CHARACTERIZING ELECTRICAL ARC BEHAVIOR IN ION ENGINES

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OVERVIEW

- Background
- Throttle Table and Test Setup
- Arc Types
- Test Results
- Conducted Susceptibility Testing
- Summary

BACKGROUND

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- Study undertaken to understand arc events on a modified engineering model NEXT ion engine as part of the Advanced NEXT project

- Electrical breakdowns are inherent during gridded ion thruster operation, and an arc extinction sequence ("recycle") is employed to protect the PPU and thruster
  - the breakdowns may be caused by: FOD, desorption of trapped gases after atmospheric exposure, sharp edges, localized ion beam steering
- - the total number of recycles is typically low on-orbit and the frequency decreases with time. For example, the three NSTAR engines flown on Dawn experienced a total of 40-70 recycles a piece during the first 20,000 hours of operation

- During a recycle event the following steps occur:
  Step 1: Disable the high voltage supplies
  Step 2: Decrease the discharge current
  Step 3: Reenable the high voltage supplies
  Step 4: Return discharge current to nominal value

- The electrical breakdown that triggers the recycle sequence is on the order of 100s of microseconds, the recycle event for the NEXT system is 800 milliseconds

- The motivation for gaining a better understanding of arc behavior stems from an anomaly with power system equipment encountered during the DART mission
  - how frequent are high voltage-to-chassis arcs during thruster operation?
  - what are the magnitudes of the chassis currents?
  - what testing can be performed at the spacecraft level to address the transients associated with arcing events?

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NEXT THROTTLE TABLE

- Tests conducted using Advanced NEXT throttle table
- Green entries ($J_b \leq 3.52$ A) correspond to "standard" NEXT-C conditions developed for planetary missions
- Blue entries ($J_b > 3.52$) correspond to high thrust-to-power conditions for earth orbital missions

	V_{bps}, V															
J_b, A	1800	1567	1396	1179	1200	1068	1021	936	870	850	700	679	650	400	300	275
7.04	1B-HP	TL55	TL54	TL53			TL52	TL51C	**1B**		TL51A					
6.00					**2B**											
5.80	1A-HP	TL50	TL49	TL48		**1A**		TL46B	TL46A		TL46					
5.50	TL46G	TL45F	TL45E	TL45D			TL45C	TL45B	TL45A		TL45					
5.00	TL44G	TL44F	TL44E	TL44D			TL44C	TL44B	TL44A		TL44		TL44-###			
4.50	TL43G	TL43F	TL43E	TL43D			TL43C	TL43B	TL43A		TL43		TL43-###	TL43-###		
4.00	TL42G	TL42F	TL42E	*TL42D*			TL42C	TL42B	TL42A		TL42		TL42-###			
3.52	TL40	TL39	TL38	TL37			ETL3.52A	ETL3.52B		ETL3.52C	ETL3.52D		TL37-###	TL37-###		
3.10	TL36	TL35	TL34	TL33			ETL3.1A	ETL3.1B		ETL3.1C	ETL3.1D	ETL3.1E		TL33-###		
2.70	TL32	TL31	TL30	TL29			TL28	ETL2.7A		ETL2.7B	ETL2.7C	ETL2.7D	ETL2.7E			
2.35	TL27	TL26	TL25	TL24			TL23	ETL2.35A		ETL2.35B	ETL2.35C	ETL2.35D	TL2.35E			
2.00	TL22	TL21	TL20	TL19			TL18	ETL2.0A		ETL2.0B	ETL2.0C	ETL2.0D	ETL2.0E			
1.60	TL17	TL16	TL15	TL14			TL13	ETL1.6A		ETL1.6B	ETL1.6C	ETL1.6D	ETL1.6E	ETL1.6F		
1.20	TL12	TL11	TL10	TL09			TL08	TL07		TL06		TL05	TL04	TL03	TL02	
1.00																TL01

