National Aeronautics and Space Administration

Planning for a Supersonic Retropropulsion Test in the NASA Langley Unitary Plan Wind Tunnel

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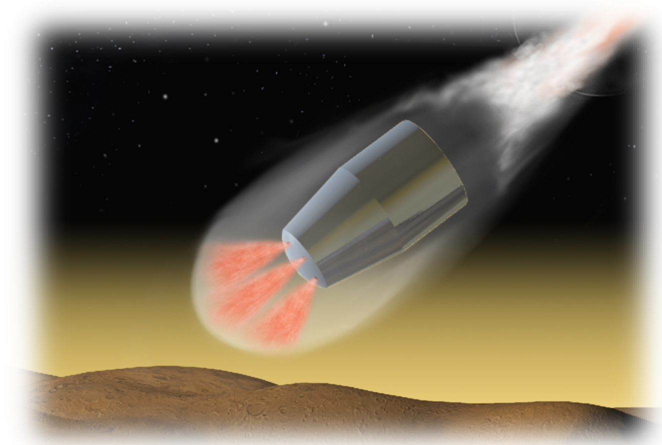
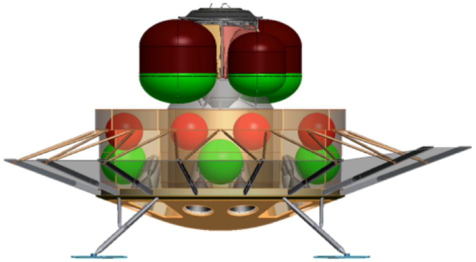


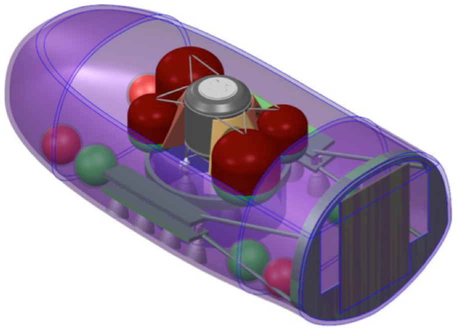
Background

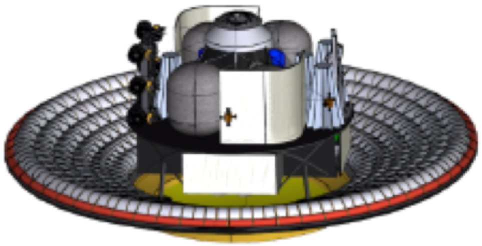
- **Retropropulsion starting at supersonic conditions, or SRP, is enabling for the descent phase of high-mass Mars EDL systems**
  - NASA has used supersonic parachutes and subsonic retropropulsion multiple times for Mars robotic landers
  - Tens of metric ton payloads (Curiosity rover = 0.9 t)
- **NASA ran high-fidelity aerosciences models against Falcon 9 SRP data (AIAA 2017-5296)**
- **NASA is preparing for a SRP test in the Langley Unitary Plan Wind Tunnel (UPWT) in 2019**

Outline:
- **Flight Reference Vehicles**
- **Test Motivation & Objectives**
- **Status of Scaling Analysis**
- **Summary**

Mars Concepts (20 t payloads) (AIAA 2016-5494)



