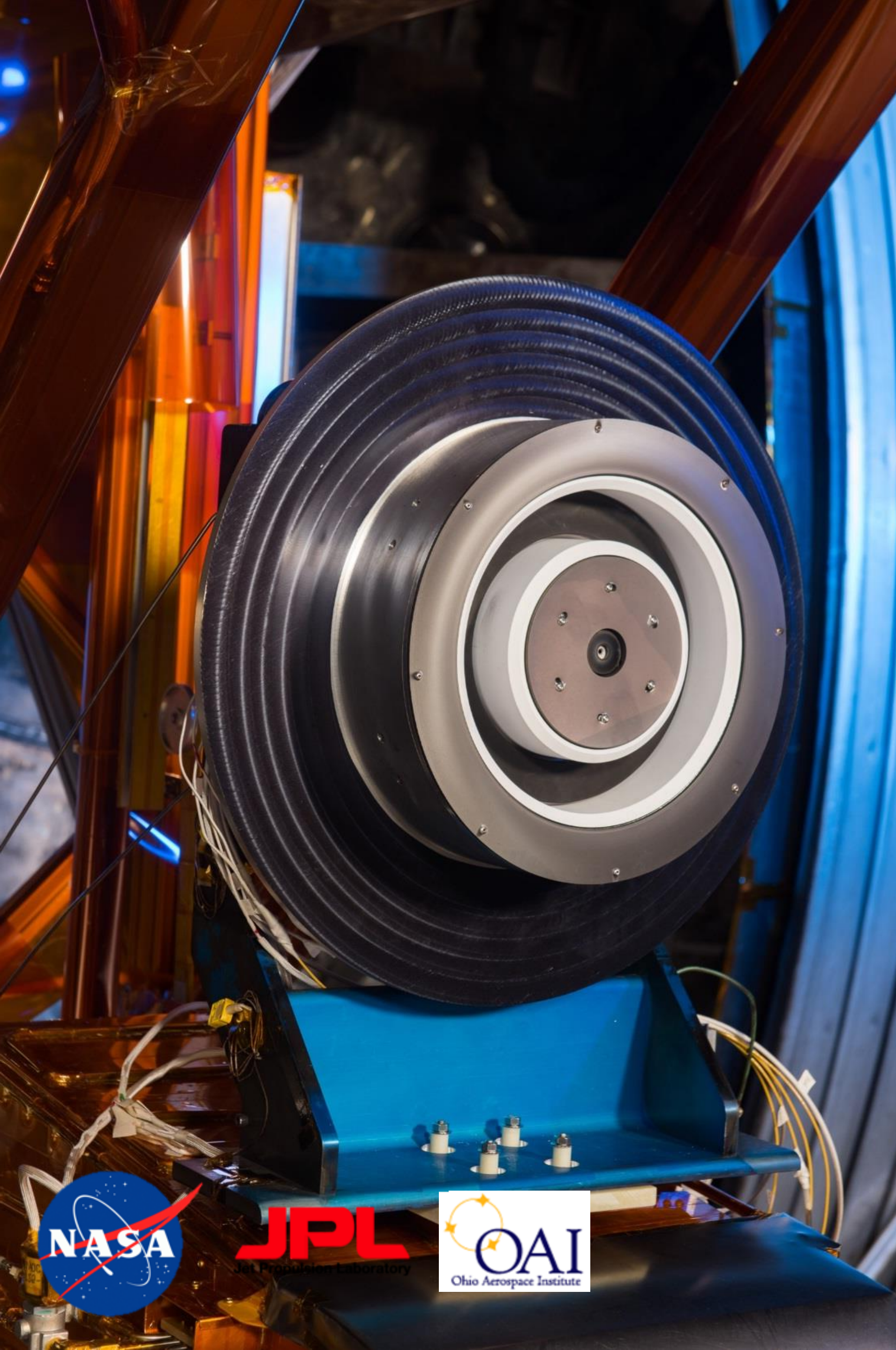

IMPACT OF FACILITY PRESSURE ON THE WEAR OF THE NASA HERMES HALL THRUSTER

2019 International Electric Propulsion Conference
September 16, 2019

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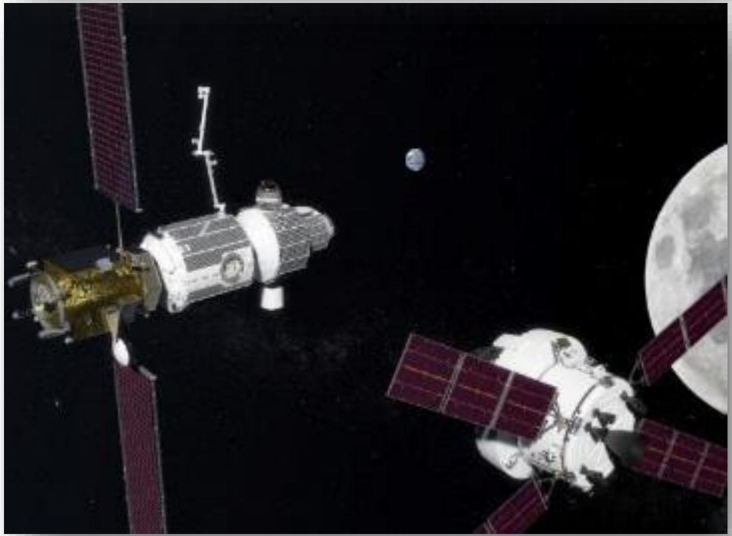
Introduction: HERMeS Development

- High-power (40-kW) SEP capability has been identified as enabling for near term and future NASA exploration architectures
  - Example: Power and Propulsion Element of NASA's Gateway
- Since 2012, NASA has been developing the Hall Effect Rocket with Magnetic Shielding (HERMeS) to serve as a SEP capability building block
- Technology development transitioned to Aerojet Rocketdyne via Advanced Electric Propulsion System (AEPS) contract
  - NASA continues to support AEPS development via mission risk reduction activities including wear testing of technology demonstration unit (TDU) thrusters