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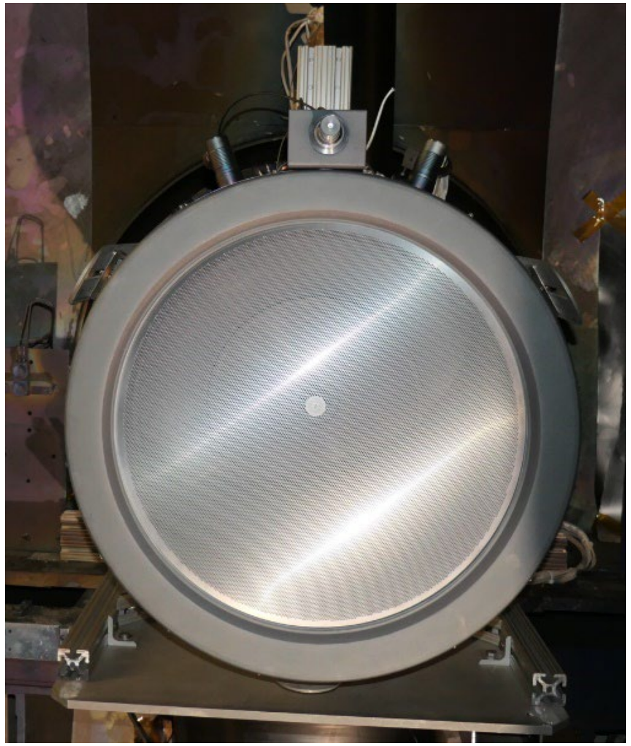
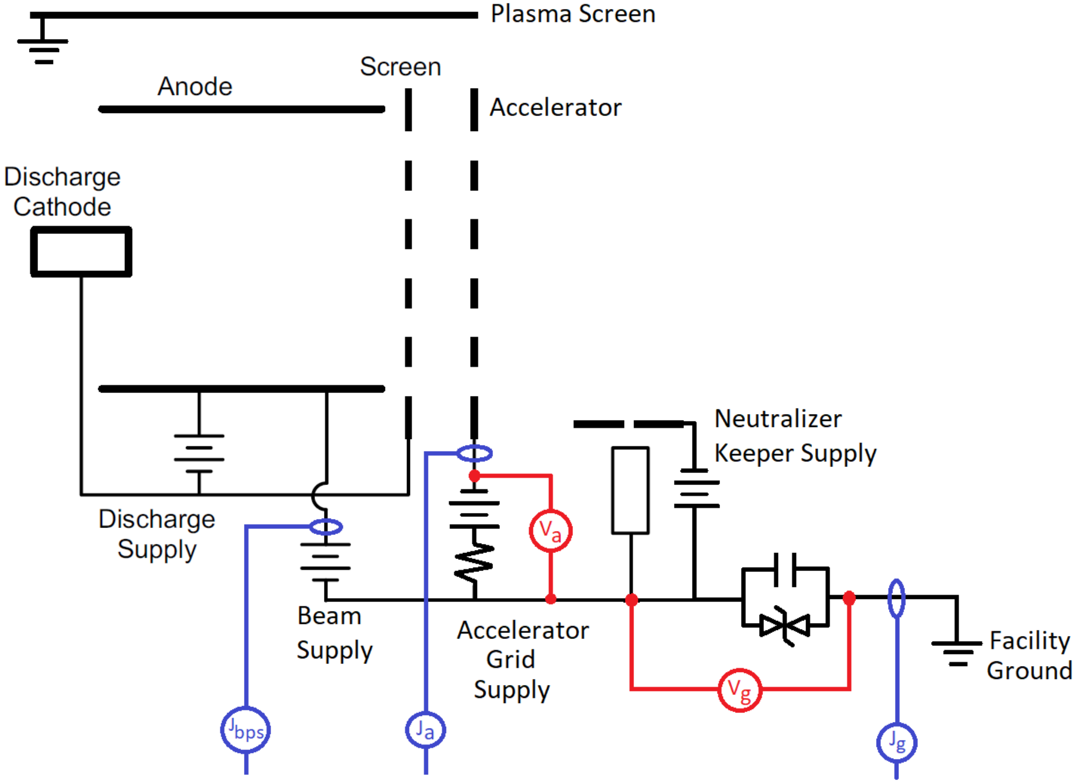
TEST HARDWARE