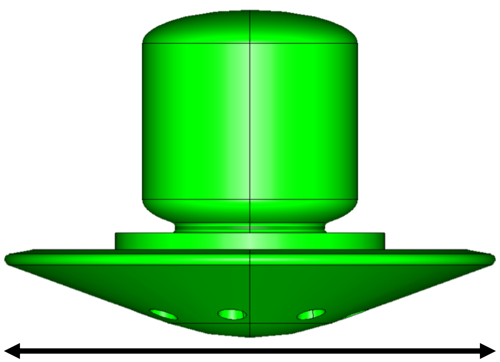




Current Flight Reference Vehicles

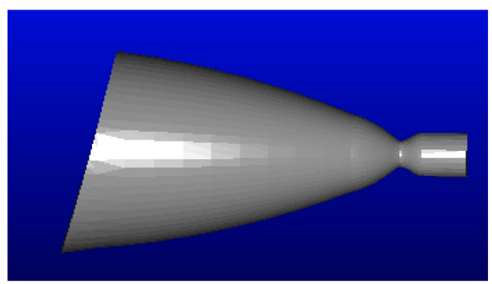
- **The planned wind tunnel test will have sub-scale models of one or both current NASA reference Mars vehicles**
  - Aerodynamic surfaces will be geometrically scaled, engine nozzles will not
- **8 LO_2/LCH_4 engines, ~100 kN each, multiple arrangements have been proposed**
- **The attitude control approach still is TBD, using the main engines and/or separate thrusters**

Low-L/D

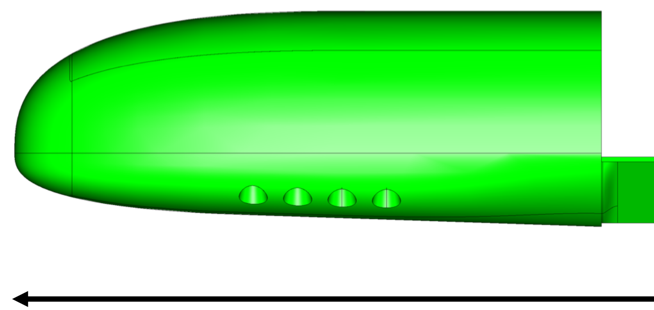


16.4 m

Flight Nozzle (177:1)



Mid-L/D



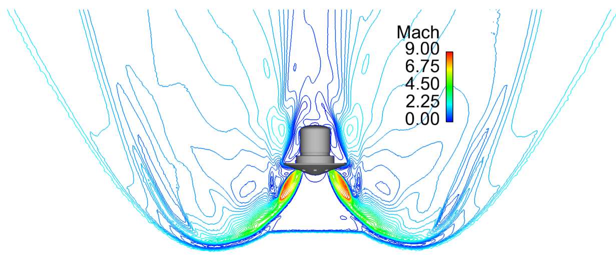
22 m

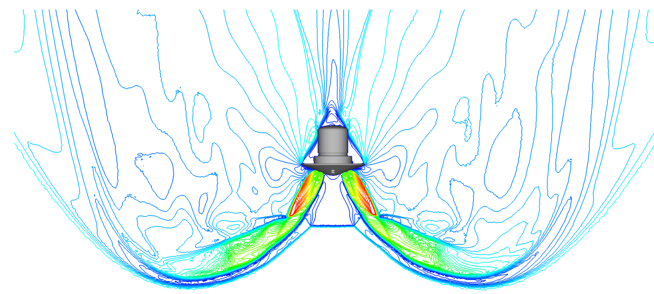
The current trajectory analysis approach is to turn off all AI F&M during propulsive descent. More fidelity is needed going forward.

Sample Flight CFD Results (Low-L/D)

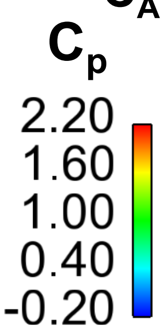
- **Time-averaged Loci-CHEM solutions at Mach 2.7 are shown**
  - Hundreds of thousands of CPU-hours per powered case
- **Pressure coefficient (C_p) > 0 produces an aerodynamic axial force (C_A), which typically is set to 0 for trajectory analysis**
- **Are the results realistic? What about moments? Non-zero angle-of-attack? Differential throttling?**

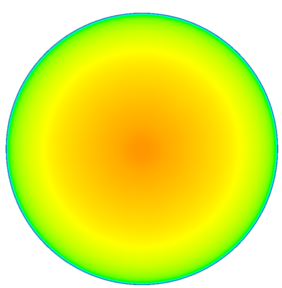
Unpowered ***"Single"*** ***"Doublet-B"***

