THE MPD THRUSTER PROGRAM AT JPL

Keith Goodfellow, Tom Pivirotto, and Jay Polk
Jet Propulsion Laboratory
Pasadena, California

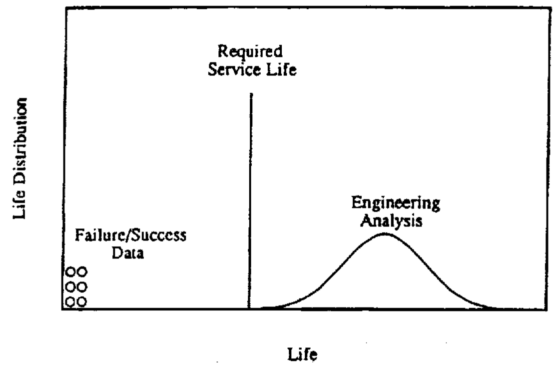
MPD THRUSTER ACTIVITIES AT JPL

- Engine Lifetime Assessment
  - Methodology for Determining Life
  - Electrode Modelling
  - Experimental Program

- Lithium MPD Thruster Development
  - Technology Review and Modelling
  - Mission Analysis (APC Group)
  - Technology Development

- Radiation-cooled, Applied-field Engine Testing
  - Anode Thermal Management
  - Pumping Speed Improvements with a Gasdynamic Diffuser
  - Dual-beam Thrust Measurements