- Tests conducted using a modified engineering model NEXT thruster
- Commercial power supplies used to power the engine
- Thruster plasma screen was electrically connected to facility ground during testing



Beam Current	J_{bps}
Accel Current	J_a
Chassis Current	J_g
Accel Voltage	V_a
Coupling Voltage	V_g



GROUND TEST HARDWARE

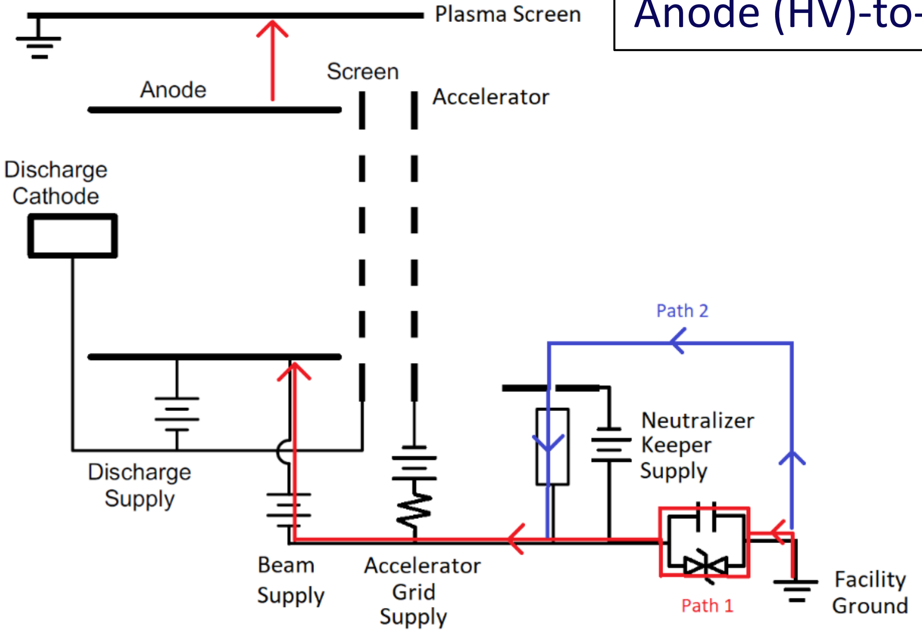
- The data collected during testing established a baseline for differentiating the various arc types, and is specific to the hardware configuration

- The ground test hardware has numerous differences with a NEXT-C flight thruster and PPU:

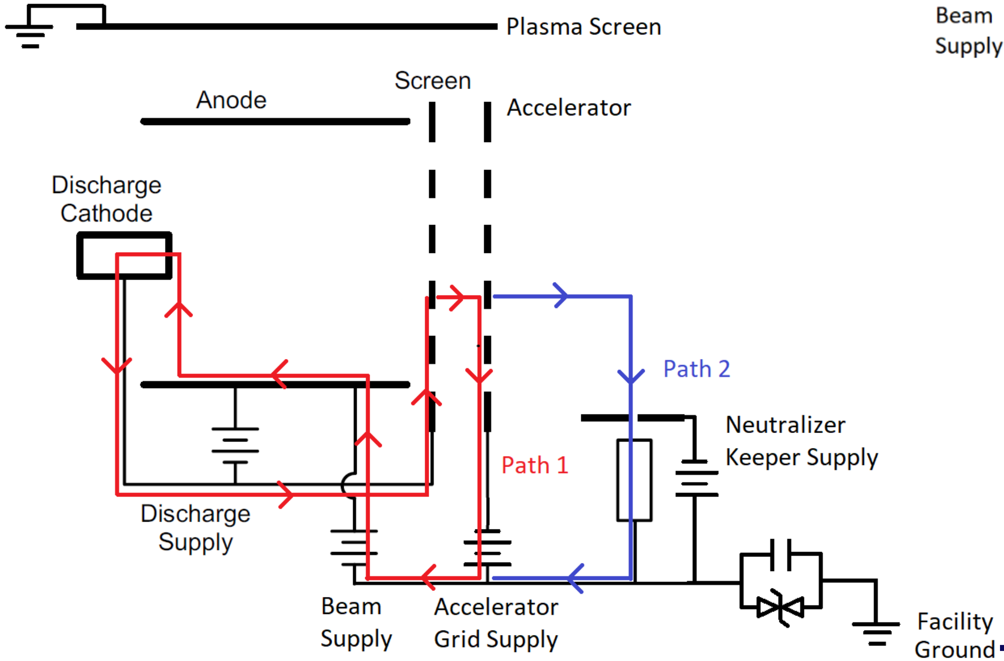
  1. The engineering model thruster design is significantly different that the flight design
     - emissivity coatings, propellant isolator design, ceramic standoffs
  2. The thruster subassemblies were built in the 2000s and have undergone significantly more handling than a flight article would
  3. The ground test electrical configuration is different than a spacecraft configuration
     - the ground test transmission line lengths are several factors longer
     - the in-line resistances of the commercial power supplies are higher that those used with the PPU
     - the output filter capacitance of the commercial beam supply is an order of magnitude than the beam module within the PPU, leading to more dissipated energy during a recycle event
  4. The input conditions at high thrust-to-power throttle levels impact engine behavior
     - higher beam currents, higher temperatures, higher discharge powers

