
Supersonic/Hypersonic Ground Testing



Model Elevator

- Vertical movement of ~ 86 inches
- Hydraulically actuated
- Hard stops





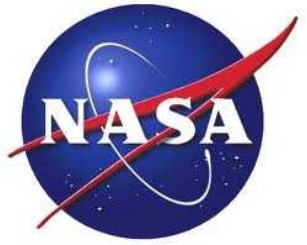
NASA Langley Research Center (LaRC)

Supersonic/Hypersonic Ground Testing



What is ground testing facility's greatest delivery?

DATA



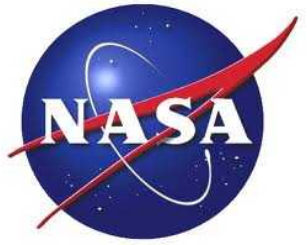
NASA Langley Research Center (LaRC)

Supersonic/Hypersonic Ground Testing



Forms of Data (not limited to):

- Pressure
- Temperature
- Force and moment
- Heat flux
- IR thermography
- Photogrammetry
- Schlieren
- Laser velocimetry



NASA Langley Research Center (LaRC)

Supersonic/Hypersonic Ground Testing



Flow Survey Apparatus (FSA)

- A series of static pressure, pitot pressure and total temperature
- Hydraulically driven rake
- Pinned above nozzle and moves like a wiper blade across nozzle exit plane.



NASA Langley Research Center (LaRC)

Supersonic/Hypersonic Ground Testing



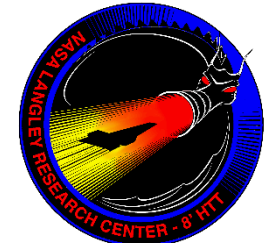
Flow Survey Apparatus (FSA)



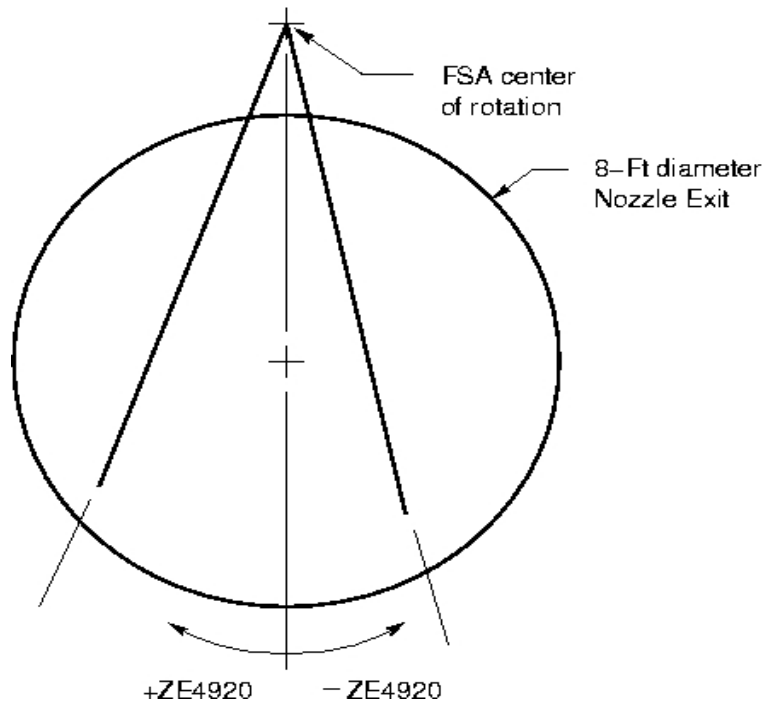


NASA Langley Research Center (LaRC)