Introduction: HERMeS Wear Tests

- 2016 TDU-1 Wear Test: AIAA Paper 2016-5025
  - Goal: provide first quantitative insight into wear and performance trends over an extended period of thruster operation
  - 1700 h of operation at 600 V/12.5 kW in Vacuum Facility 5 (VF-5) at NASA GRC (~4 µTorr operating pressure)

- 2017 TDU-3 Short Duration Wear Test (SDWT): IEPC Paper 2017-207
  - Goal: quantify the impact of operating condition on thruster life
  - 200 h segments (7x) each performed at a different operating condition in VF-5 (~4 µTorr operating pressure) and 6 (~11 µTorr operating pressure)

➢ 2017-2018 TDU-3 Long-Duration Wear Test (LDWT)
  - Pathfinder test for the planned 23 kh AEPS life and qualification campaign intended to quantify the performance, stability, plume, and wear trends of TDU-3 over at least 3,000 hours of operation using methods planned for AEPS testing
  - All segments performed in VF-5 (~4 µTorr nominal operating pressure)

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What is the impact of facility pressure on measured erosion rates?

Test Summary

- The TDU-3 LDWT was conducted between 10/23/2017 and 10/4/2018 and accumulated approximately 3,570 h of total operating time in six segments:
  - I: Repeat of the TDU-1 wear test
  - II-IV: Assess impact of discharge voltage and magnetic field strength on component wear
  - V: Assess performance and wear using an alternate pole cover material (carbon-carbon composite) with increased strength and crack resistance
  - ➢ VI: Assess the impact of facility pressure on performance and wear

*All segments completed at a discharge current of approximately 20.8 A

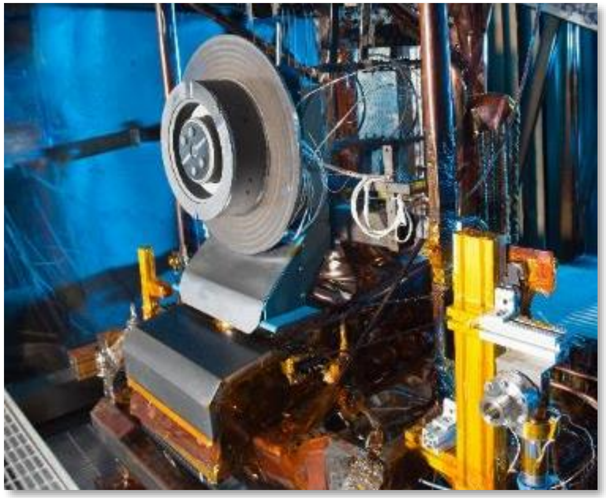
Segment	I	II	III	IV	V	VI
Operating Condition	600 V/ 1 B	300 V/ 1 B	300 V/ 0.75 B	300 V /1.5 B	600 V/ 1 B	600 V/ 1 B
Facility Pressure (μTorr)	5.7	4.2	4.1	4.2	4.3	11.7
Duration (h)	1015	252	214	240	1579	270

AIAA Paper 2018-4645
AIAA Paper 2019-3895

This Work

HERMeS TDU-3

- Same thruster used for SDWT with minor modifications:
  - Thickness and position of cathode keeper
  - New magnet coils (field shape unaltered)



Experimental Apparatus

HERMeS TDU-3

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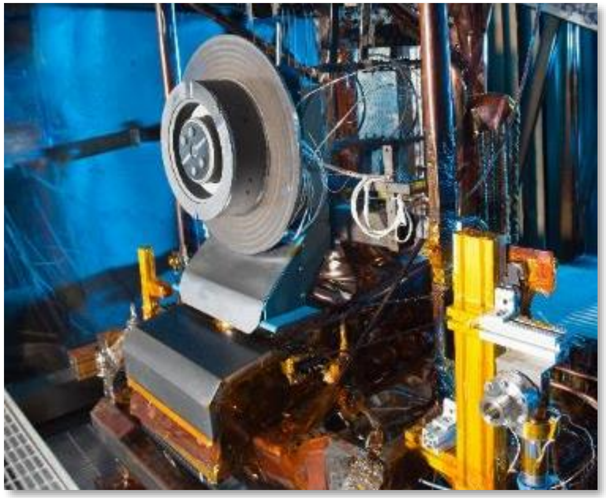
Diagnostics

- Thrust measured with an inverted pendulum thrust stand (± 0.8% uncertainty) (AIAA Paper 2018-4516)
- Faraday probe, retarding potential analyzer, Langmuir probe, ExB probe mounted to a two-axis positioning system (AIAA Paper 2016-4828)



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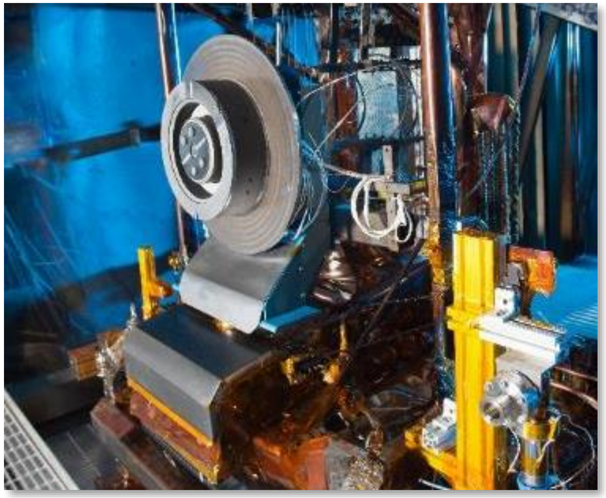
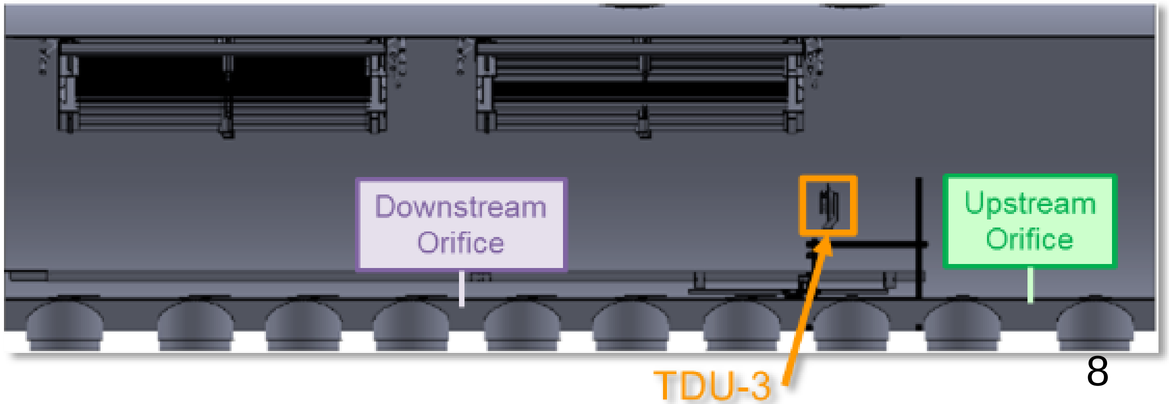
GRC VF-5