ARC CURRENT PATHS

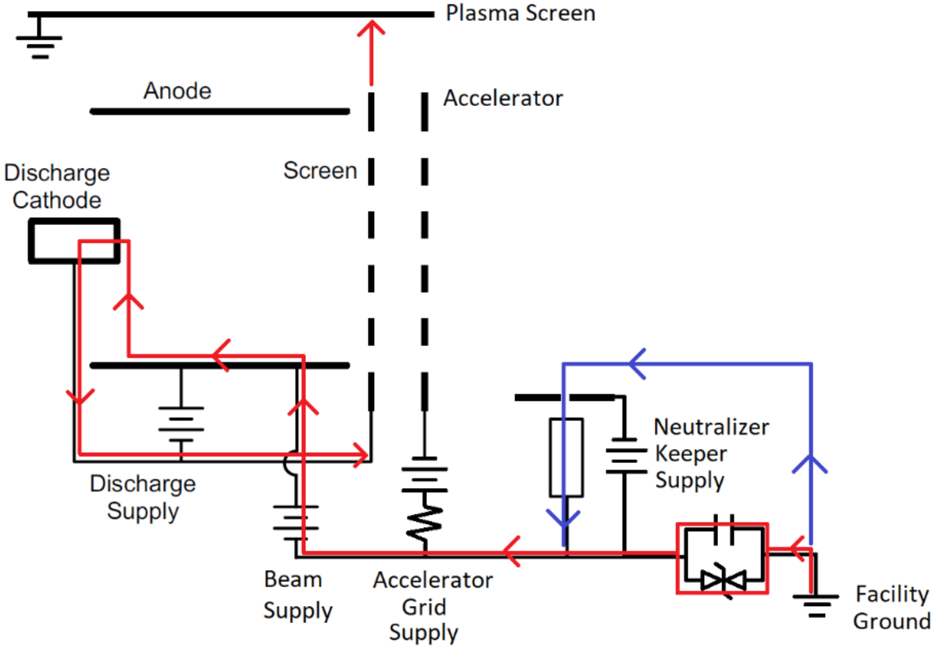
Anode (HV)-to-chassis



Grid-to-grid



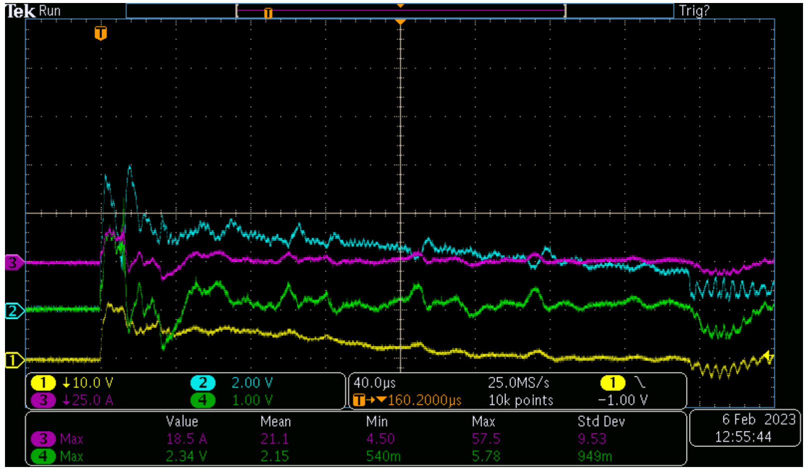
Cathode (HV)-to-chassis



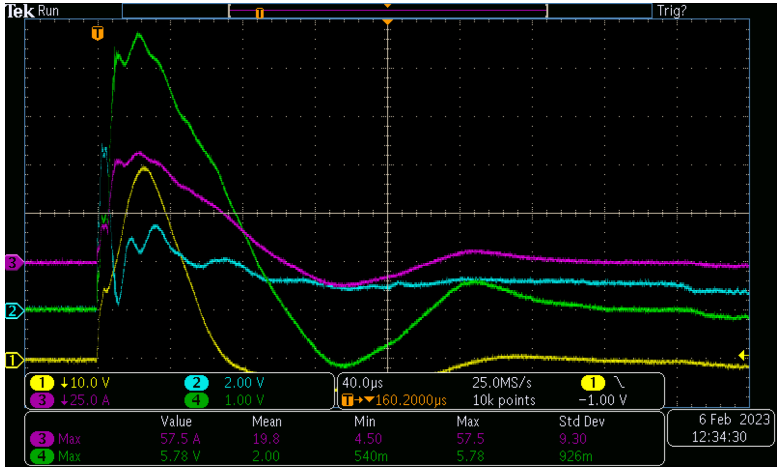
TYPES OF ARCS

- Grid-to-grid arc currents contained within NEXT-C system
