Conceptual Design of a Z-Pinch Fusion Propulsion System

Advanced Concepts Office
George C. Marshall Space Flight Center
National Aeronautics and Space Administration

Robert Adams, Ph.D.

Team Members

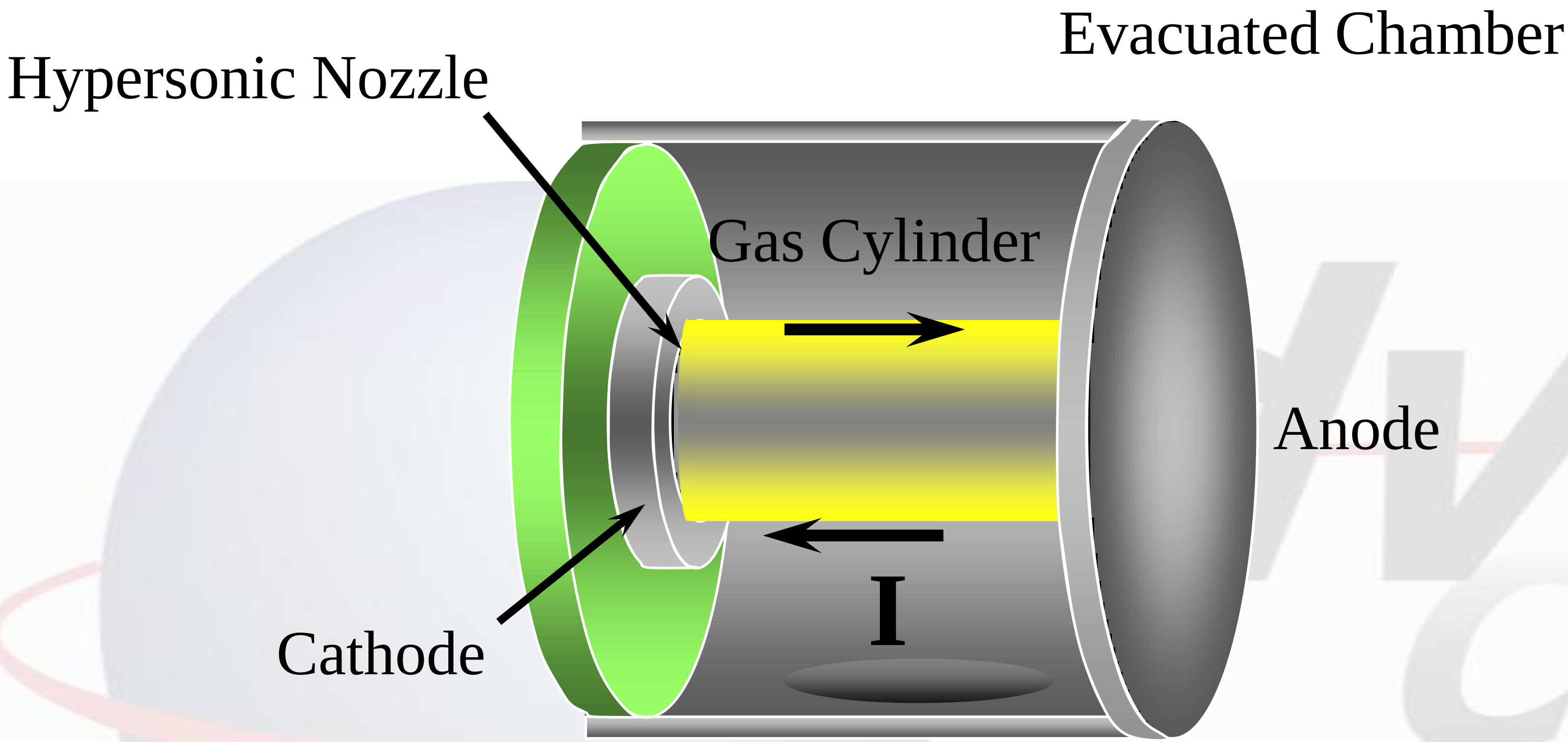
- *Polsgrove T., Fincher, S., Adams, R.* – **NASA (MSFC)**
- *Fabisinski, L.* - **International Space Systems, Inc.**
- *Maples, C.* - **Qualis Corporation**
- *Miernik, J., Statham, G.* - **ERC, Inc.**
- *Cassibry, J., Cortez, R., Turner, M.* - **UAHuntsville**
- *Santarius, J.* - **University of Wisconsin**
- *Percy, T.* - **SAIC, Inc.**

Z-Pinch Fusion: Background

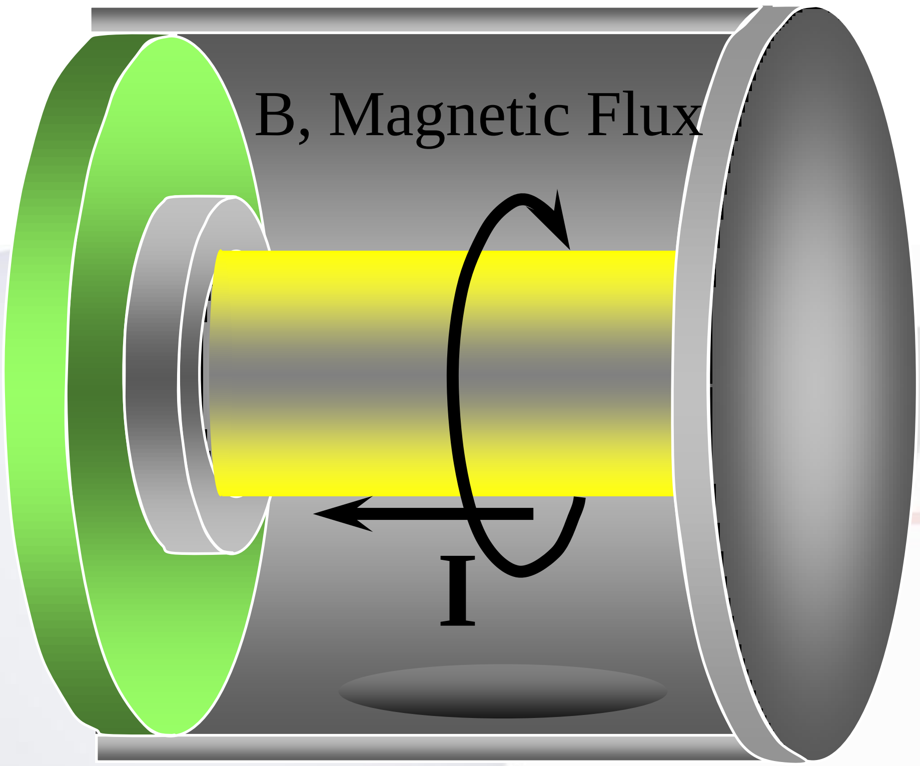
- Nuclear weapon x-rays are simulated through Z-Pinch phenomena.
- New developments in multi-keV plasma radiation sources are progressing to thermonuclear fusion temperatures*
- Such technology could be applied to develop advanced thruster designs that promise high thrust/high specific impulse propulsion
- This project would develop a conceptual design for such a thruster.

*Velikovich, A. L., R. W. Clark, J. Davis, Y. K. Chong, C. Deeney, C. A. Coverdale, C. L. Ruiz, et al. 2007, Z-pinch plasma neutron sources, *Physics of Plasmas 14, no. 2: 022701. doi:10.1063/1.2435322.*