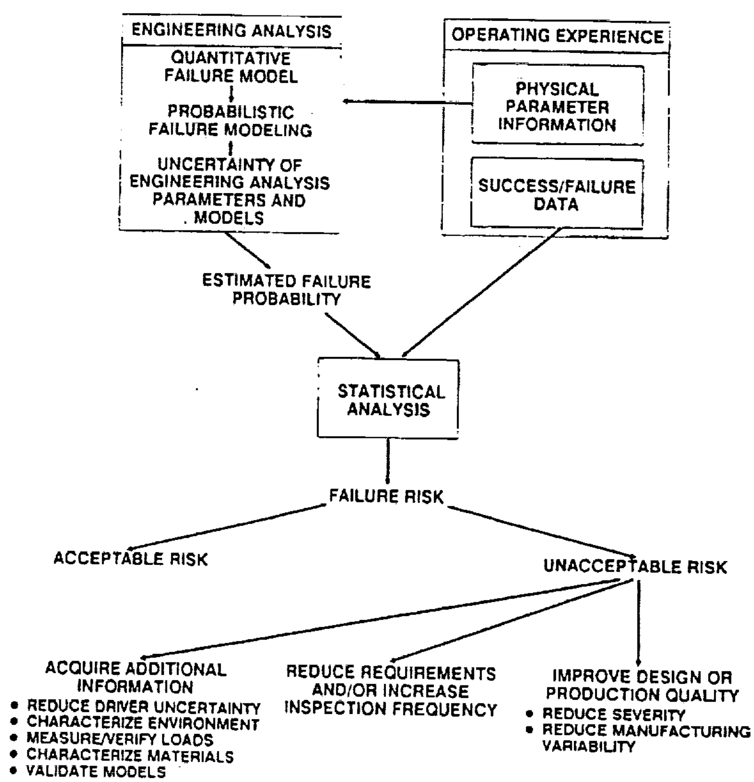
DEFINING ENGINE LIFETIME



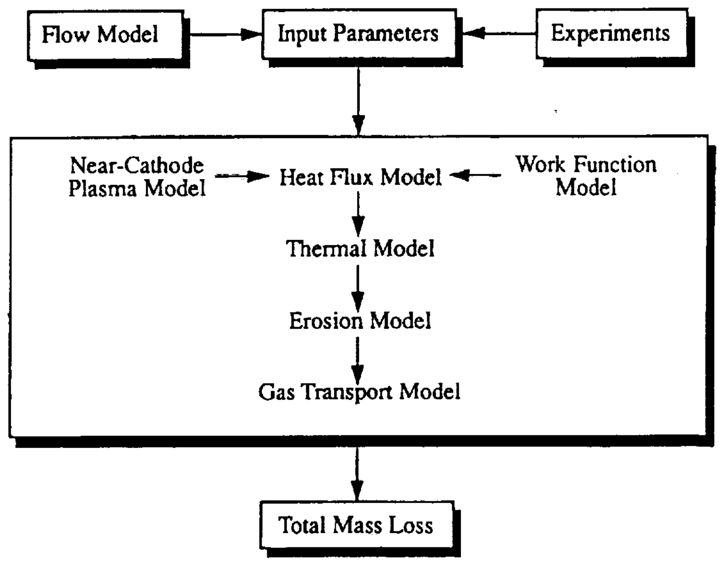
Engine lifetime, requirements and operating experience

- CURRENT STATUS
  - Required service life is not well defined
  - Critical failure modes have not been identified
  - No theoretical or experimental characterization of life distribution
- IMPORTANT OBSERVATIONS
  - Life distribution characterization by system-level operating experience is not feasible
  - Engine lifetime is inherently probabilistic