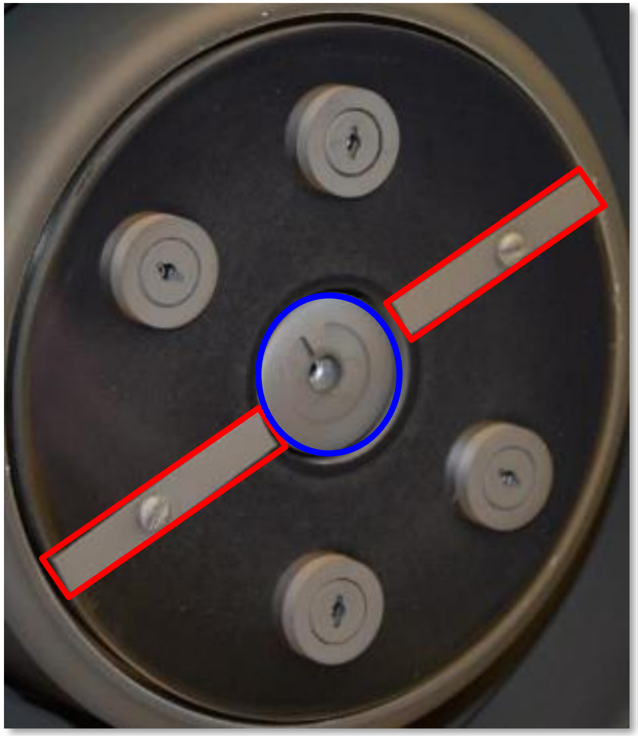
- Nominal operating pressure: 4.5 µTorr at 600 V/12.5 kW
- Pressure measured using 3 EP-configured ion gauges distributed around thruster test station
  - 2 gauges faced radially outward
  - 1 gauge faced axially downstream
- Pressure controlled using auxiliary flow of xenon injected upstream and downstream of TDU-3
  - Auxiliary flow rates varied until the ion gauges facing radially and downstream both measured ~11 µTorr
  - Auxiliary flow injection technique intended to match the near-field backpressure environment observed in VF-6



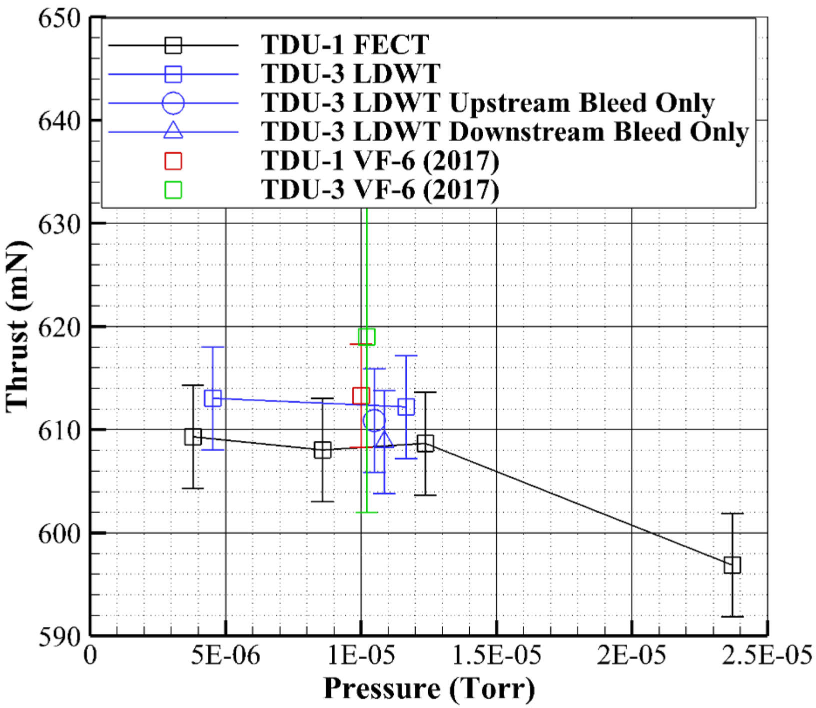


Experimental Apparatus: Wear Measurements

- Inner front pole cover (IFPC), keeper, and outer front pole cover (OFPC) modified to enable wear measurements
  - Graphite components polished pre-test to maximize surface uniformity
  - Graphite masks installed to provide unexposed reference surfaces:
    - IFPC: two graphite strips covering approximately 95% of radius
    - Keeper: graphite ring with a tab protruding radially inward
    - OFPC: series of graphite strips covering approximately 95% of radius
- Erosion measurements made with a chromatic, white-light, non-contact profilometer
  - Data analyzed per ISO 5436-1 guidance for a type A1 step
  - Typical uncertainties ±2 μm accounting for:
    - Instrument error
    - Surface roughness
    - Non-flat surface geometry



Results: Performance



Key Observations:

1) Increasing the operating pressure during the LDWT changed the thrust by less than the measurement uncertainty
   - Consistent with results from Facility Effects Characterization Test (FECT)