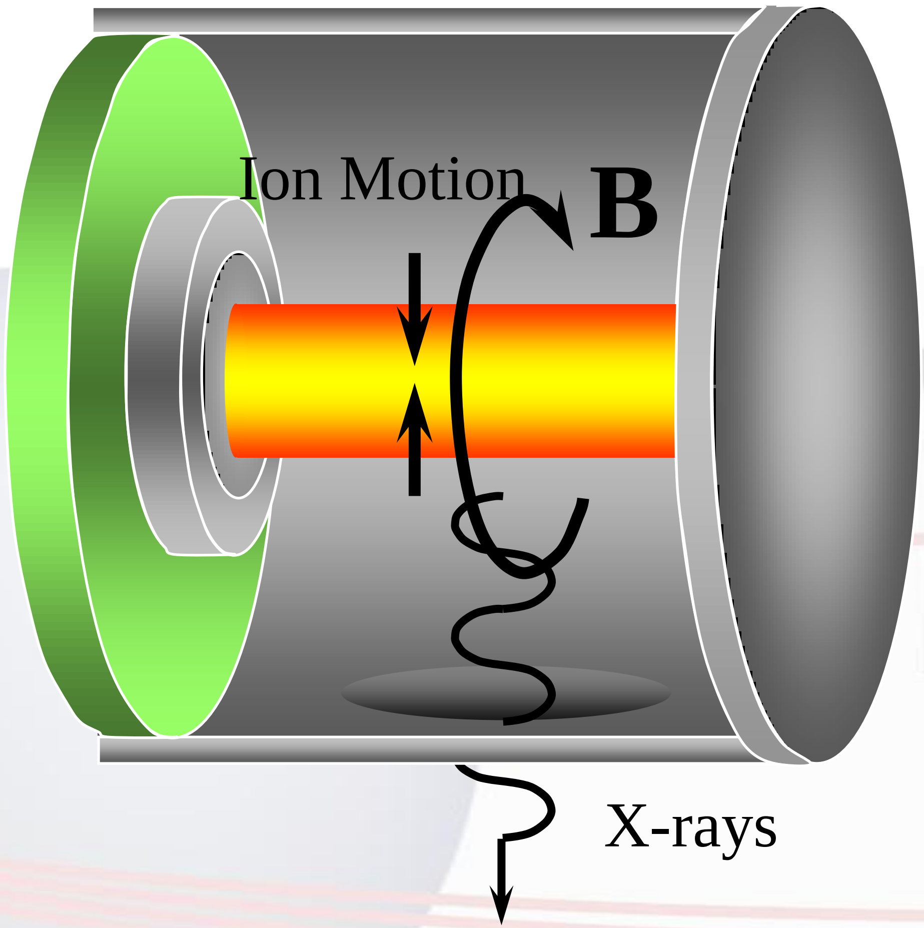
Operation of a Z Pinch



High Current Generates Intense Magnetic Fields

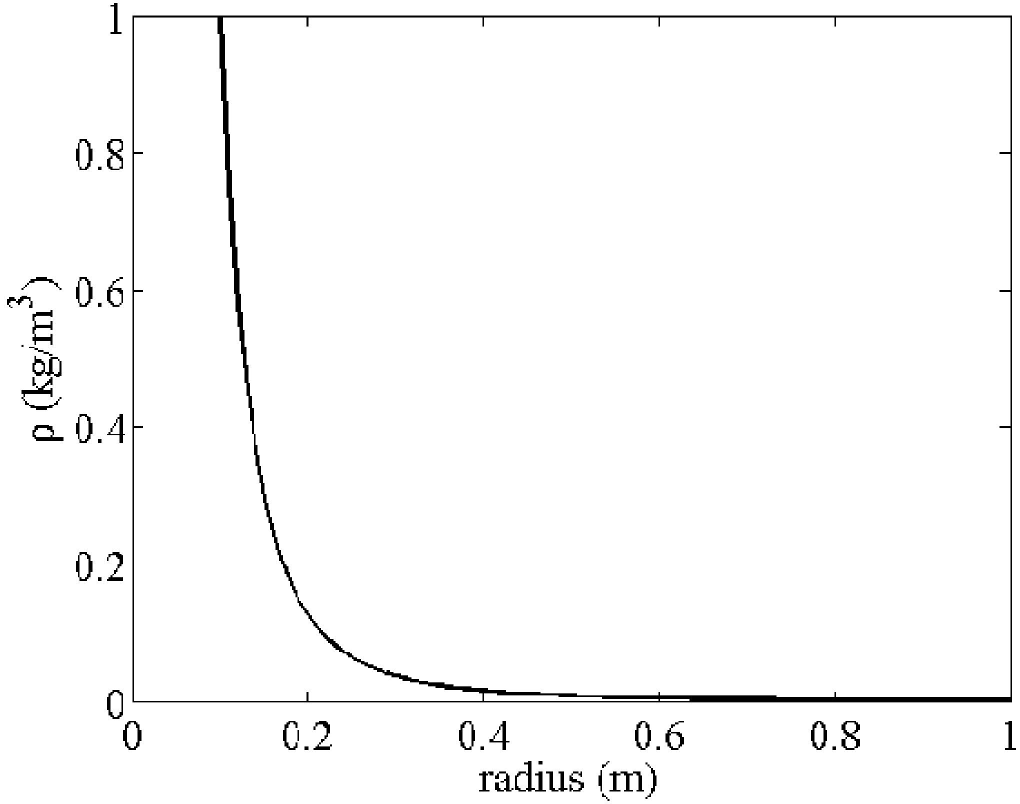


Magnetic Fields Compress the Plasma to X-Ray Temperatures



Plasma Instability

- Rayleigh-Taylor is most deleterious effect preventing success, can be overcome with tailored density profile*

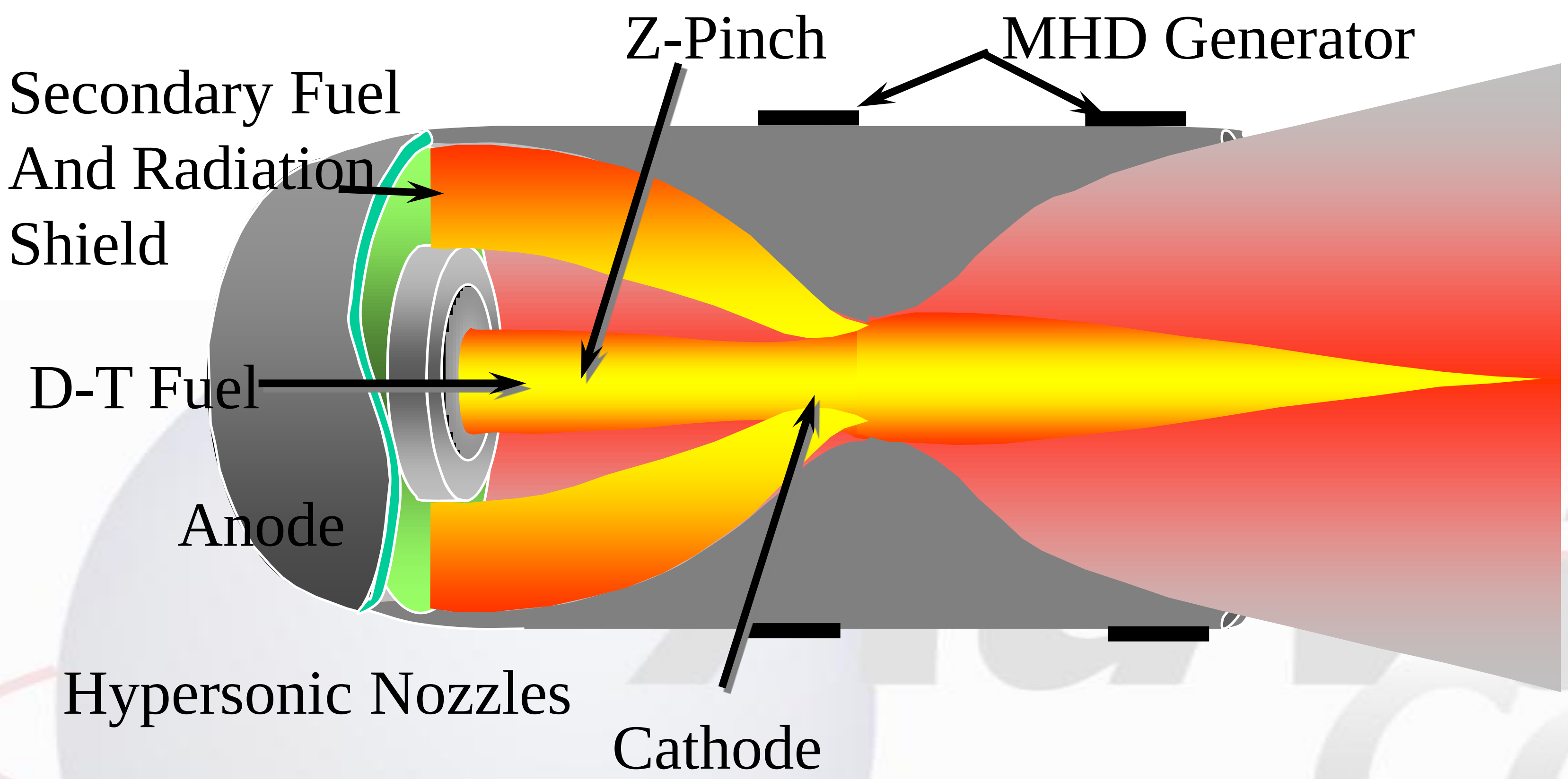


*Velikovich, Cochran, and Davis, Phys. Rev. Let. 77(5) 1996.