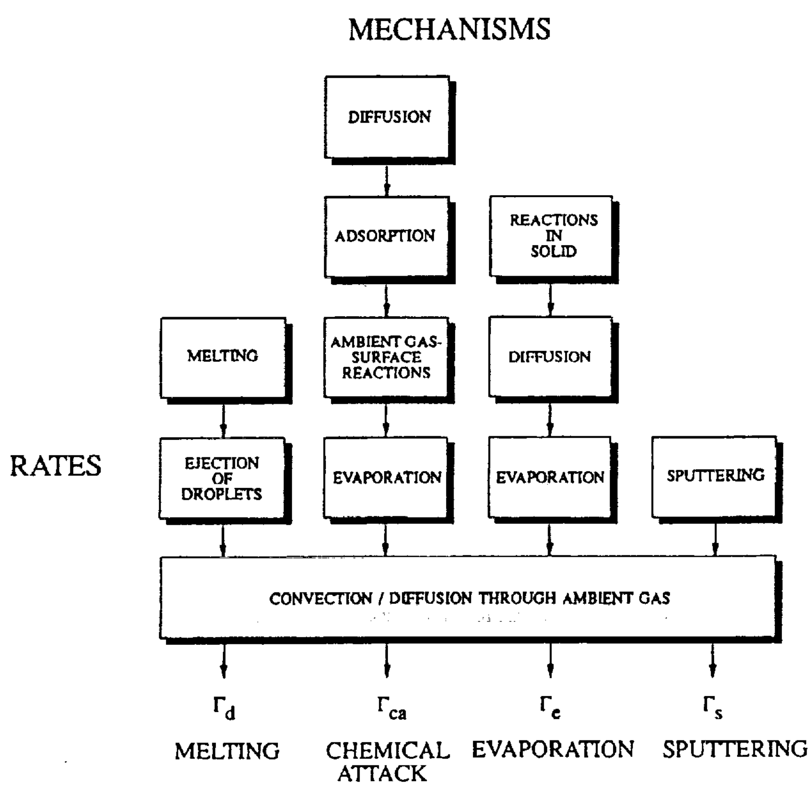
PROBABILISTIC FAILURE ASSESSMENT



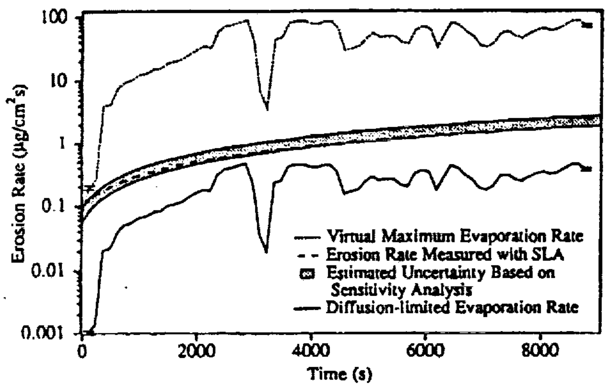
QUANTITATIVE CATHODE FAILURE MODELLING



CATHODE EROSION MODELLING



COMPARISON OF CALCULATED AND MEASURED CATHODE EROSION RATES



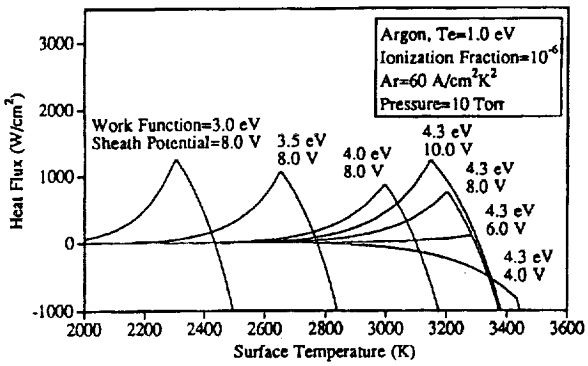
Cathode erosion measurements performed with Stuttgart thruster NCT-1 at 2500 A, 1.0 g/s of argon, 71 kWe and 20 Torr ambient pressure

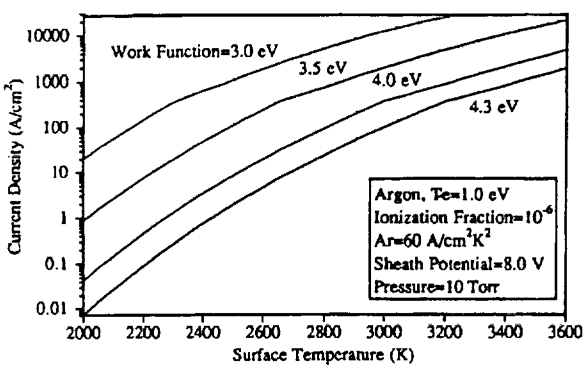
- Diffusion-limited evaporation of tungsten is the dominant mechanism
- Model underpredicts erosion rate by a factor of 6, reflecting uncertainties in transport rate through concentration boundary layer
- Calculated erosion rates are based on measured temperatures--thermal model required for fully predictive capability

CATHODE THERMAL MODELLING

- HT8 - 1D thermal model with variable grid spacing and non-linear thermal and electrical conductivity. Allows specification of radiation, conduction, convection and arc attachment boundary conditions on ends and inner and outer radii.
- AFEMS - Commercial 2D finite-element model with nonlinear material properties. Very flexible solid modeller for geometry specification, but definition of boundary conditions is more cumbersome than in HT8.
- Fully 2D version of HT8 under development.

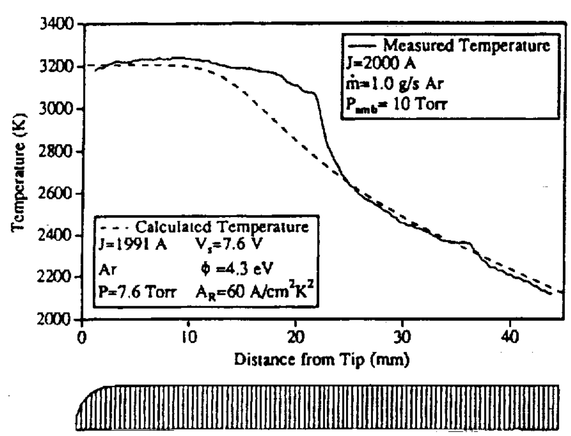
NEAR-CATHODE PLASMA MODELLING





- The model describes the electrostatic sheath, presheath and ionization zones
- Current and heat fluxes are calculated as functions of gas properties, thermionic properties, surface temperature and sheath potential
- Terms normally neglected in high-pressure noble gas arc models are included to allow accurate modelling of low-pressure alkali metal arcs