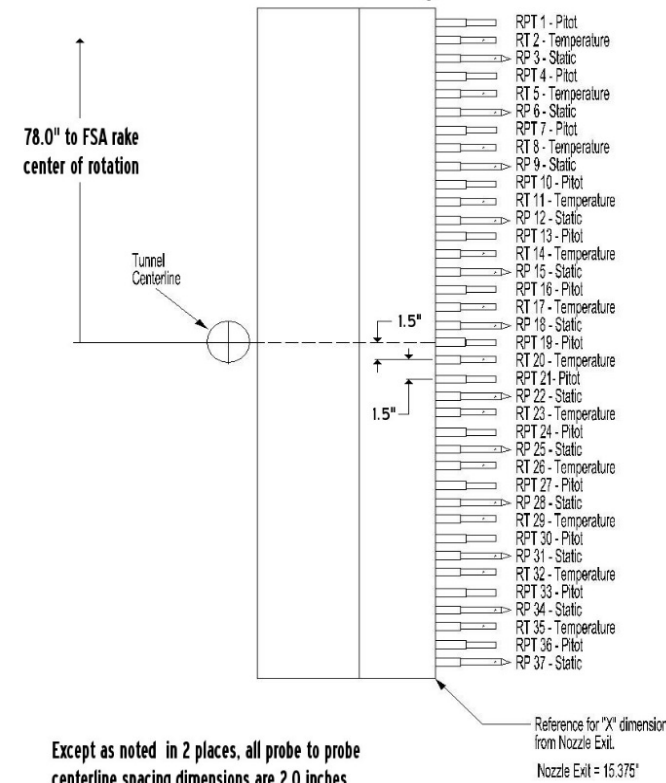
Supersonic/Hypersonic Ground Testing



FSA



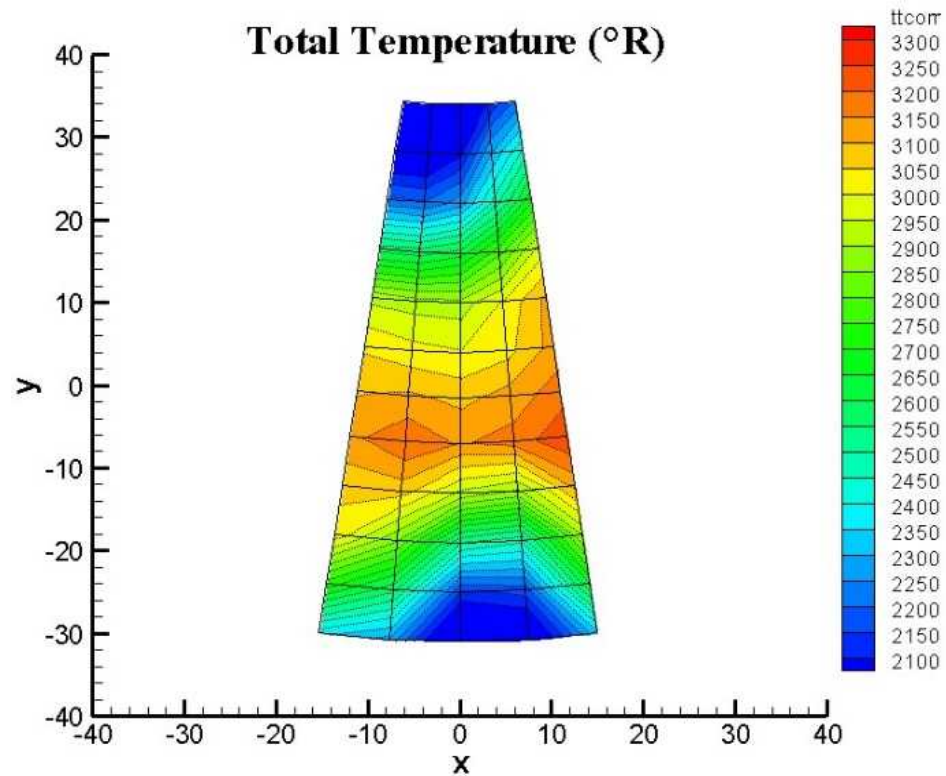
FSA (Flow Survey Apparatus) INFO Baseline Configuration





NASA Langley Research Center (LaRC)

Supersonic/Hypersonic Ground Testing



***** AREA WEIGHTED AVERAGE PROPERTIES *****

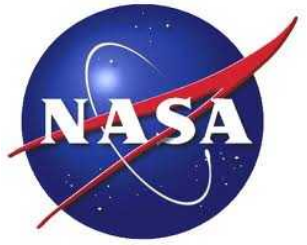
TOTAL EXIT AREA (IN²) = 361.00000000001
INTEGRATED $\rho U A$ (LBM/SEC) = 26.240597490958
INTEGRATED STREAM THRUST (LBF) = 5358.1035388961

*** AVERAGE INTEGRATED VALUES WEIGHTED BY:

	AREA	MASS	STREAM THRUST
PT2	13.8351	13.8386	13.8412
TT	3160.82	3160.79	3161.67
HT1	-399.571	-399.585	-399.271
PT1	1068.97	1069.38	1070.44
P1	0.256872	0.256923	0.256898
MCH1 ...	6.41934	6.41951	6.42041