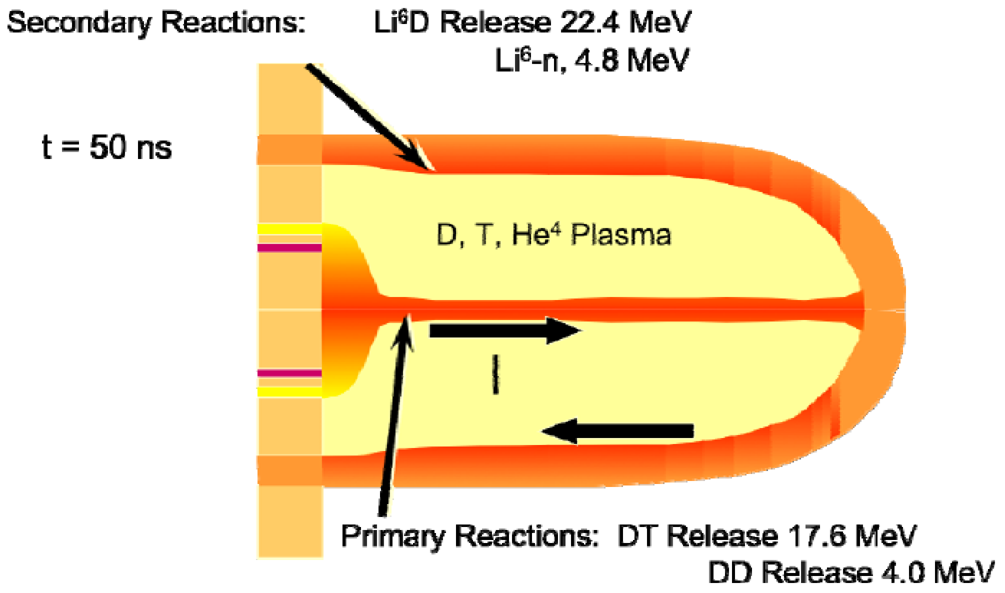
Electrode Erosion

- Coupling electrical energy to plasma
  - Directly coupled devices lead to erosion
  - All susceptible to x-ray radiation and neutron damage
- Potential workarounds
  - Allow electrodes to erode!
  - Consider inductively coupled techniques

Thruster Concept



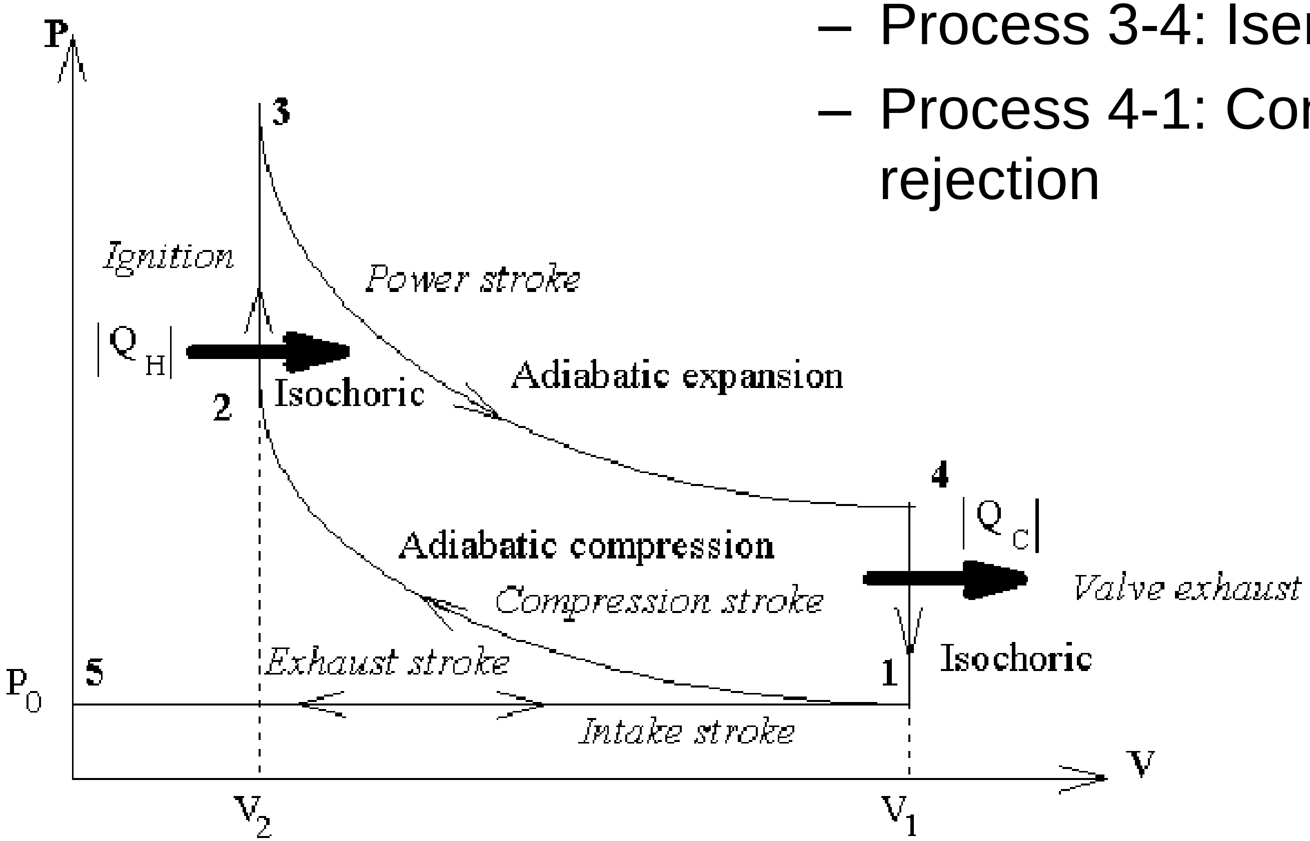
Z-pinch Design



- Annular nozzles with Deuterium-Tritium (D-T) fuel in the innermost nozzle
- Lithium mixture containing Lithium-6/7 in the outermost nozzle.
- The D-T fuel and Lithium-6/7 mixture acts as a cathode

Z-pinch modeling

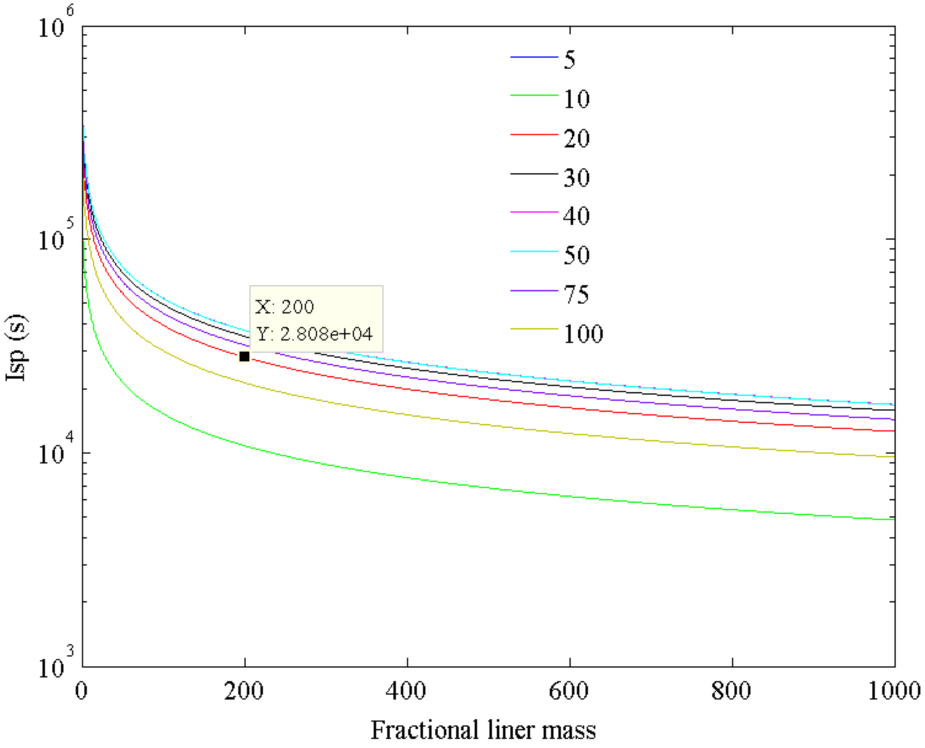
- Treat Z-pinch as Otto cycle
  - Process 1-2: Isentropic compression
  - Process 2-3: Constant volume heat addition
  - Process 3-4: Isentropic expansion
  - Process 4-1: Constant volume heat rejection