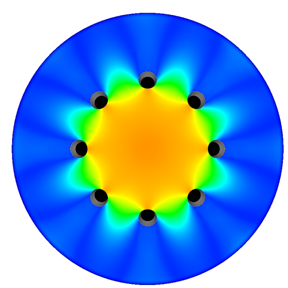


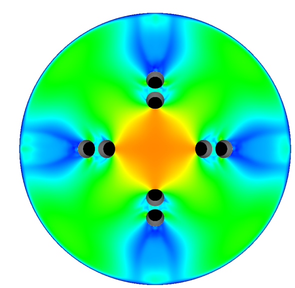


C_A = 1.7 (100% of total) **C_A = 0.58 (14%)** **C_A = 0.93 (21%)**







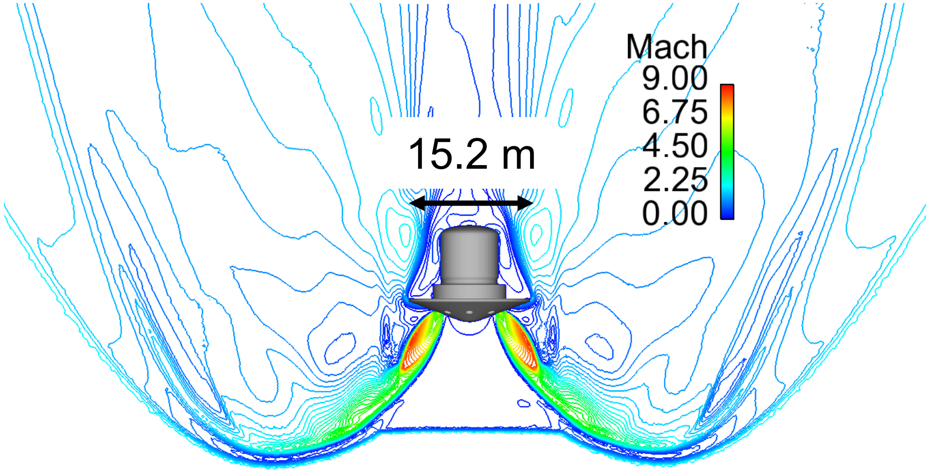


F. Canabal, NASA MSFC

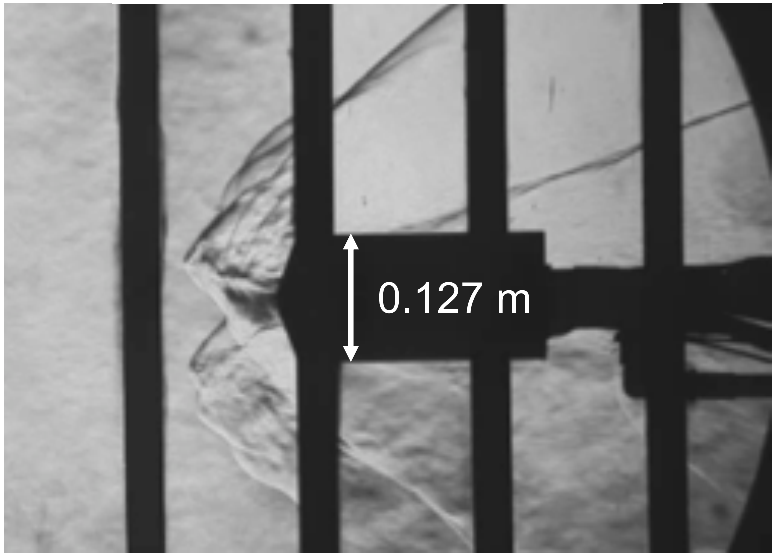
Motivation for Wind Tunnel Test

- **Predicting aerodynamic interference (AI) forces & moments (F&M) poses a significant challenge for Mars EDL**
- **Computational fluid dynamics (CFD) is the high-fidelity method for predicting AI F&M, but <u>relevant</u> ground test data to anchor the CFD are scarce**