- HV-to-chassis arcs characterized by large output beam currents (100s of A), moderate chassis currents (25-70 A)

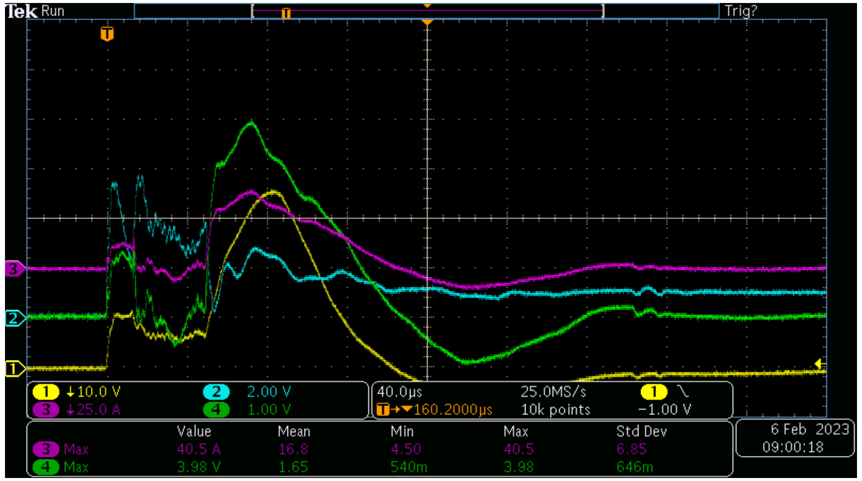
Grid-to-grid arc



HV-to-chassis arc



Combination



CH1: Beam Current **CH2: Accel Current** **CH3: Ground Current** **CH4: Ground Current**

