Arcjet supplemental diagnostics

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1 Summary

This document proposes a new set of diagnostics designed to be implemented on the NASA Ames miniature Arcjet Research Chamber (mARC) for improved characterization of the flow. The diagnostics are grouped into three classes: higher cadence measurements, higher spatial resolution, and computer vision techniques for improved analysis of existing imaging. The goal is to better understand and quantify the following properties:

- Flow statistics/uncertainty
- Temporal & spatial non-uniformities, instabilities
- Flow temperature/enthalpy

2 High speed diagnostics

High speed diagnostics needed to characterize the temporal and spatial non-uniformities present in the arcjet. Since much of the ablation chemistry and radiative heat transfer is non-linear, slow time-averaged measurements are not necessarily representative of the flow profile.

2.1 Magnetics

Magnetic sensors are a convenient way to measure the position, rotation, and magnitude of the internal arc. The magnetic sensors can be placed outside the apparatus and do not need optical access to measure the arcjet interior. Inductive probes (coils, also called Bdot probes) can measure the time derivative of the magnetic field. These probes are useful for detecting small fast variations (e.g. rotation of arc attachment location). Hall sensors are another type of magnetic probe which can measure the field directly but have slower response time (kHz) than inductive probes (MHz).

- Time Required: 1-3 weeks
- Equipment
  - Inductive probes ($0.25 each)
  - Mounts and wiring for probes (from internal supplies)
  - Digitizer/oscilloscope (already purchased)
- Deliverables
  - Tracking of arc position inside column at MHz frequencies
  - Rotation frequency of arc attachment point

2.2 Photodiodes

Photodiodes are an inexpensive robust method for measuring radiation at high frequency (MHz). A set of three to five photodiodes with different line filters could resolve high-frequency variation in intensity and temperature. A photodiode linear array (usually 12-48 elements in a line) could also measure the intensity profile of the arc at high frequency.

- Time Required: $1-3$ weeks
- Equipment
  - Photodiode ($1)
  - Photodiode array ($150)
  - Assorted lenses/filters ($2000)
  - Digitizer/oscilloscope (already purchased)
- Deliverables
  - 0D or 1D imaging of arc profile at MHz frequencies
  - Visualize non-uniformities in flow
  - Profile averaged temperature estimate at MHz

2.3 High Speed Imaging

Imaging can visualize fast arc behavior in 2D. This would require a high-speed intensified CCD camera. High speed movies of the arc would provide useful information on motion, breathing modes, and temperature.

- Time Required: 1 week
- Equipment
  - High speed camera ($15-50k)
- Deliverables
  - Imaging of arc profile at high frequencies
  - Visualize flow modes in 2D

2.4 Electrostatic Probes

These sensors are used to measure density and temperature of an ionized plasma. These probes cannot withstand high heat flux but would be appropriate for fast insertions or off-axis measurements. The density/temperature measurements taken with these diagnostics are typically only accurate within a factor of 2. Since electron density is an exponential function of temperature, this is still a useful diagnostic for CFD validation.

- Time Required: 3-5 weeks
- Equipment
  - Water cooled ceramic sleeve for probe
  - Probe rod (tungsten/tantalum, 1mm) ($20)
  - Isolated power supply ($250)
  - Isolated signal output ($50)
- Deliverables
  - Electron density/temperature
  - Ion density/temperature

3 High spatial resolution spectral diagnostics

Higher spatial resolution is needed from spectral diagnostics to validate numerical simulations of the arcjet flows and improve estimates of the flow temperature.

3.1 Multichannel Emission Spectroscopy

Higher spatial resolution of spectral measurements is important for quantitative comparisons with CFD and flow characterization. Assuming axial symmetry, high resolution measurements can be inverted to recover a 2D profile of temperature and velocity.

Current equipment is suitable for a linear array focused on the shock-stagnation layer up to the model surface. The goal of this particular measurement is to identify the spatial variation in emission near the surface and potentially the chemistry occurring in this region.

Another application is to measure 1D-2D velocity profiles of the flow from Doppler shifts.

- Time required: 3-10 weeks
- Equipment
  - Spectrometer (already acquired)
  - High speed camera (already acquired)
  - Optics (use in-house materials)
  - Fiber array (16 and 24 channel arrays acquired)
- Deliverables
  - Elemental composition profile
  - Temperature/pressure profile
  - Velocity profile

3.2 Planar Laser Induced Fluorescence (PLIF)

This technique illuminates a 2D plane of a fluorescent medium using a laser at a particular wavelength. Imaging of the fluorescence, perpendicular to this plane provides information about temperature and density. This technique is useful because it gives high spatial resolution and can operate at high frequency.

4 Computer Vision Analysis

The arcjets already have several video camera diagnostics, but do not yet extract quantitative information from them. Given the advent of machine learning and free computer vision tools, this data can be better analyzed to characterize many useful quantities such as realtime recession, sting arm motion, and particle tracking.

- Time required: 10 weeks
- Equipment

  - 1-3 capable summer interns
  - Calibration QR code placed on sting arm

- Deliverables

  - Computer vision software which calculates
    * Sting arm motion/orientation
    * Realtime recession tracking
    * Particle tracking velocimetry
    * 3D model reconstruction from stereo imaging
  - Graphical user interface for general use