CFD



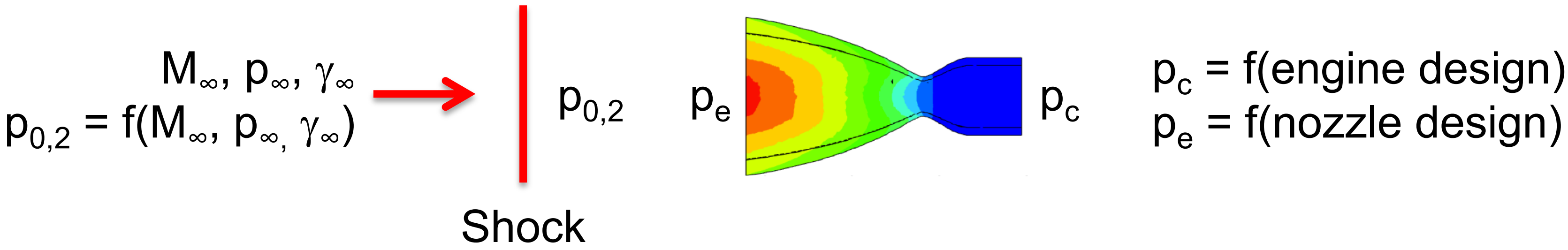
Ground Testing (2010)



Wind tunnel testing on an appropriately-scaled model would provide valuable data for calibrating CFD tools that currently are used for flight calculations