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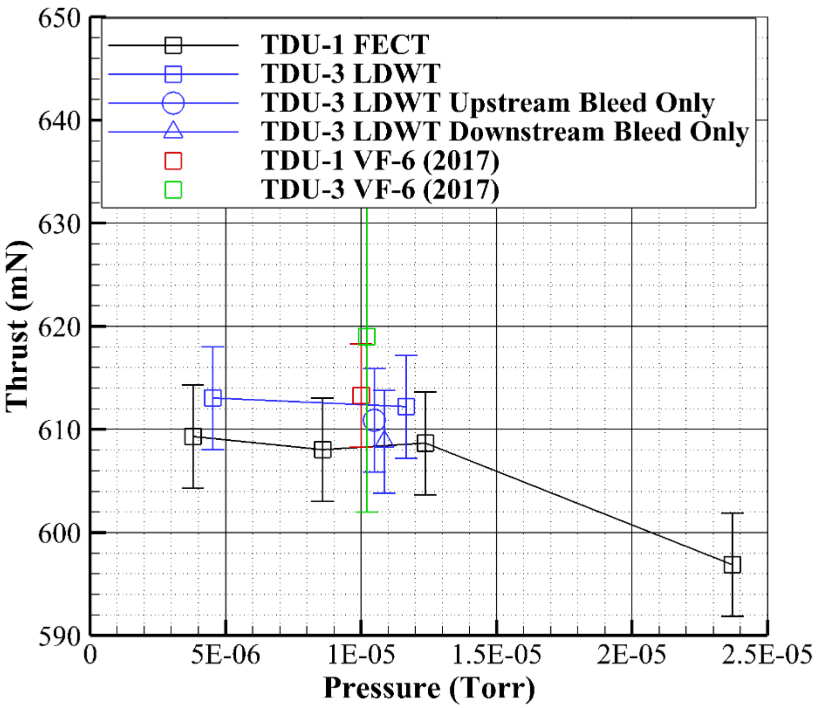

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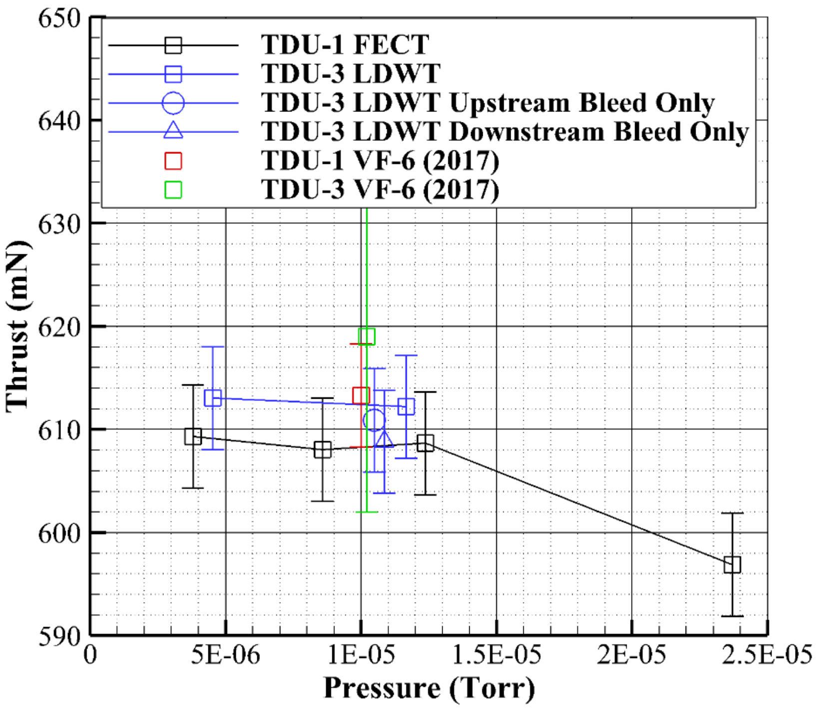

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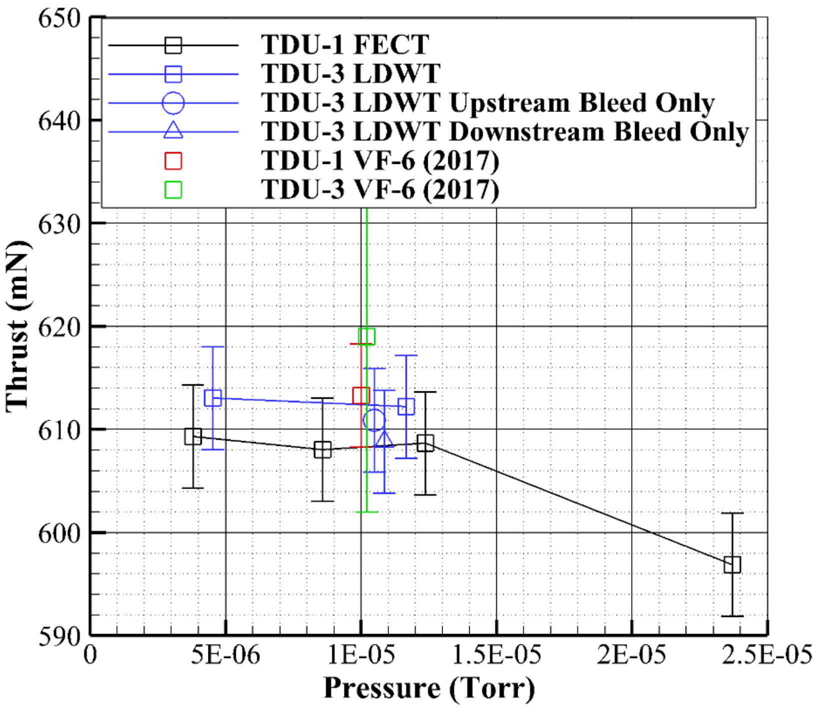