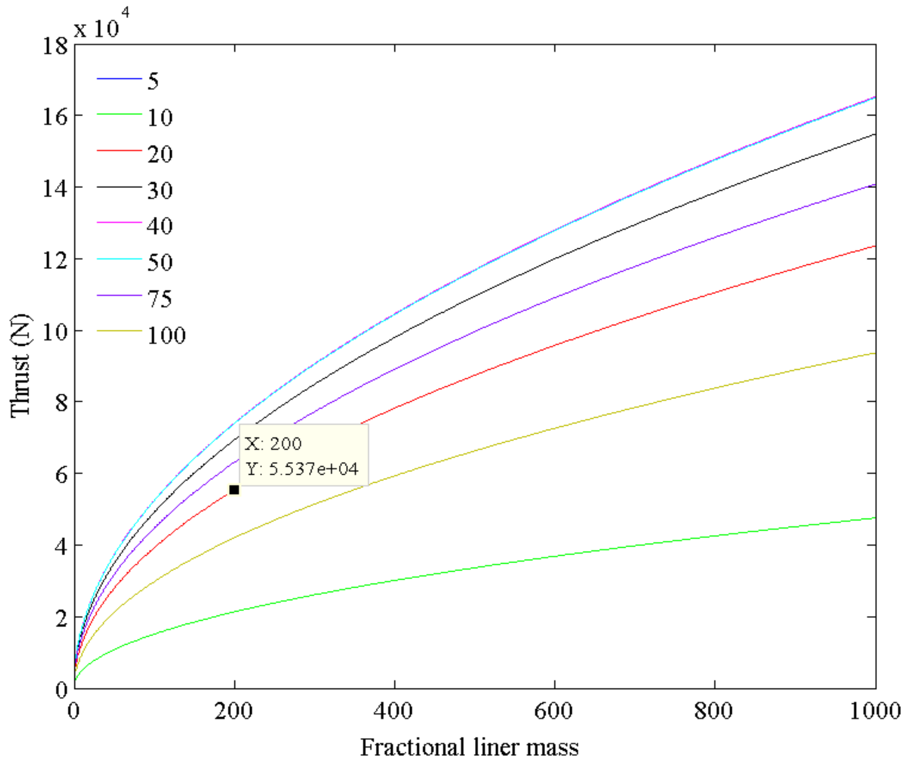


Engine Performance

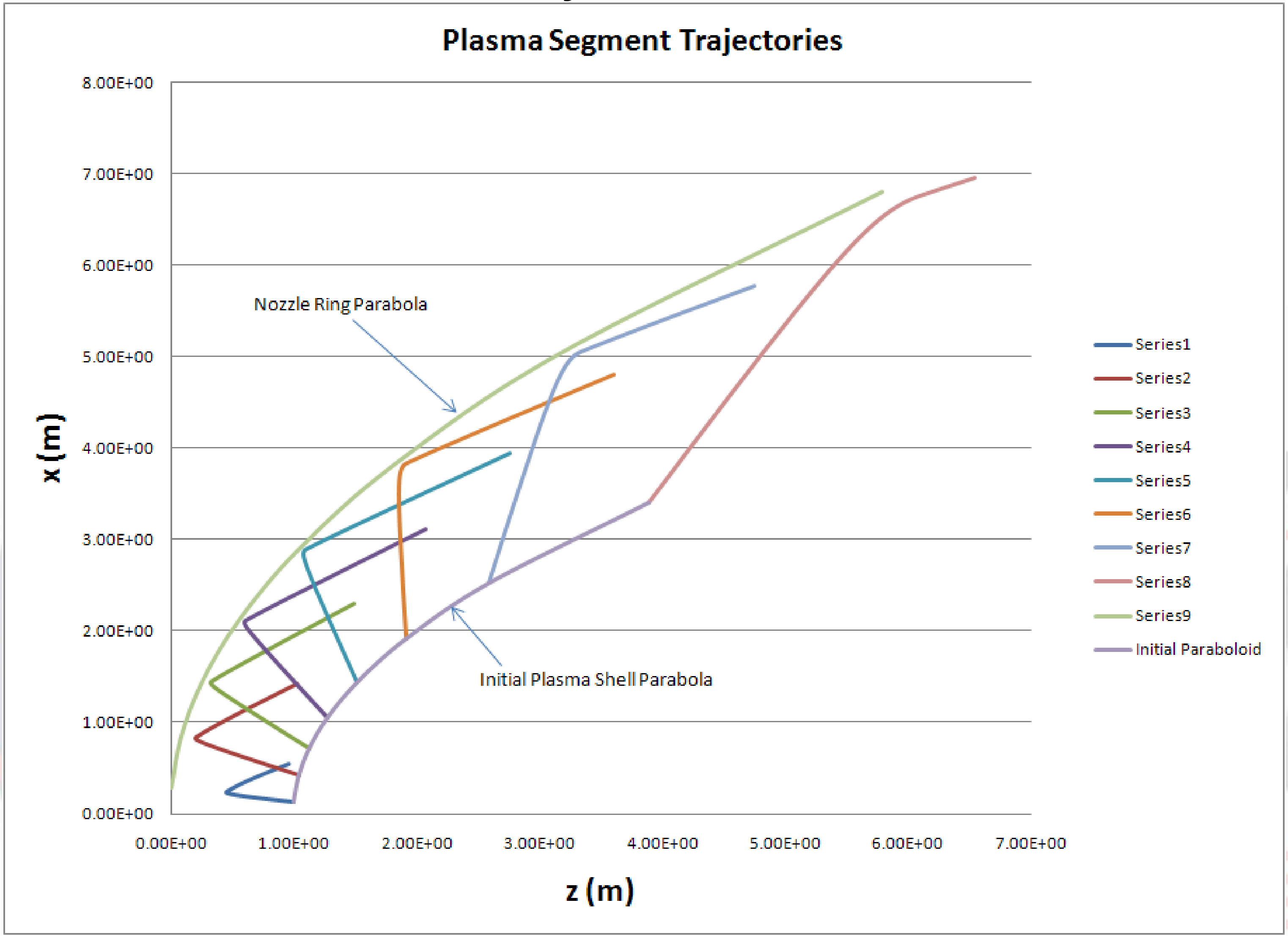
- Engine Performance as a function of liner mass

- Design point picked based on mission needs

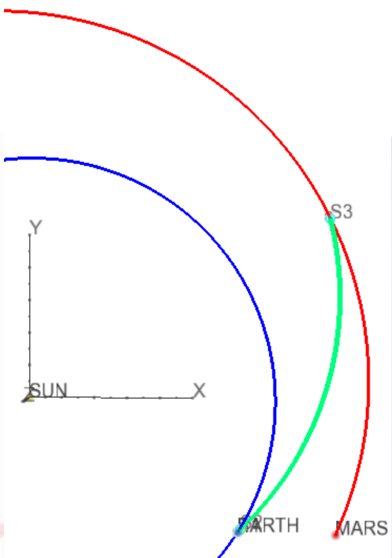




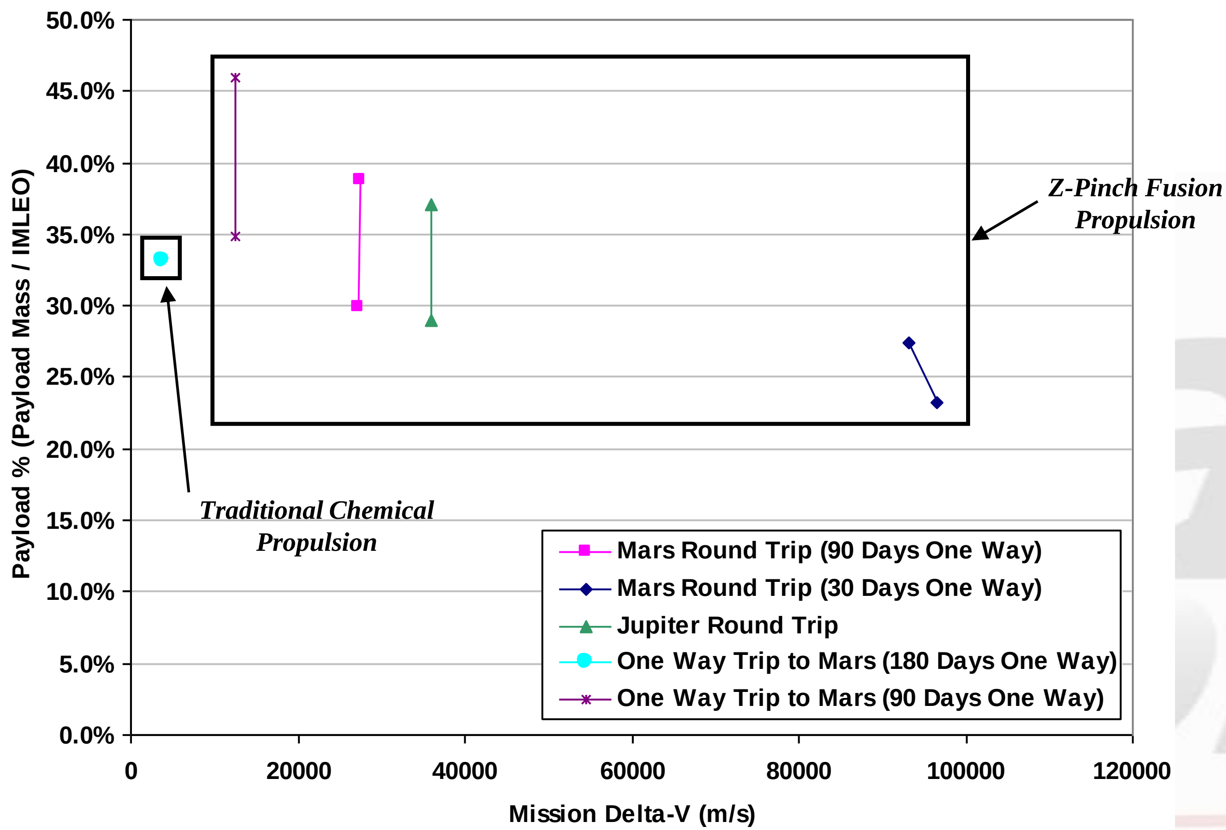
- Particle trajectory modeling required to estimate performance and correctly size nozzle.