EQUIVALENT 1-D PROPERTIES OF INTEGRATED FLOWFIELD:

T1D (R)	=	422.04885116572
P1D (PSIA)	=	0.25735535568629
H1D (BTU/LBM)	=	-1231.9028360086
S1D (BTU/LBM/R)	=	1.9438935213890
RHO1D (SLUG/FT3)	=	5.0393890230636D-05
MW1D ()	=	28.554360660005
GAM1D ()	=	1.3779575028533
MCH1D ()	=	6.4131182259302
U1D (FT/SEC)	=	6455.7405269182
C1D (FT/SEC)	=	1006.64611184239
HT1D (BTU/LBM)	=	-399.58482349663
HT_ZANE (BTU/LBM)	=	931.70961460729
TT1D (R)	=	3165.0840385773
PT1D (PSIA)	=	1064.6732606247
PT21D (PSIA)	=	13.788756039107
Q1D (PSF)	=	1050.1226437591



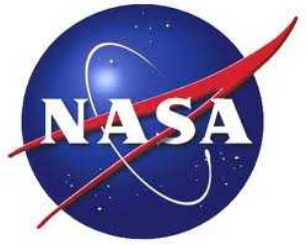
NASA Langley Research Center (LaRC)

Supersonic/Hypersonic Ground Testing



Engine Testing:

- Types
 - Performance – Thrust measurements, forces and moments on vehicle.
 - Ignition (not limited to):
 - Pyrophoric
 - Solid propellant
 - Electrical park



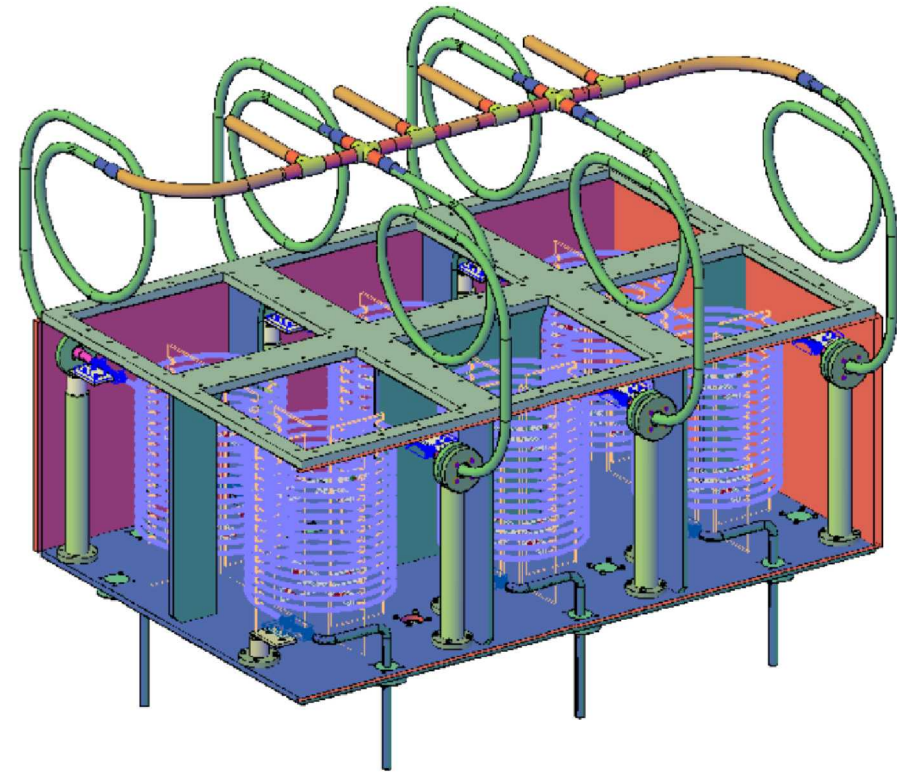
NASA Langley Research Center (LaRC)

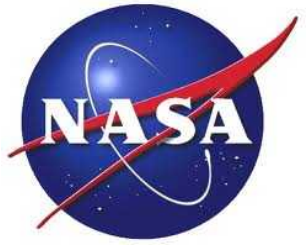
Supersonic/Hypersonic Ground Testing



Engine Testing Techniques:

- Fuel Heater
 - 6 coils @ 1 MW each
 - Heat fuels up to $\sim 1450^{\circ}\text{F}$
 - Flow rates up to $\sim \text{XX lbs/s}$