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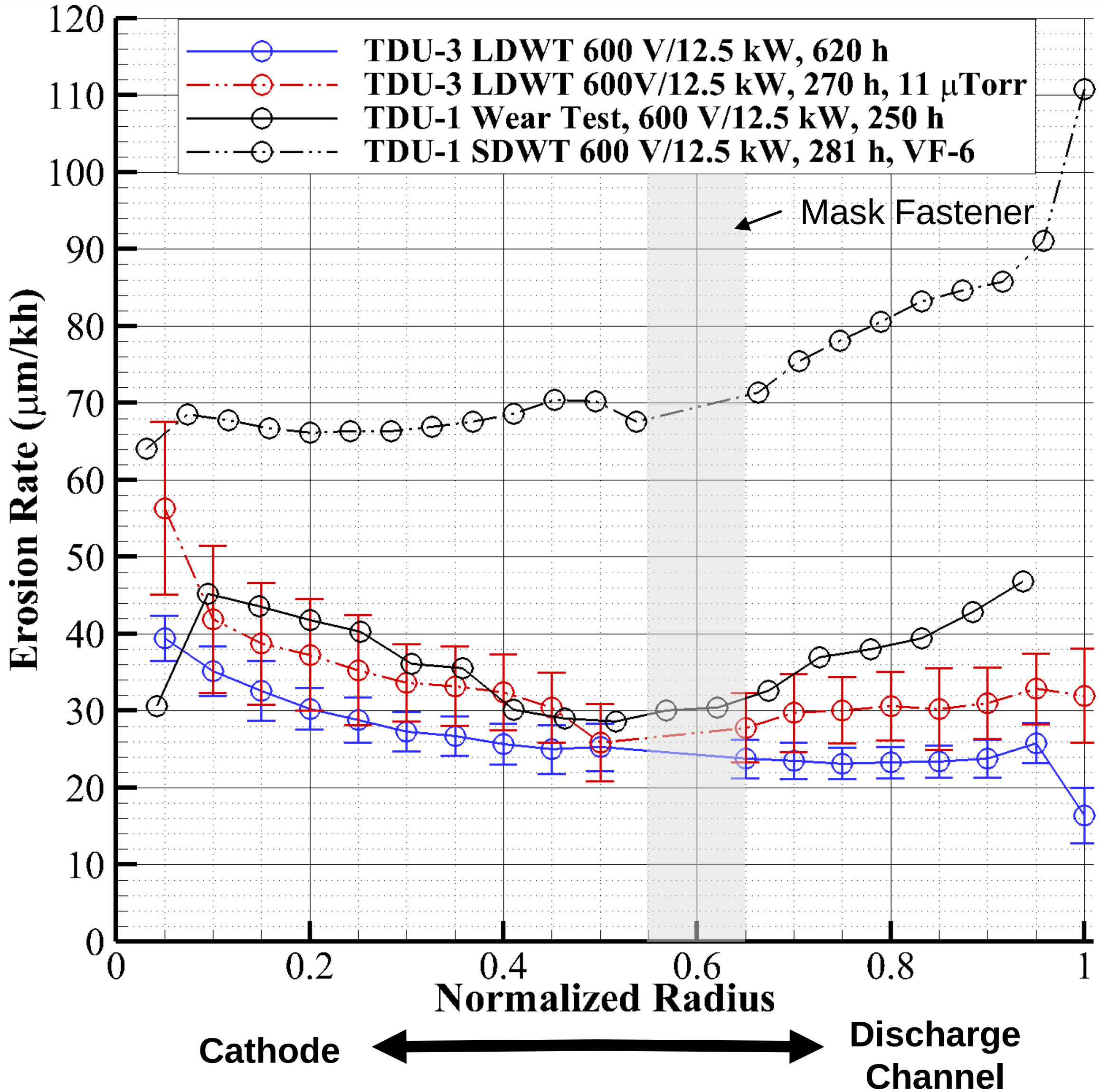
Bleed flow did not significantly impact thruster performance or plume properties

Results: IFPC Wear



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1) The IFPC erosion rates in VF-5 at 11 μTorr largely match those at ~4 μTorr to within the measurement uncertainty

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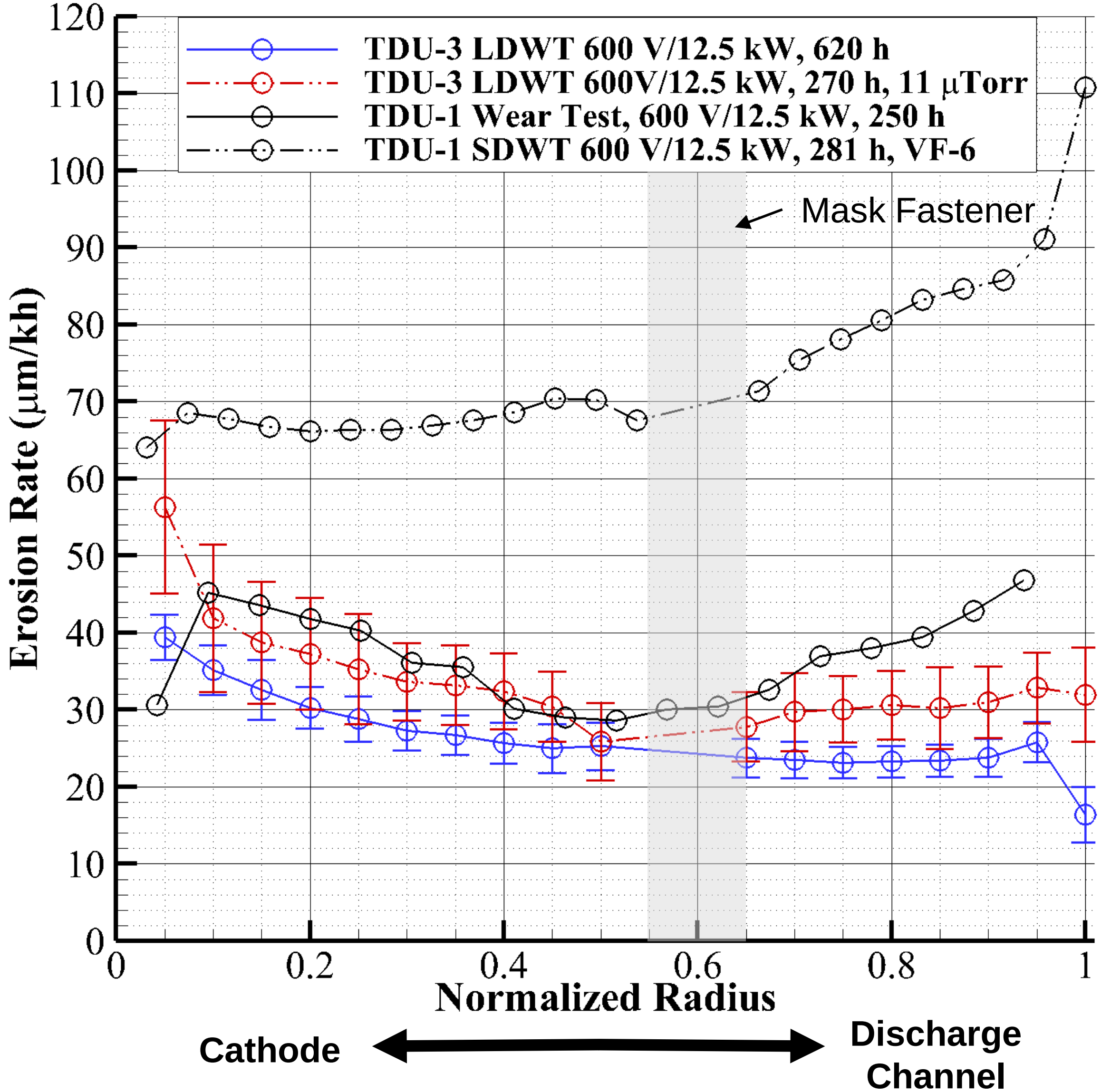