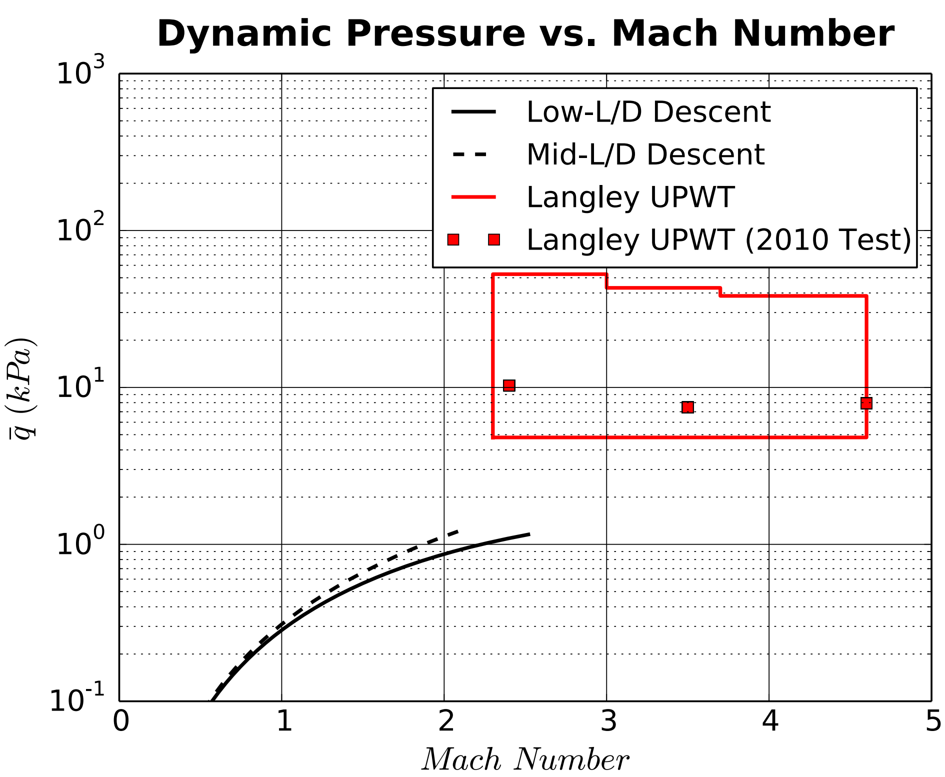
Scaling for a SRP Wind Tunnel Test

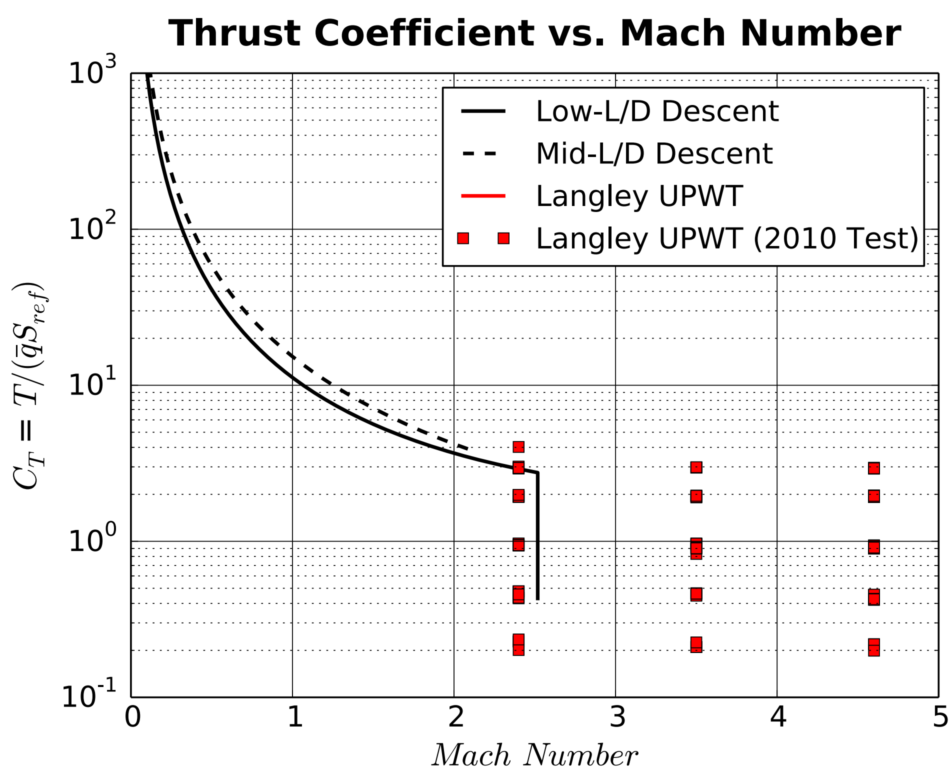
- **Most aerodynamic facilities require using an inert gas (typically unheated air) to simulate rocket engine plumes**
- **<u>Geometric scaling</u> is used on the aerodynamic surfaces**
- **<u>Jet scaling</u> is used to adjust the nozzle design to account for differences between the flight engine combustion products and the plume simulant gas**
- **Jet scaling parameters from historical literature (missiles) include:**
  - Thrust coefficient, thrust / ($\frac{1}{2}\rho_\infty V_\infty^2 S_{ref}$)
  - Ratio of nozzle exit pressure to freestream stagnation pressure, $p_e / p_{0,2}$
  - Ratio of nozzle-to-freestream momentum
  - Ratio of nozzle-to-freestream mass flow rate
  - Many others not listed



Nominal Flight vs. Tunnel Conditions

- The only dimensional flight parameter that overlaps with the UPWT, and only for the Low-L/D vehicle, is freestream Mach number
- Differences in dynamic pressure can be accounted for in the test design
- We have recent experience (2010) in the UPWT testing at thrust coefficients that are similar to current flight values





Scaling of Flight Nozzle (Low-L/D)

- **Compare geometric and jet scaling of the 177:1 flight engine on the Low-L/D vehicle to a 5-in diameter wind tunnel model (unheated air plumes)**
  - Tunnel test section is approximately 4-feet square
- **Results:**
  - Geometric scaling gives a small nozzle throat and very low temperature (multi-phase flow)
  - Reducing the tunnel nozzle area ratio is required to eliminate the effects of low gas temperatures at the nozzle exit
- **The inability to heat the air significantly (only up to ~350 K) will most likely lead to a nozzle area ratio that is close to what was tested in 2010 (4:1)**