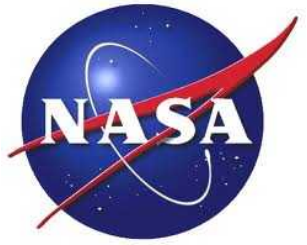
NASA Langley Research Center (LaRC)

Supersonic/Hypersonic Ground Testing



Engine Testing Techniques:

- Ignition Source
 - Silane/Hydrogen mixture
 - Hydrogen/Oxygen torch
 - TEB (Triethylborane)
 - Solid propellant
 - Electrical spark



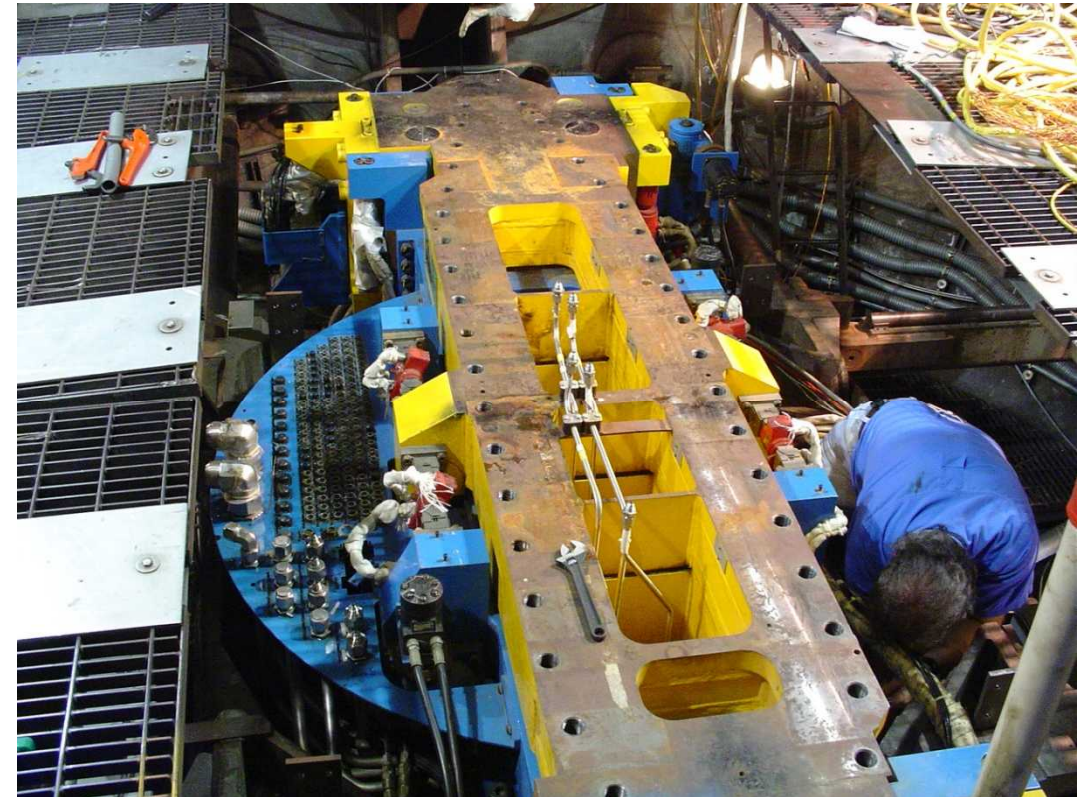
NASA Langley Research Center (LaRC)

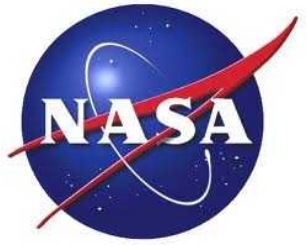
Supersonic/Hypersonic Ground Testing



Engine testing capabilities:

- Force Measurement System (FMS)
 - 16 measuring load cells (T-cells) with redundant bridges on each (A and B bridge)
 - 6 calibration cells
 - Hydraulically screw jack to apply loads
 - Higher accuracy
 - Allows for in situ calibrations/check loads