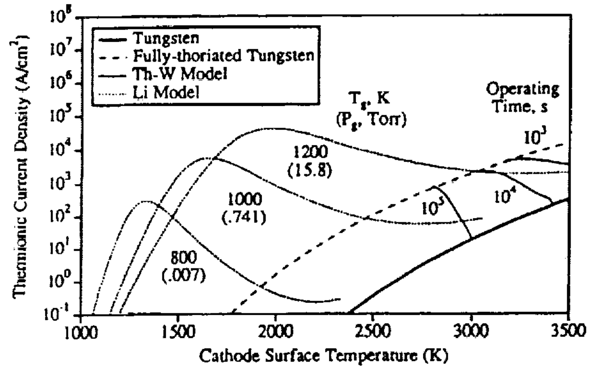
COMPARISON OF CALCULATED AND MEASURED TEMPERATURE DISTRIBUTIONS



Cathode model geometry and results

- The model includes radiation, conduction out the base and heat input over the first 20 mm from the near-plasma model
- The model reproduces the tip temperature and shaft behavior for reasonable values of the input parameters
- Width of the attachment zone and the high gradient in the middle are not predicted--this may be due to 2-D effects, axially varying gas properties, or convection

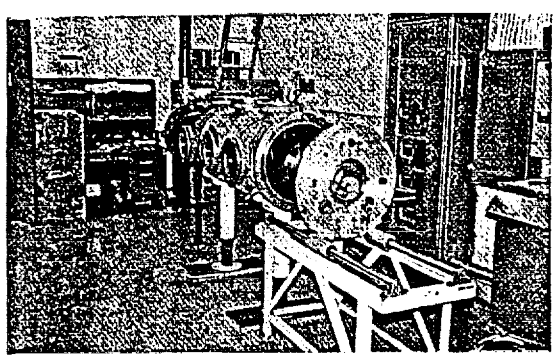
CATHODE WORK FUNCTION MODELLING

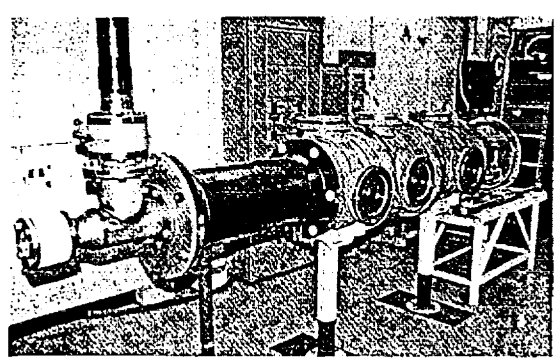


Emission capability of tungsten metal with Th and Li adsorbed on the surface.

- "Activator" may be electropositive material in the cathode bulk or in the propellant
- Two models were developed for cathode additive transport and propellant-surface interaction
- Th-W effect on work function is limited by depletion of thorium additive
- Li supply from propellant is unlimited, but surface coverage depends on gas pressure and temperature
- There is considerable uncertainty in model input parameters

CATHODE TEST FACILITY





CATHODE TEST FACILITY

- Demonstrate feasibility of new cathode concepts
- Measure cathode temperature distributions and erosion rates to validate models
- Measure model input parameters
- Collect success/failure data in long endurance tests

ANODE MODELLING

- Objective: Determine failure mechanisms, model life distribution and develop methods for thermal management
- Finite element model of existing anode design is complete
- Subsequent tasks:
  - Apply sheath analysis to anode region
  - Review existing data and theoretical treatments of magnetic field effects in the anode region
  - Formulate proper boundary conditions for anode thermal models
  - Develop an improved anode radiator design

LITHIUM MPD THRUSTER TECHNOLOGY REVIEW

(Presented at the SEI Technologies Conference, Sept. 1991)