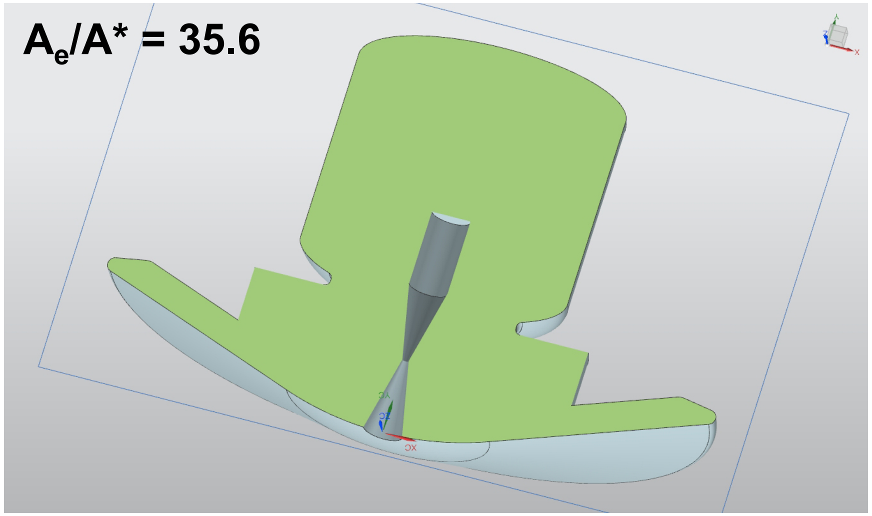
Nozzle Parameter	Flight	Tunnel Geometric	Tunnel Match C_T and $p_e/p_{0,2}$	Tunnel Match C_T or $p_e/p_{0,2}$
Area Ratio (A_e/A^*)	177	177	35.6	4
Specific Heat Ratio	1.28	1.4		
Throat Diameter (in)	3.01	0.024	0.053	0.159
Exit Mach Number	5.55	7.87	5.45	2.94
Exit Temperature (K)	841	26	50	128

Differences between inert gases and flight engine combustion products prevent full simulation of hot gas rocket plumes, and require compromises in testing

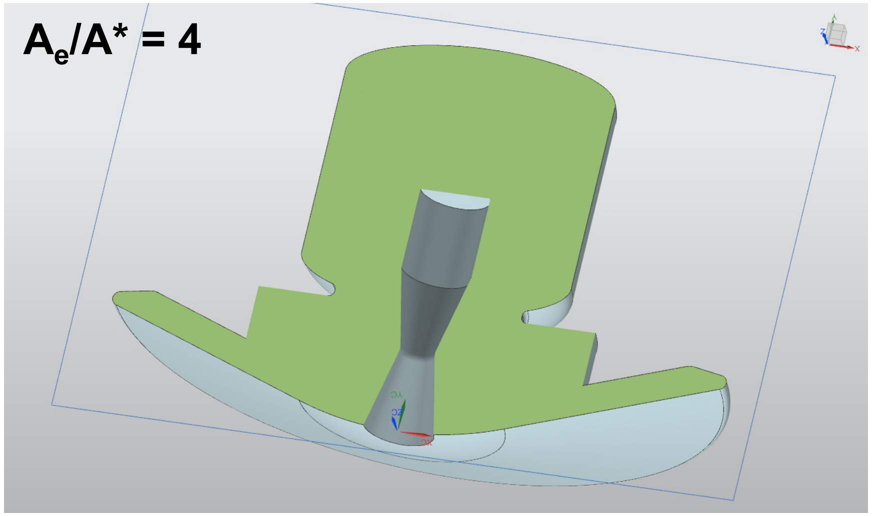
Sample Tunnel Nozzle Profiles

- **There is little experience scaling a flight engine nozzle to wind tunnel model scale where an inert gas is used as the plume simulant**
  - It is not yet known if the ”standard” jet scaling parameters apply to SRP
- **Pre-test analysis is underway to compare single-engine CFD at flight conditions to single-engine CFD at tunnel conditions, to support tunnel nozzle design**
  - A_e/A^* = 4 was tested in 2010

Matches flight C_T <u>and</u> $p_e/p_{0,2}$
Not an option due to nozzle temperatures



Matches flight C_T <u>or</u> $p_e/p_{0,2}$
Avoids lower temperatures, but only matches one parameter