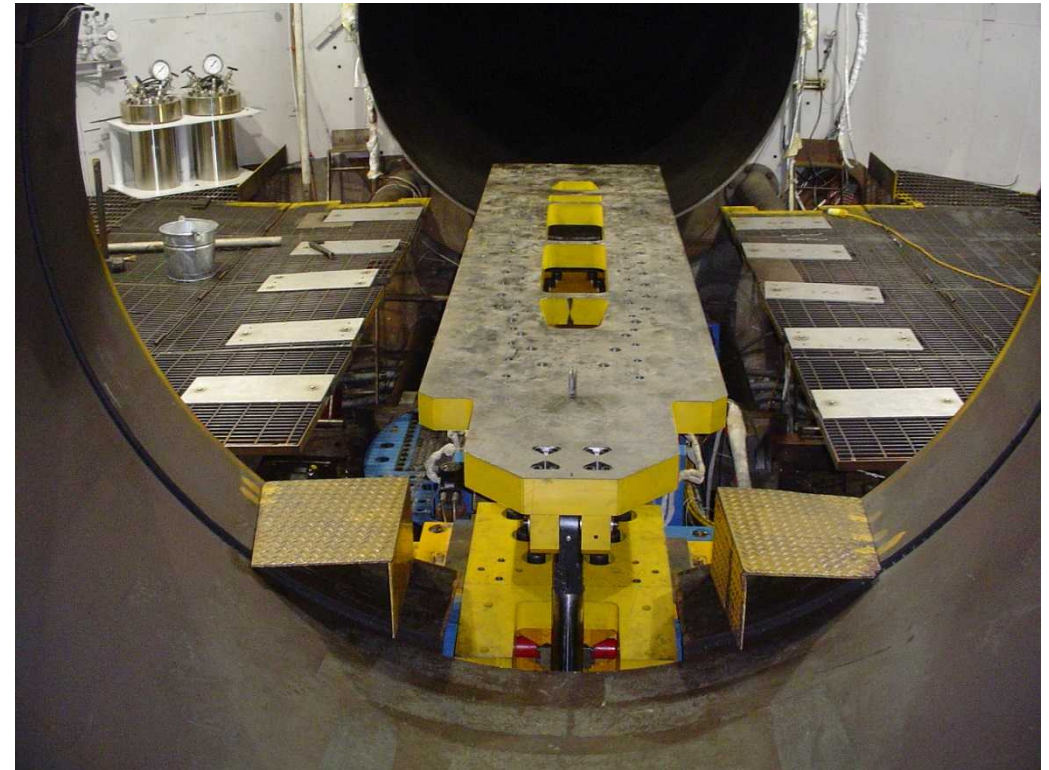
NASA Langley Research Center (LaRC)

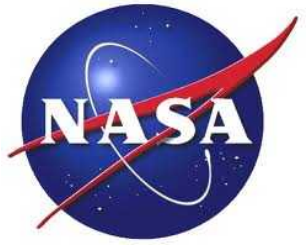
Supersonic/Hypersonic Ground Testing



Angle of Attack

- When mounted with FMS
- Front pivot
- Hydraulically actuated cylinder (AFT)





NASA Langley Research Center (LaRC)

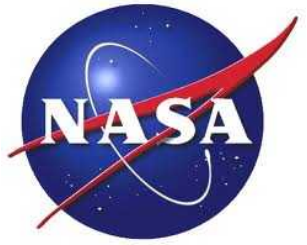
Supersonic/Hypersonic Ground Testing



Angle of Attack – “C-Strut”

- Non FMS utilization
- Greater range (0 - 20°)
- Hydraulically actuated





NASA Langley Research Center (LaRC)

Supersonic/Hypersonic Ground Testing



Programmable Logic Controller (PLC) – control system of the test facility.

Uses Allen Bradley software and ladder logic to operate.