- The review was motivated by Russian and US data from the 60's and 70's indicating substantial performance and cathode lifetime gains with alkali metal propellants

- Scope
  - Critical review of existing data
  - Analysis of the physical basis for performance and lifetime gains
  - Examination of systems and testing considerations

- Conclusions
  - The available data are persuasive and provide a sound rationale for renewed examination of alkali metal propellants, particularly lithium
  - Alkali metals offer a tremendous advantage in facility pumping requirements
  - The greatest risk is the potential for spacecraft contamination

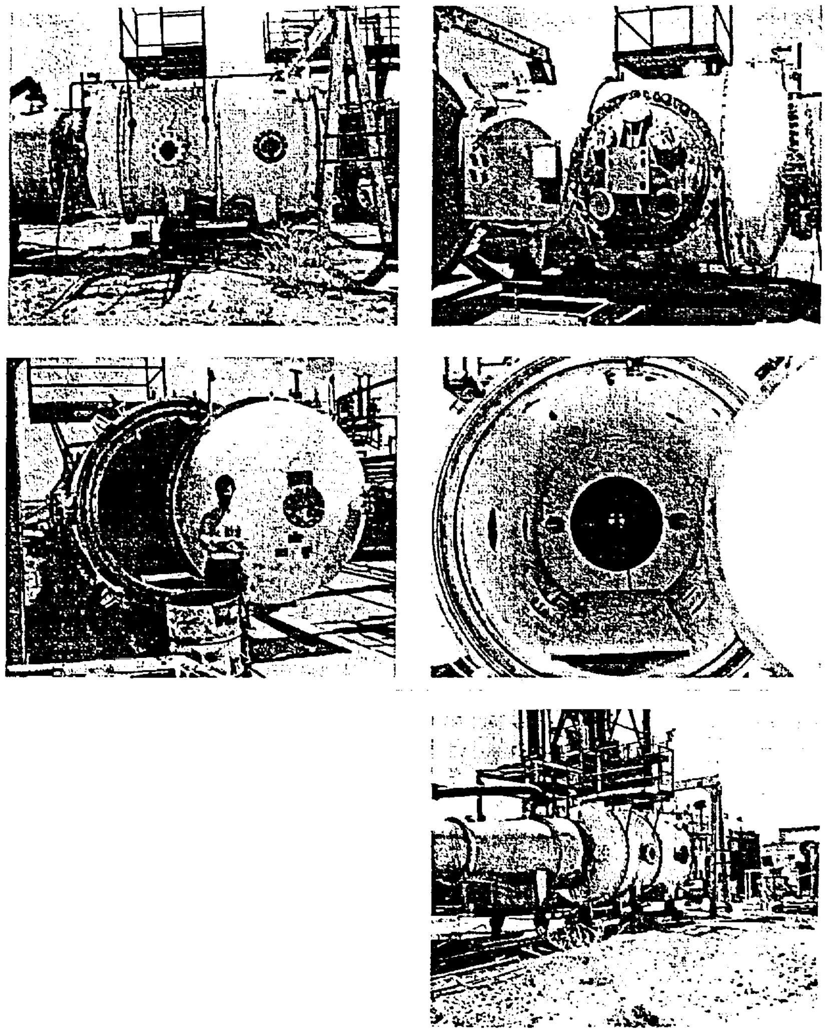
LITHIUM MPD THRUSTER TECHNOLOGY DEVELOPMENT AT JPL

- Funded by NPO in FY92 to develop a lithium feed system
  - Reservoir and vaporizer designed and under construction
  - Flow rate calibration system design complete, components under construction