Key Observations:

1) The IFPC erosion rates in VF-5 at 11 µTorr largely match those at ~4 µTorr to within the measurement uncertainty
2) IFPC erosion rates measured in VF-6 at an equivalent background pressure and operating condition are 54% larger (on average) than those measured in VF-5

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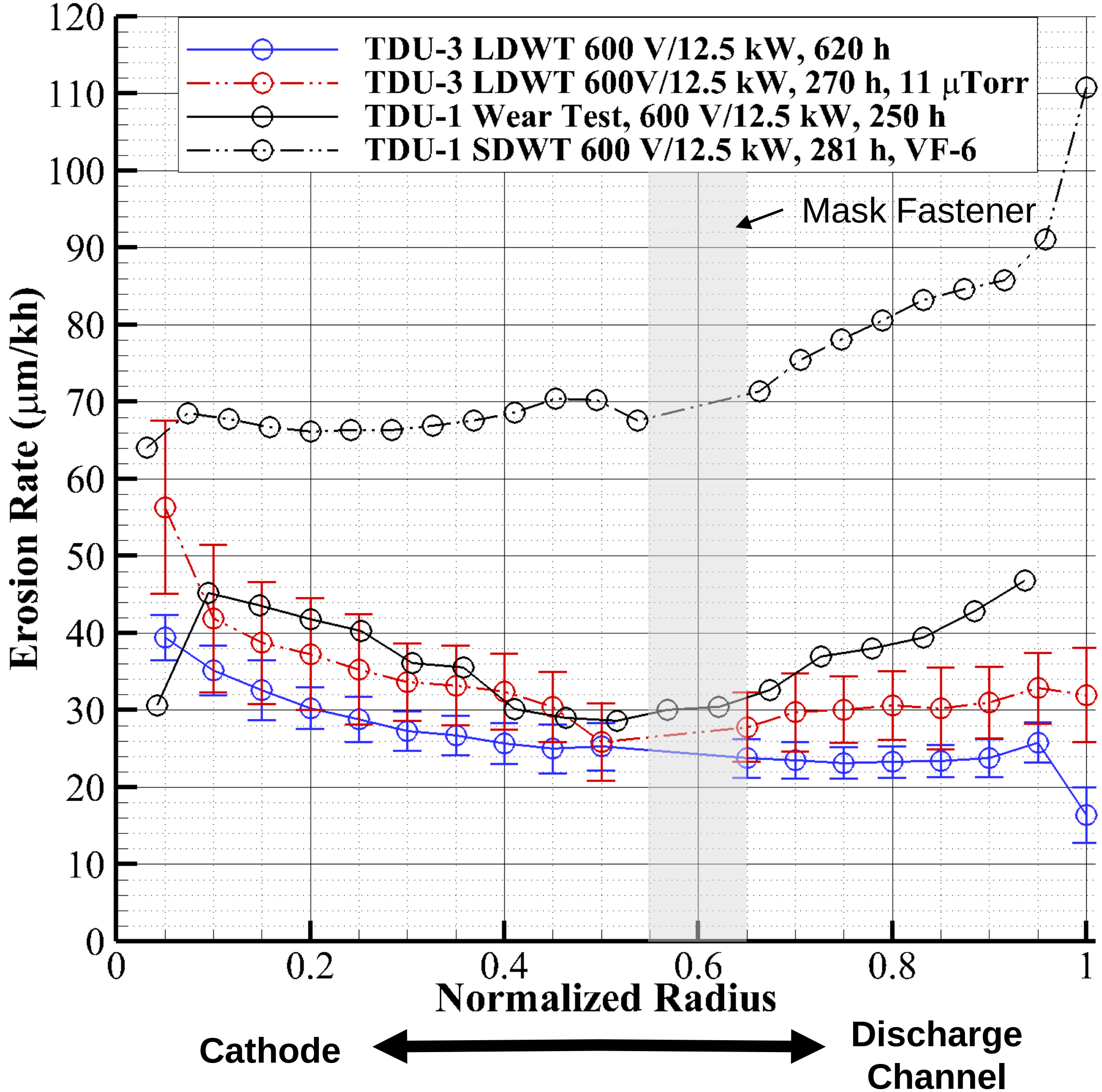

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3) Similar results obtained for the OFPC