Missions to Mars, Jupiter, and Beyond can be achieved with significantly reduced trip times when compared to state of the art chemical propulsion



90 day transfer from Earth to Mars



Mission Analysis

	Mars 90	Mars 30	Jupiter	550 AU
Outbound Trip Time (days)	90.2	39.5	456.8	12936
Return Trip Time (days)	87.4	33.1	521.8	n/a
Total Burn Time (days)	5.0	20.2	6.7	11.2
Propellant Burned (mT)	86.3	350.4	115.7	194.4
Equivalent DV (km/s)	27.5	93.2	36.1	57.2

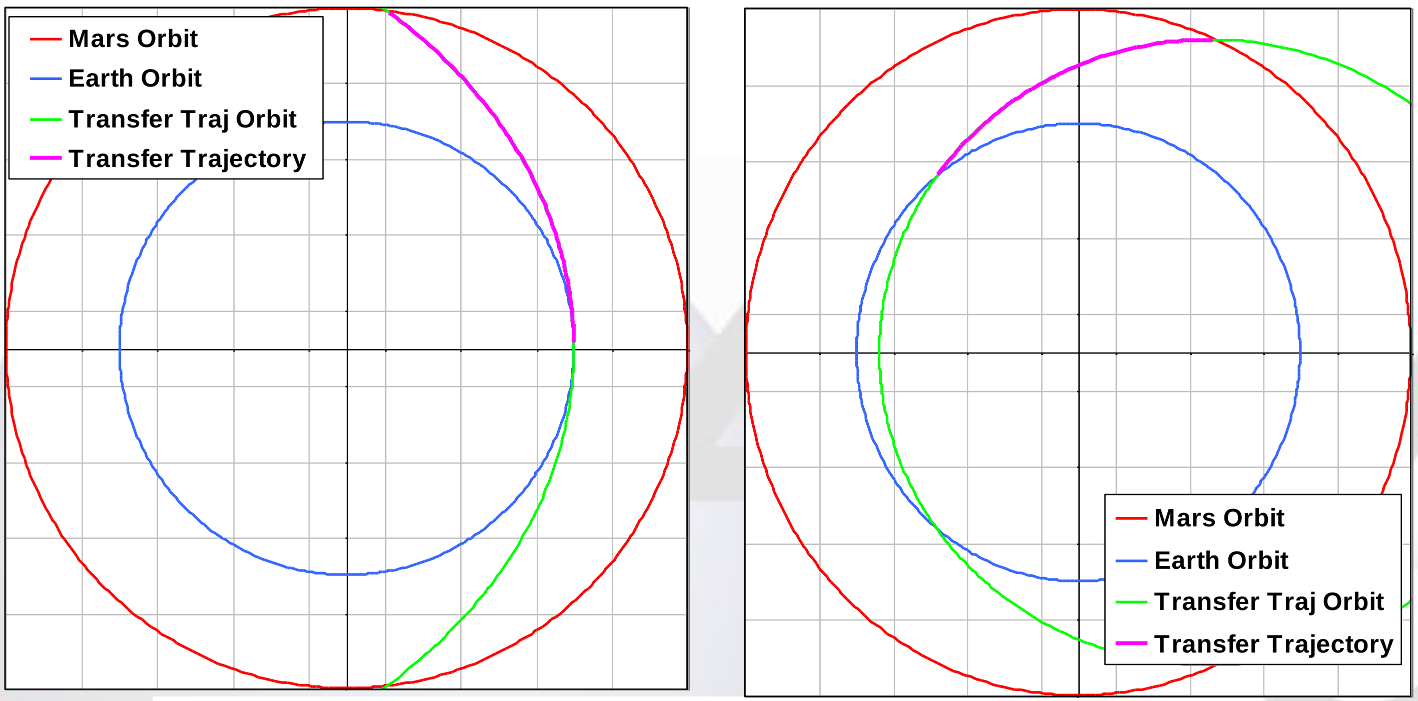
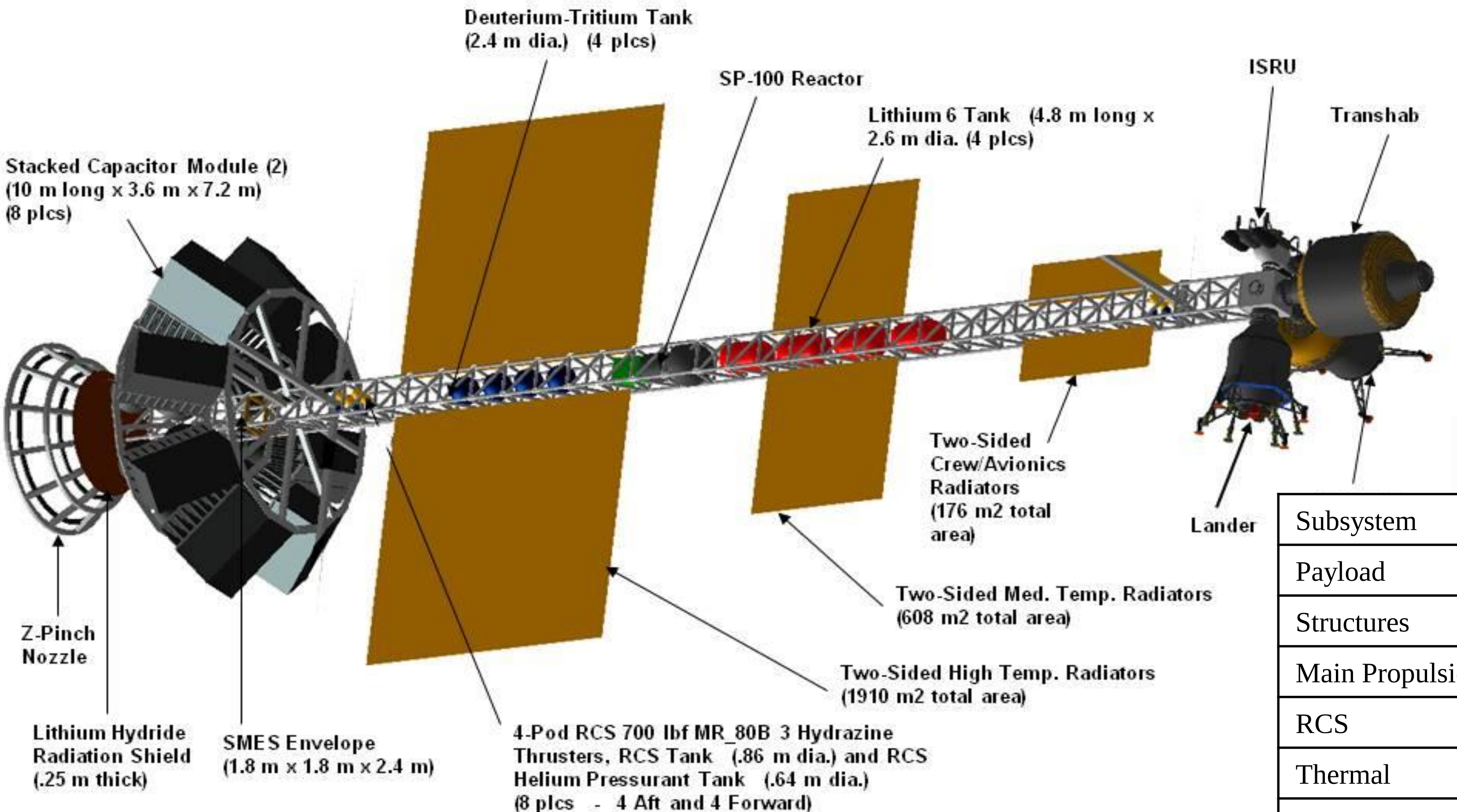


Figure 4.1 Mars 90 Day Transfer Trajectories

Vehicle Configuration



Subsystem	Mass (kg)
Payload	150,000
Structures	54,600
Main Propulsion	95,138
RCS	586
Thermal	77,164
Power	16,480
Avionics	389
Total Dry Mass	394357
30% MGA	73,307
Total Mass	467,664

Thrust Coil Configuration

- FLiBe protects thrust and seed coils from thermal flux and other radiation.