Programmed to control and interlock facility operations

Four (4) PLC's

- Main
- Ejector
- Process
- Model



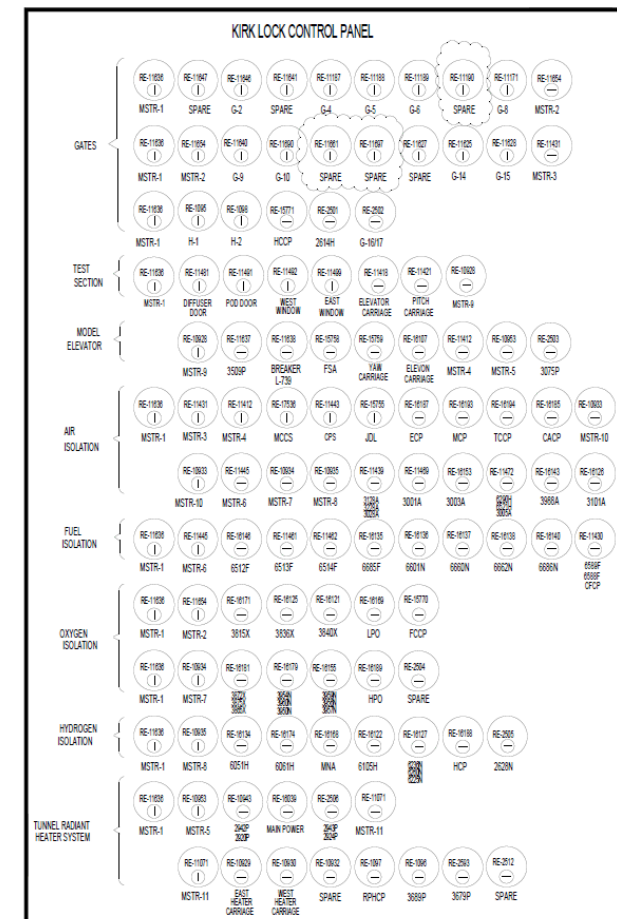
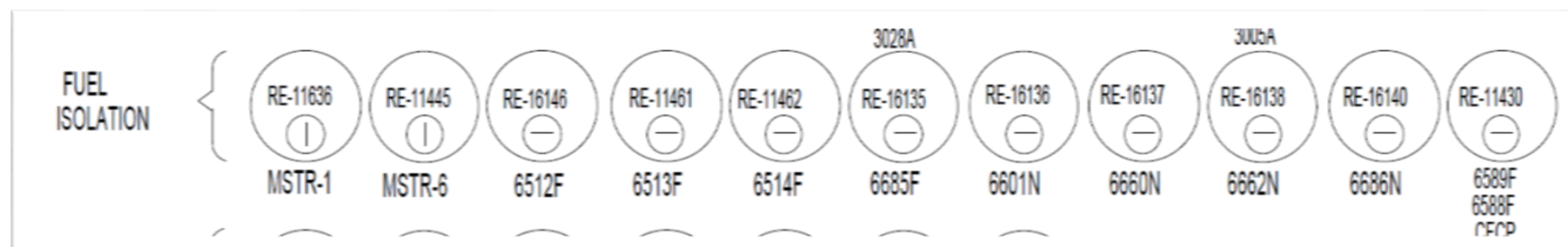
NASA Langley Research Center (LaRC)

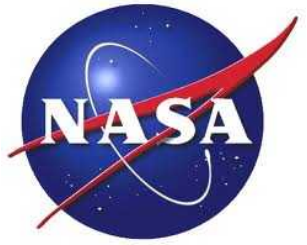
Supersonic/Hypersonic Ground Testing



Safety: Kirk Lock System

A key or a series of keys to lock/unlock a string of valves for a particular system





NASA Langley Research Center (LaRC)

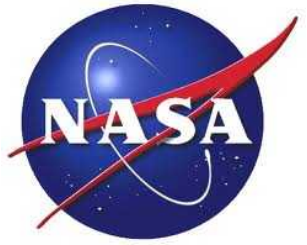
Supersonic/Hypersonic Ground Testing



8'HTT Fluid Systems:

- Air
 - Combustion air
 - Instrument/operators air
 - Air ejector





NASA Langley Research Center (LaRC)

Supersonic/Hypersonic Ground Testing



8' HTT Fluid Systems

- Methane
 - Facility combustion
- Nitrogen
 - Purge lines before and after operations
 - Test pod fire arrestor
- Water
 - Cooling – hardware or instrumentation
- LOX
 - Re-enriching tunnel air with O₂ for air breathing engines
 - Cools combustor liner