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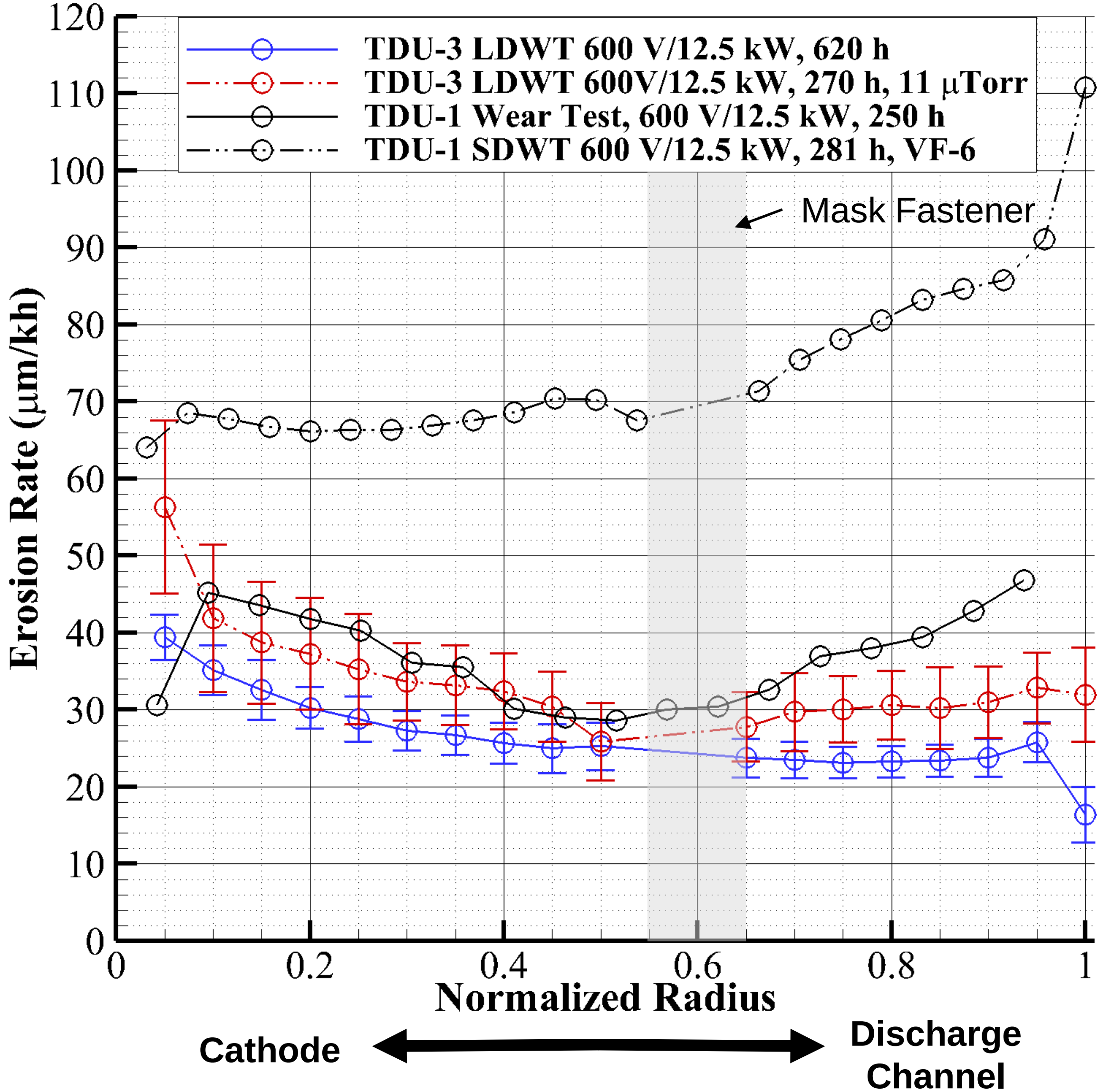

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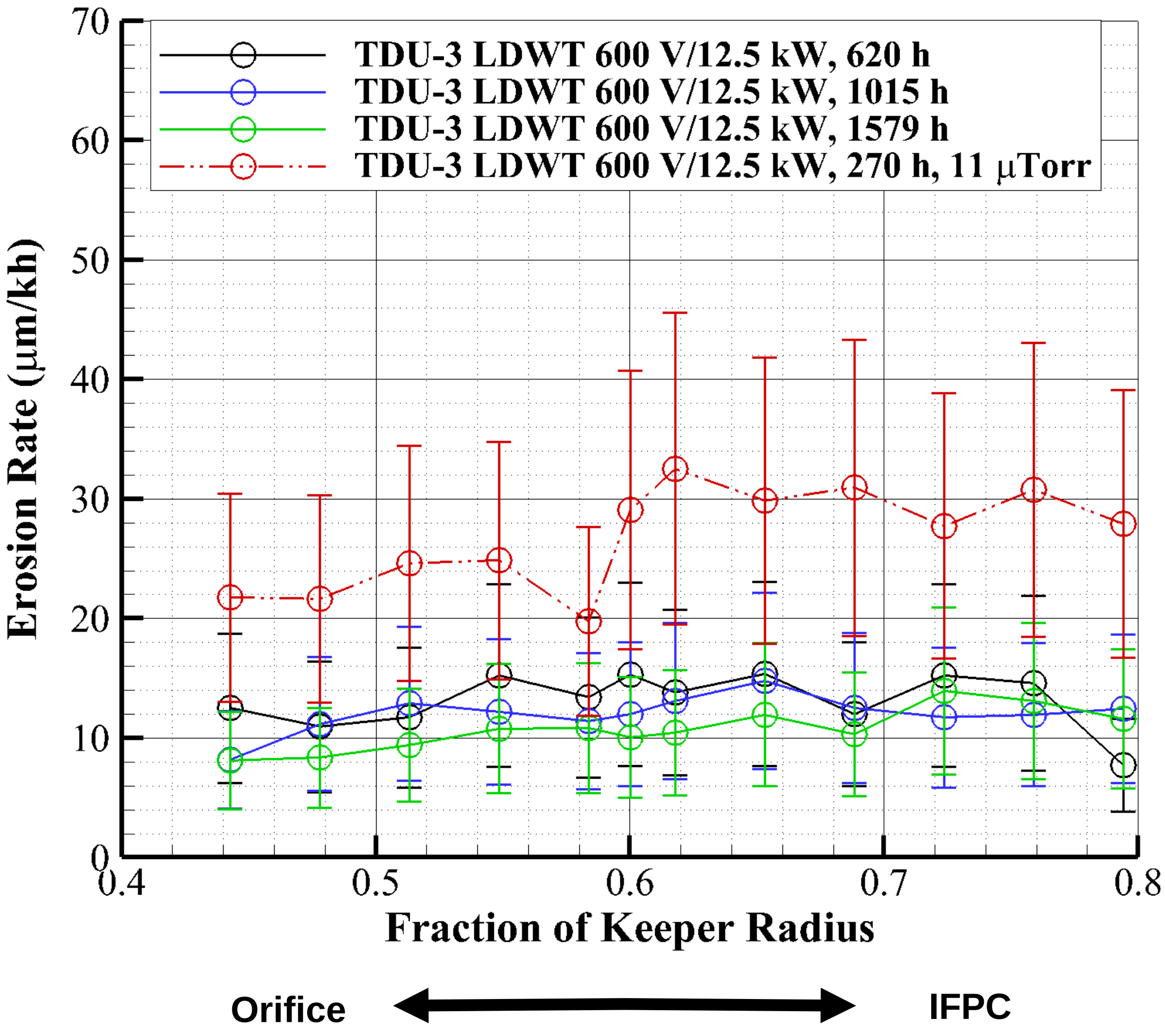
3) Similar results obtained for the OFPC