Summary

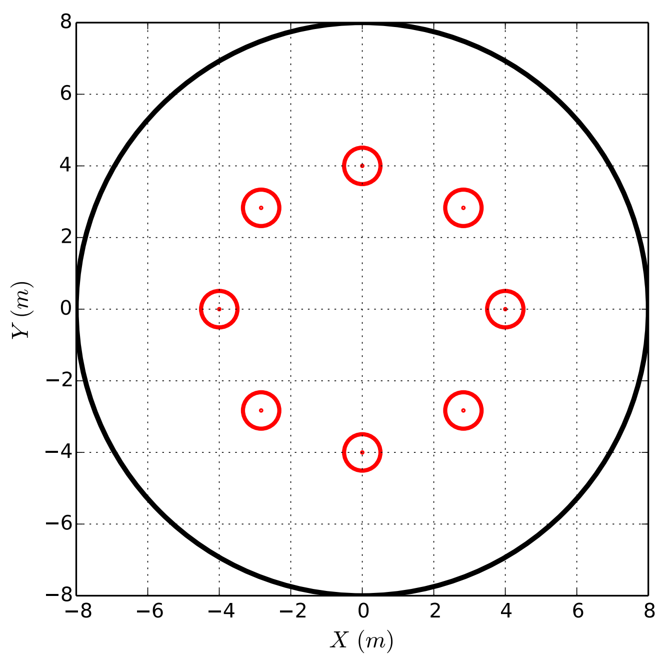
- **A SRP test in the NASA Langley Unitary Plan Wind Tunnel will be completed to investigate scaled versions of current human Mars EDL flight reference vehicles**
- **The test will be conducted in 2019 and will:**
  - Investigate the applicability of historical jet scaling laws to SRP
  - Attempt to match CFD-predicted flight AI F&M
  - Provide valuable data on relevant configurations against which current CFD codes will be compared

Backup

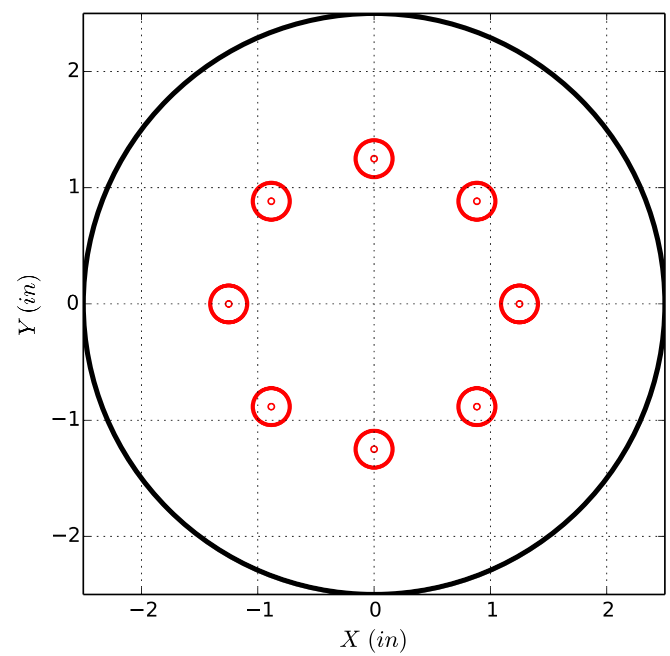
Tunnel Parametrics

- **Freestream conditions**
  - Mach, dynamic pressure, angle of attack
- **Nozzle parameters**
  - Chamber pressure (up to ~1500 psi)
  - Radial location (1)
  - Throat area (2)
  - Area ratio (2)
  - Cant angle (2)

Flight Vehicle (A_e/A^* = 177)



Tunnel Model (Air, A_e/A^* = 35.6)



General Schedule

- **The SRP test is one of 5 tests in planning for the UPWT**
- **Model design (Q3/Q4 of 2018)**
  - CFD analysis just started and will be used to investigate flight-to-tunnel nozzle scaling
  - Consider multiple (2?) nozzle area ratios and cant angles for each model
- **Test matrix design (Q4 of 2018)**
- **Model fabrication (Q1 of 2019)**
- **Testing (Q1/Q2 of 2019)**
- **CFD analysis and uncertainty quantification (Q3/Q4 of 2019)**