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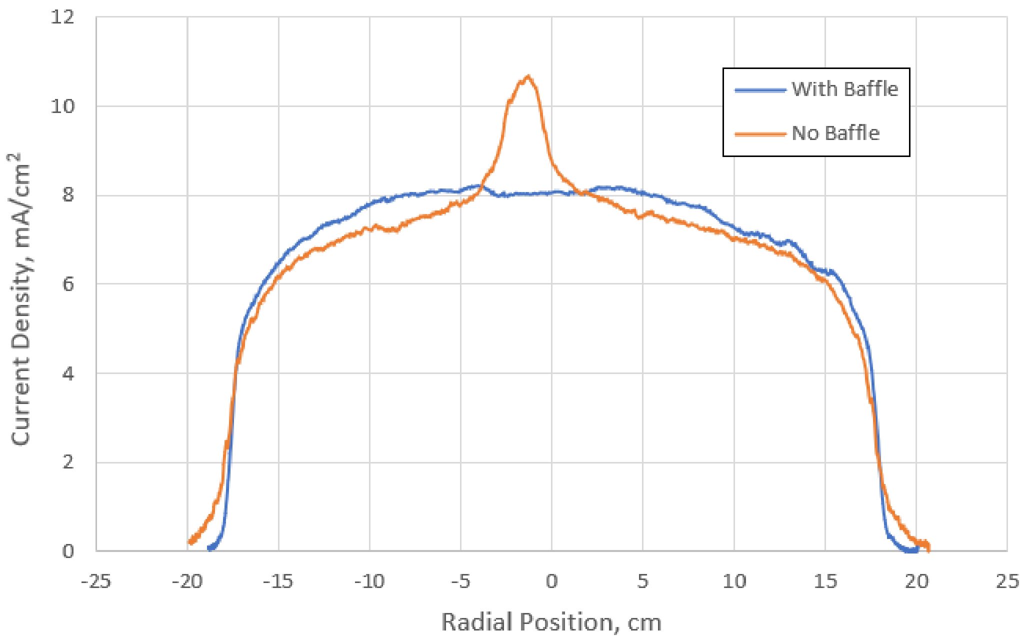
THRUSTER CONFIGURATIONS

- Two major changes were made to the engineering model NEXT thruster for the Advanced NEXT project
  1) High perveance optics (reduced electrode thickness, larger apertures) were utilized for a subset of tests
  2) A discharge chamber baffle was utilized to eliminate a performance limiting current density peak

- Tests conducted using three different hardware configurations shown below

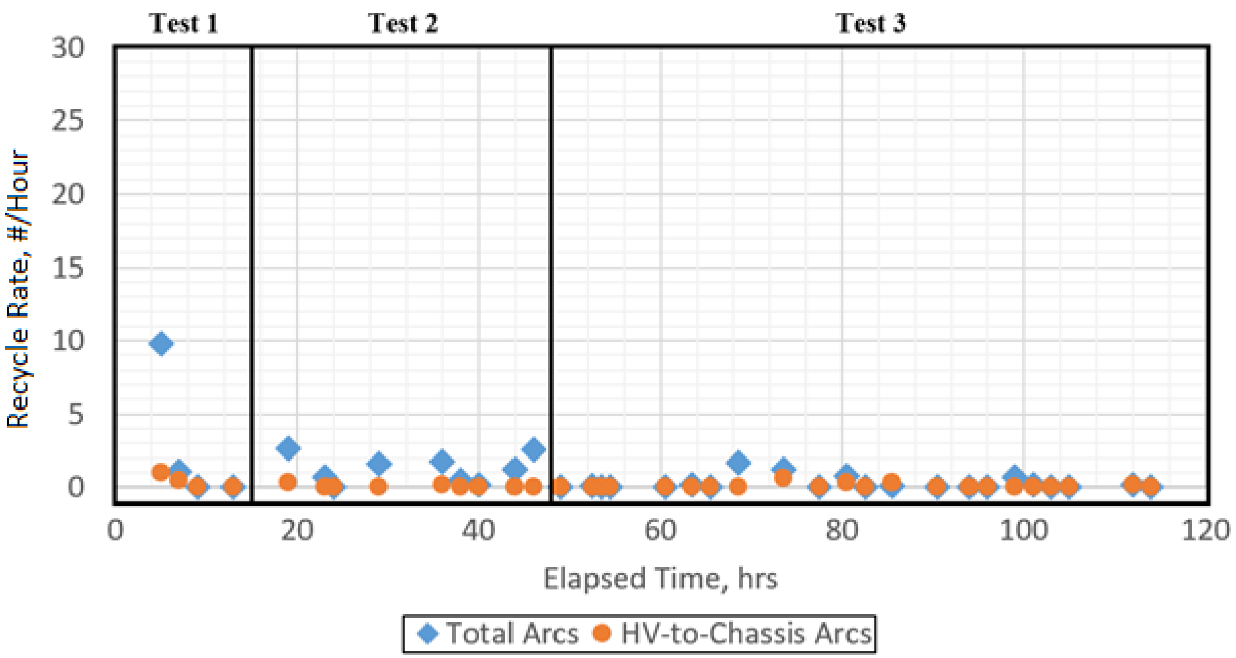
Test Segment	Ion Optics Assembly	Baffle?
#1	High Perveance Design	No baffle
#2	High Perveance Design	With baffle
#3	Heritage NEXT-C Design	With baffle