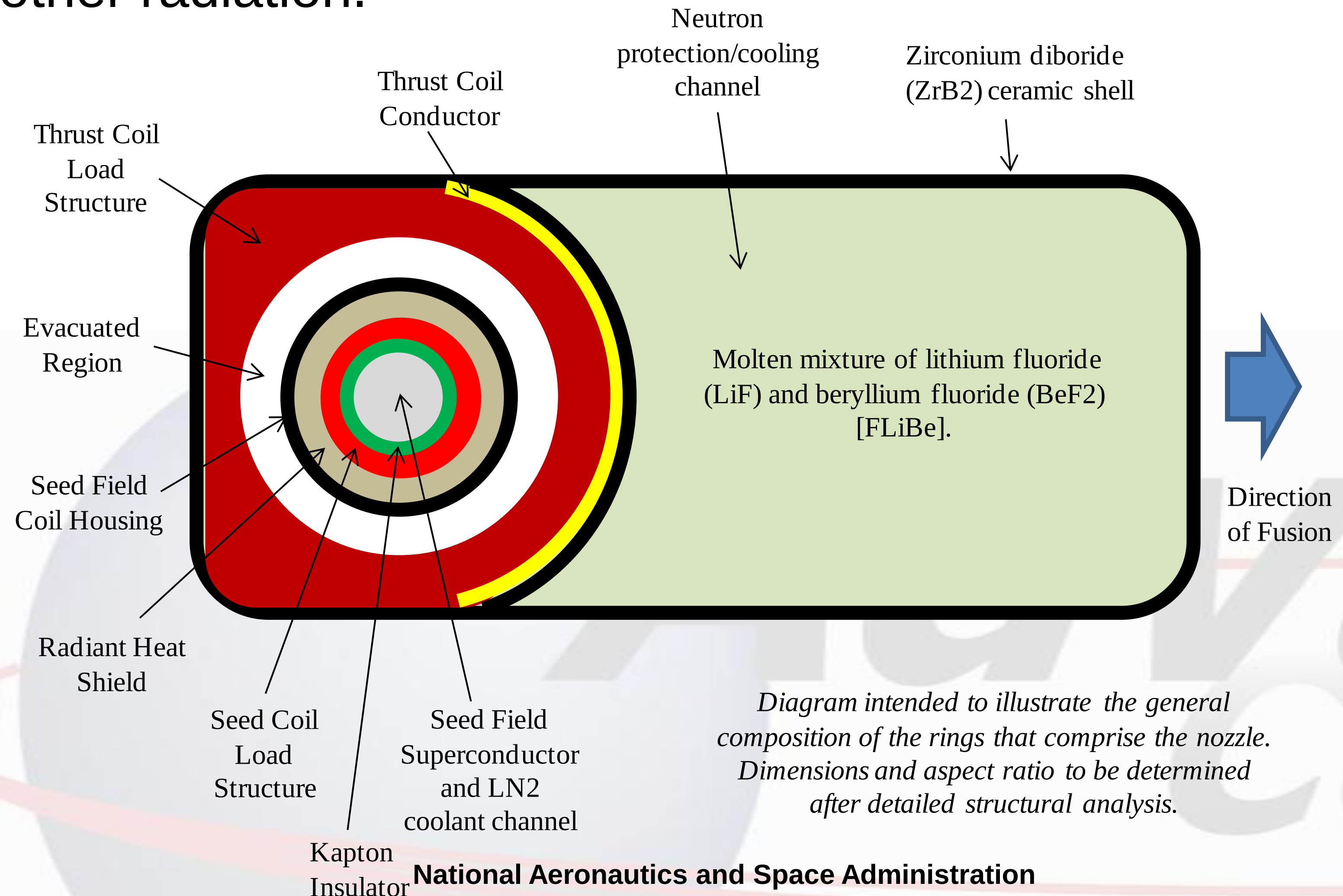
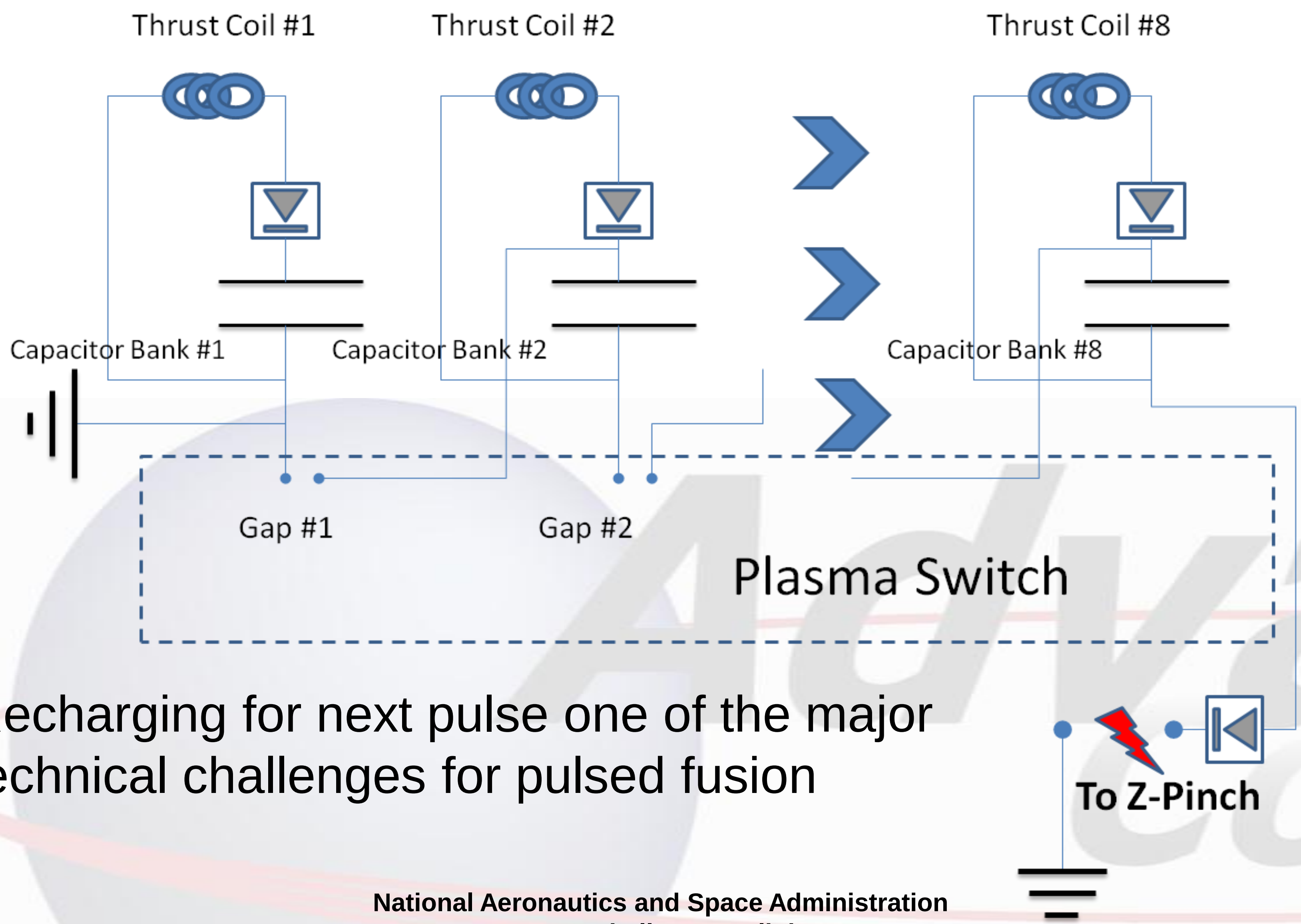


Diagram intended to illustrate the general composition of the rings that comprise the nozzle. Dimensions and aspect ratio to be determined after detailed structural analysis.