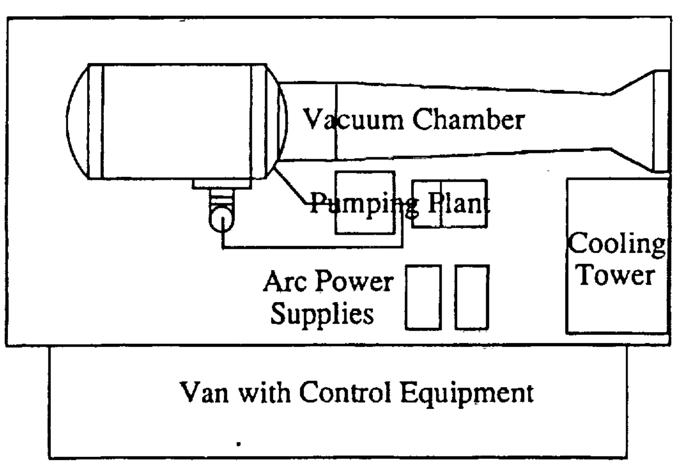
- Test facility design nearly complete, construction to be completed in FY93
  - 6' x 15' double-walled stainless chamber with 27' long extension to be used as a beam dump pumped by a 20" diameter oil diffusion pump

- Initial testing of 100 kWe-class radiation-cooled engine to begin in FY93

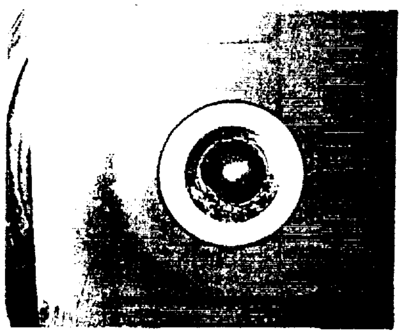
LITHIUM MPD THRUSTER TEST CHAMBER



LITHIUM MPD THRUSTER TEST FACILITY

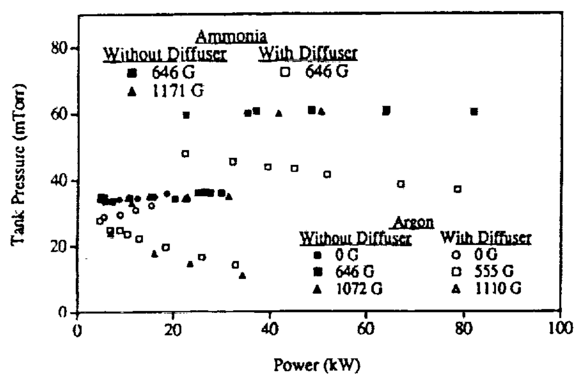


RADIATION-COOLED, APPLIED-FIELD ENGINE TESTING



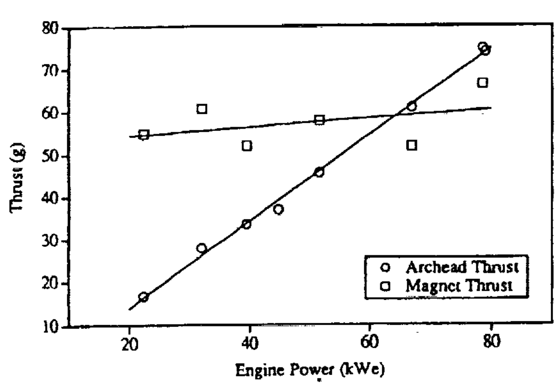
- Operation of radiation-cooled anode up to a power level of 80 kWe was demonstrated on ammonia with no further anode degradation beyond initial melting encountered in earlier testing with argon propellant
- The testing confirms the results of simple thermal modelling which indicated that the open-throated configuration could tolerate higher heat loads

MPD ENGINE PLUME DIFFUSER STUDIES



- Tank pressures are generally higher with ammonia compared to argon, but the diffuser still has a strong effect on the backpressure
- The gasdynamic function of the diffuser and its effect on thruster operation are still not well understood

PRELIMINARY THRUST MEASUREMENTS



- The measurements were made with ammonia propellant and an applied field strength of 646 G
- The magnet thrust appears to be approximately constant, while the engine thrust increases linearly with power
- Similar trends are observed when plotted versus J^2 and JB_z