Pressure alone cannot explain difference in wear rates between VF-5 and VF-6

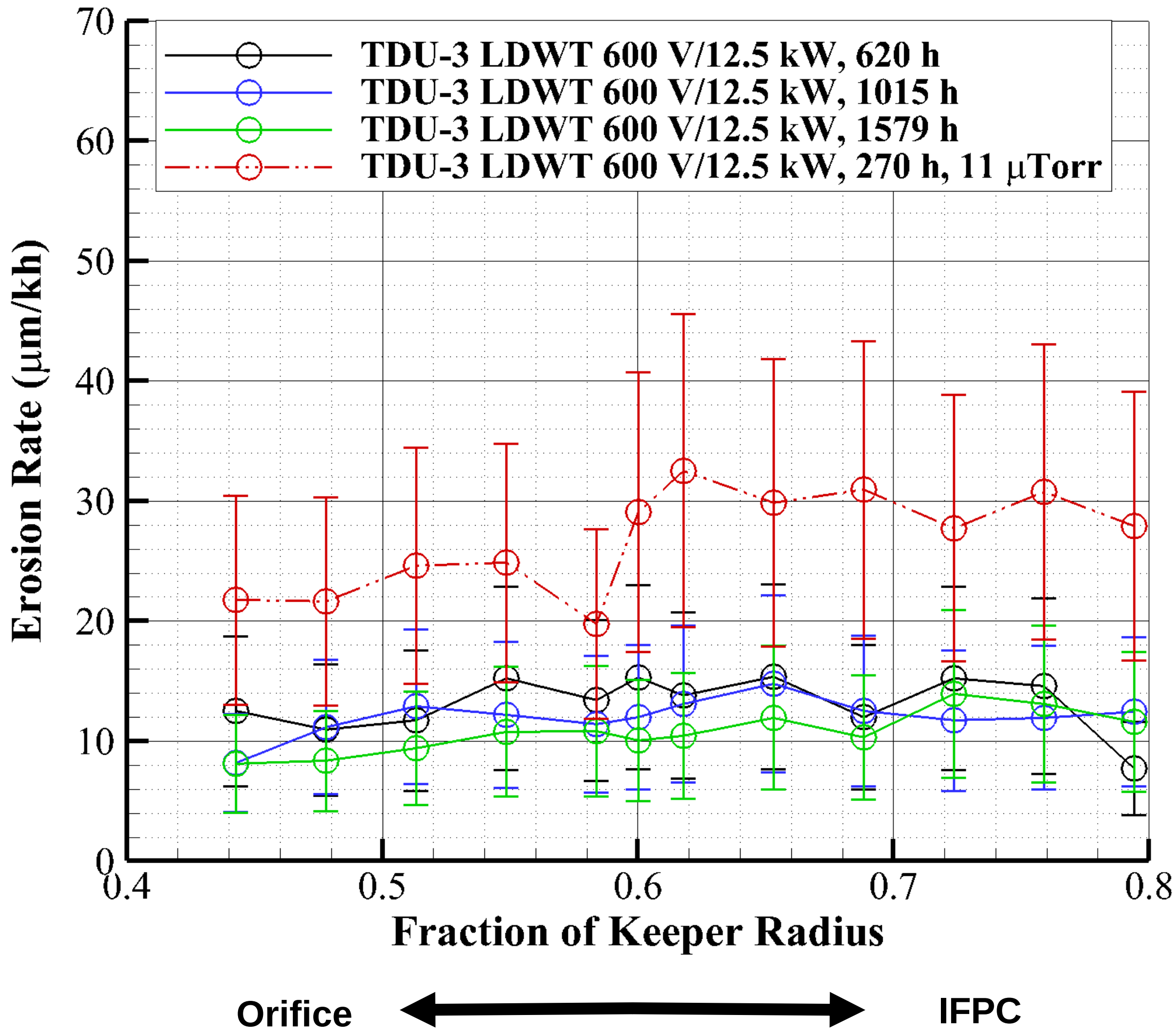
Results: Keeper Wear



Key Observations:

1) The keeper erosion rates in VF-5 at 11 μTorr are 152% greater (on average) than those at ~4 μTorr (○, ○, ○)

Results: Keeper Wear



Key Observations:

1) The keeper erosion rates in VF-5 at 11 μTorr are 152% greater (on average) than those at ~4 μTorr (○, ○, ○)

2) No corresponding change observed in cathode performance and stability parameters:
   - Cathode-to-ground voltage
   - Keeper floating voltage
   - Keeper voltage oscillation characteristics (peak-to-peak, RMS, σ, power spectra)

Conclusions

- The performance and wear of the NASA HERMeS TDU-3 Hall thruster at elevated pressure was assessed in order to determine the sensitivity of these parameters to facility effects
- Performance and plume properties were shown to vary by less than the empirical uncertainty between operation at nominal (4 µTorr) and elevated (11 µTorr) facility pressure
- Erosion rates of the IFPC at 11 µTorr matched those obtained in the same facility at 4 µTorr, but were 54% smaller than those measured in another facility at matched operating pressures and throttle conditions
- Keeper erosion rates were shown to increase by 152% for operation at 11 µTorr relative to 4 µTorr in the same facility
- Overall, this suggests that facility parameters other than pressure play a role in determining component erosion and that additional work is required to fully characterize facility-to-facility variations in wear rates