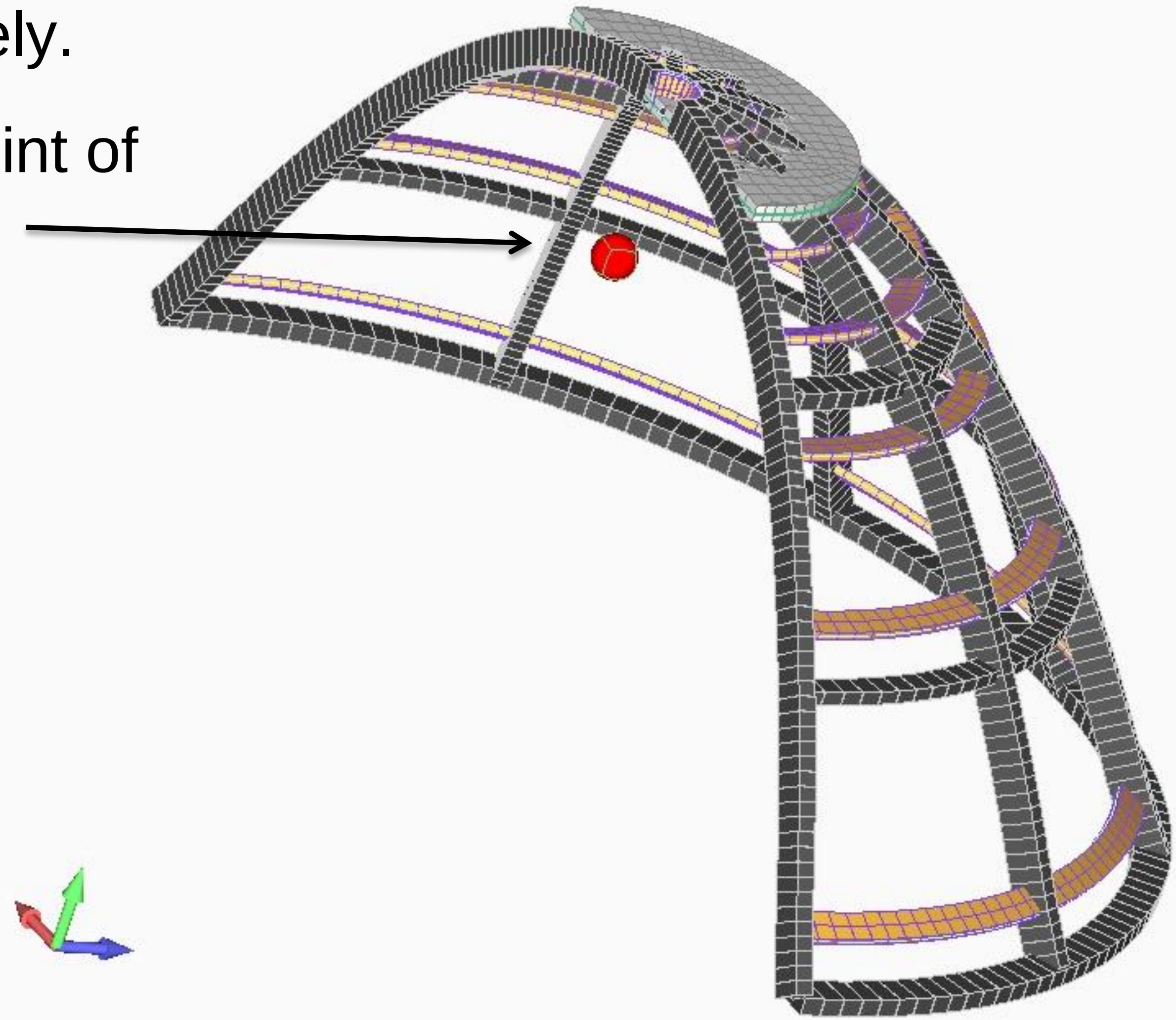
Power Management System



Recharging for next pulse one of the major technical challenges for pulsed fusion

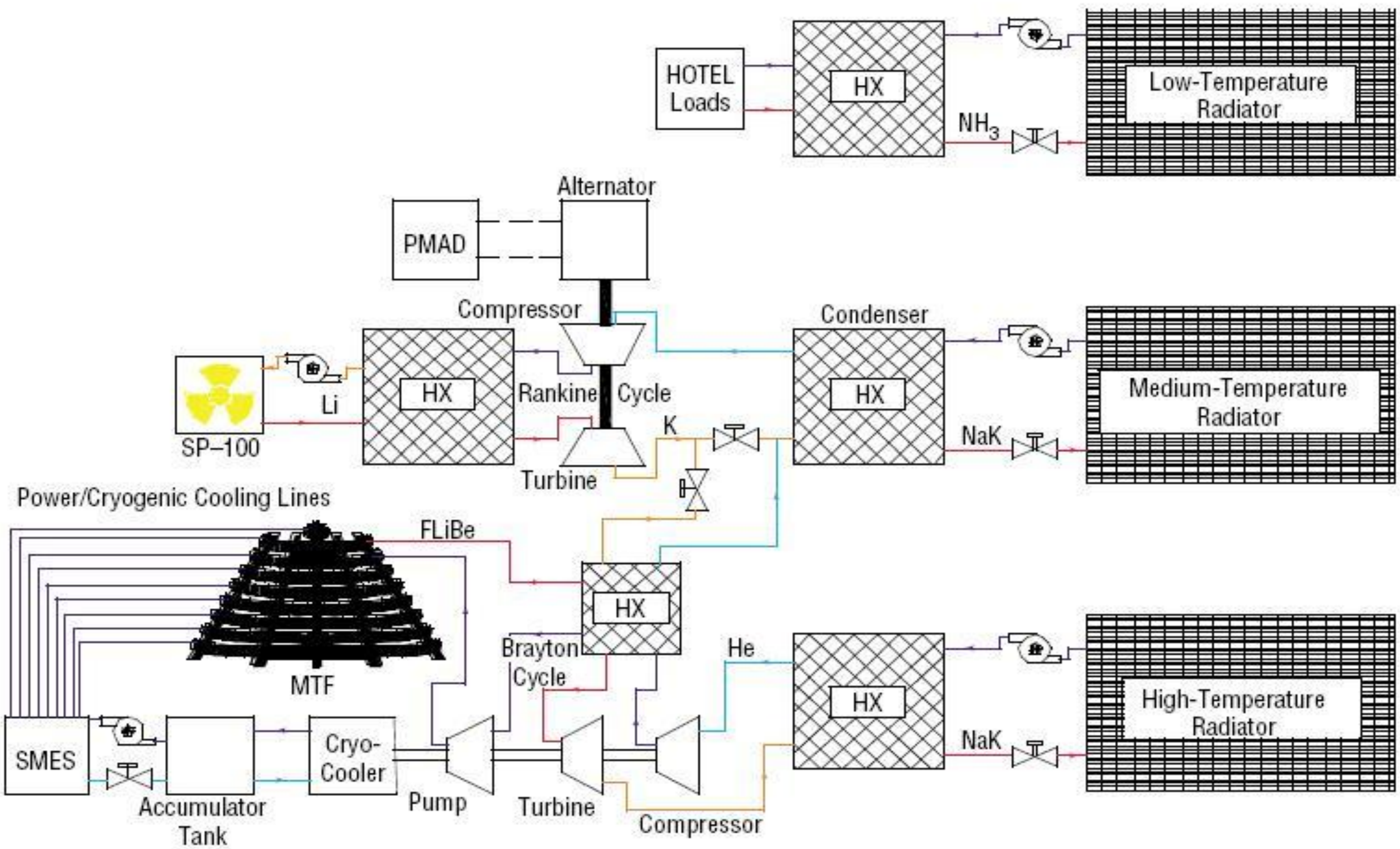
Structural Analysis of Magnetic Nozzle

- Structural truss can handles stresses from pulsed fusion indefinitely.
- Focal point of nozzle