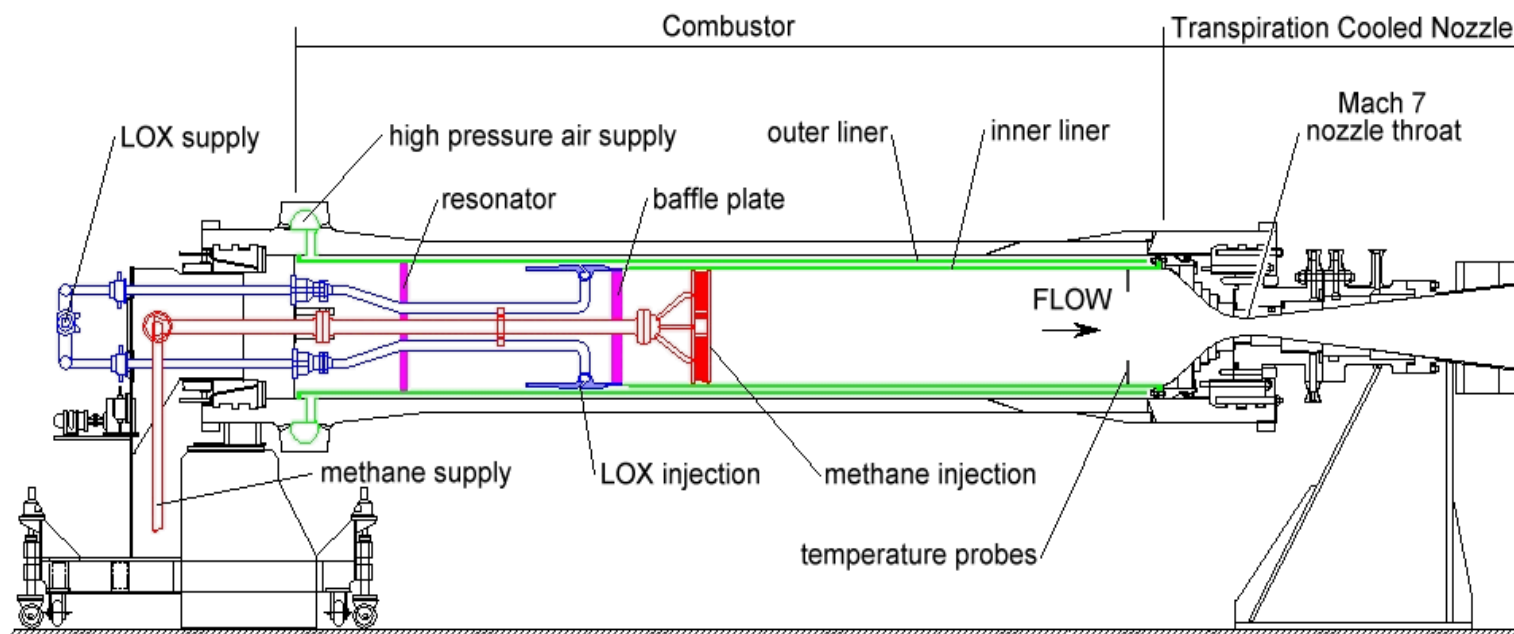


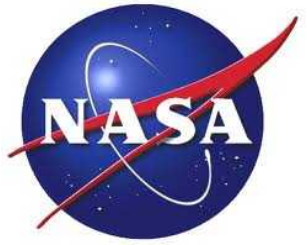
NASA Langley Research Center (LaRC)

Supersonic/Hypersonic Ground Testing

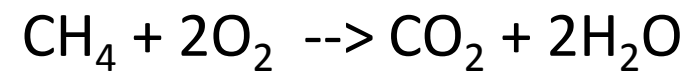


Liquid oxygen injection



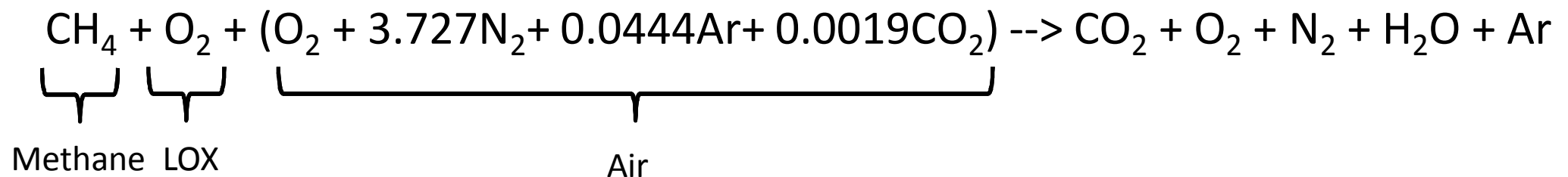


Methane combustion



Vitiate

8'HTT combustion process





NASA Langley Research Center (LaRC)
Supersonic/Hypersonic Ground Testing



BACKUP SLIDE

SED X1 Video



NASA Langley Research Center (LaRC)

Supersonic/Hypersonic Ground Testing