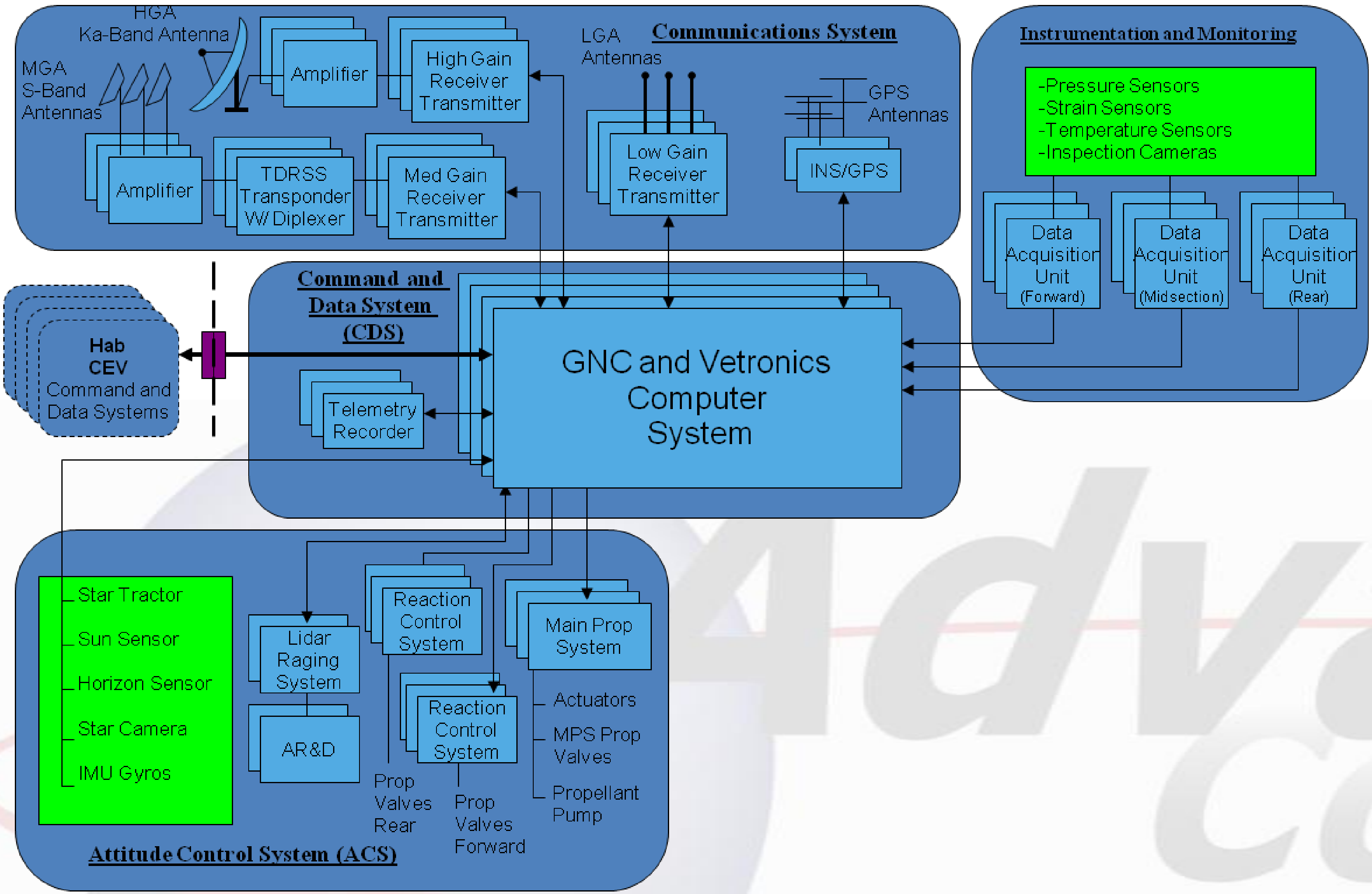


Thermal Management System

- Radiators operate at 300 K, 800 K and 1400 K.



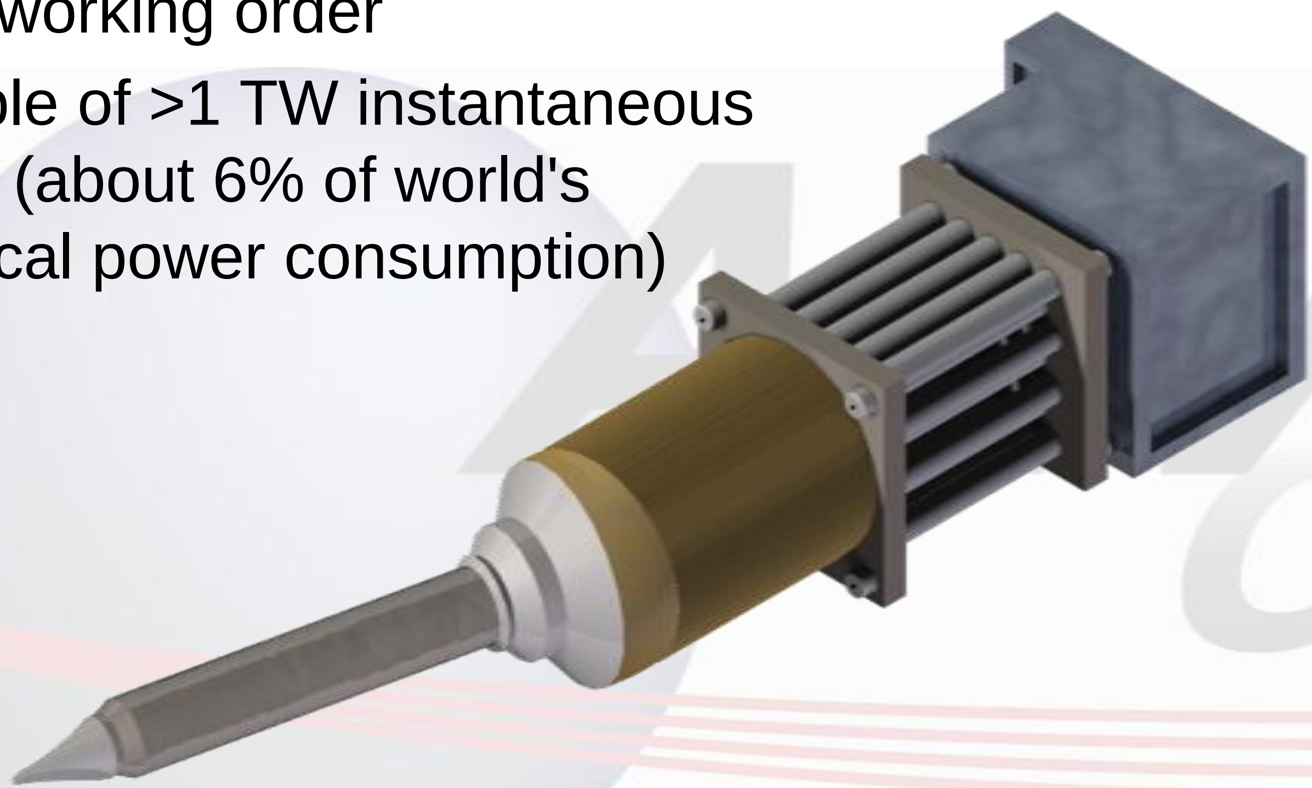
Avionics Suite



National Aeronautics and Space Administration
George C. Marshall Space Flight Center
ED04/Advanced Concepts Office

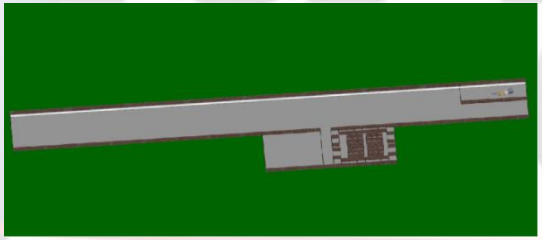
DECADE Module II

- 500 kJ pulsed power facility
- Last prototype built before DECADE construction
- Defense Threat Reduction Agency
  - Nuclear Weapons Effects (NWE)
  - Plasma Radiation Sources (PRS)
- Good working order
- Capable of >1 TW instantaneous power (about 6% of world's electrical power consumption)



Pulsed Fusion Facility

- DM2 Utilization Arrangements
  - L3 Communications, Pulsed Science Division
  - Boeing
  - Oak Ridge National Labs
- Other fusion collaborations
  - LANL
  - HyperV Corp.
  - Univ. of New Mexico
- Expected Capabilities
  - 500 ns pulse, 2 MA current
  - 1 keV, 10^{25} /m^3 plasma state
  - Effective dwell time of ~100 ns



Aerophysics lab

Summary

- No showstoppers found for this technology
  - Preliminary analytical results are promising
  - The technology development required for this propulsion system is achievable on a reasonable timescale given sufficient resources.
- Z-pinch has potential for a number of missions of interest
  - Reusable vehicle that recaptures in Earth Orbit does round trips to Mars
  - Interstellar precursor missions
  - Crewed Missions to other solar system targets
- Opportunity to create new facility to explore z-pinch and other pulsed fusion concepts
  - Looking for funding to move module to MSFC for installation
  - Completed facility would allow proof of principle experiments on pulsed fusion concepts.
- Our team thanks the NASA Innovative Programs and Partnerships Program for funding this work