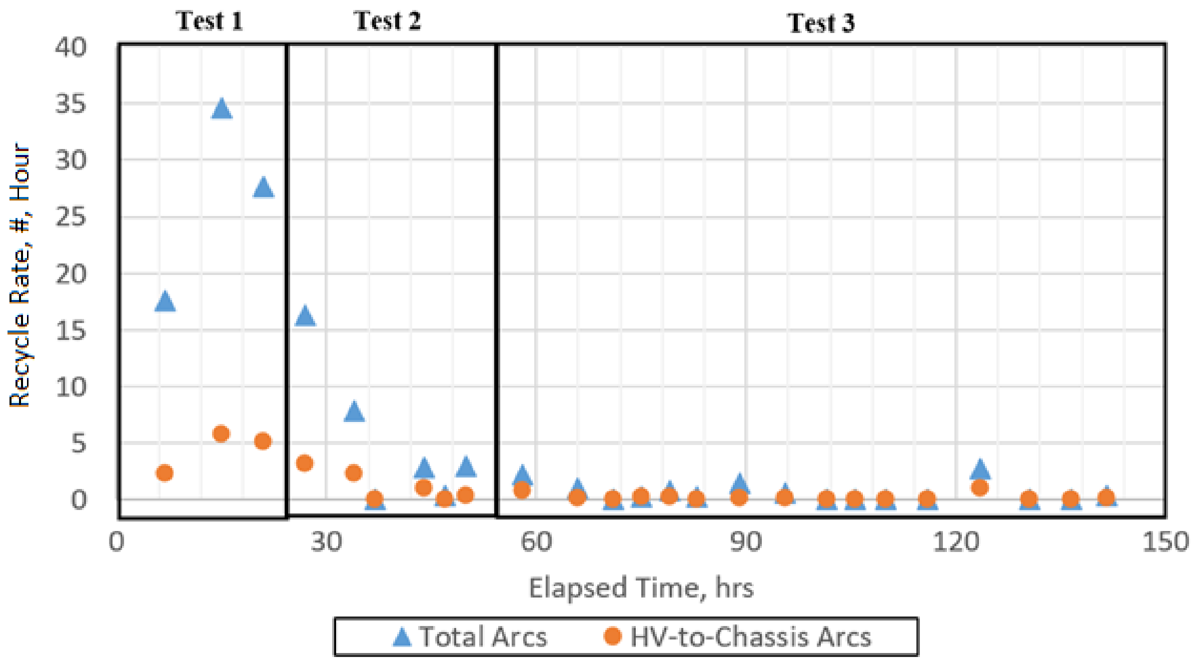
RECYCLE RATE

- Recycle rate generally low (< 1 per hour) at standard throttle conditions
- Recycle rate higher at high thrust-to-power conditions
  - recycle rate dropped by order of magnitude by use of a discharge chamber baffle

Standard throttle conditions (Jb ≤ 3.52 A)



High thrust-to-power conditions (Jb > 3.52 A)



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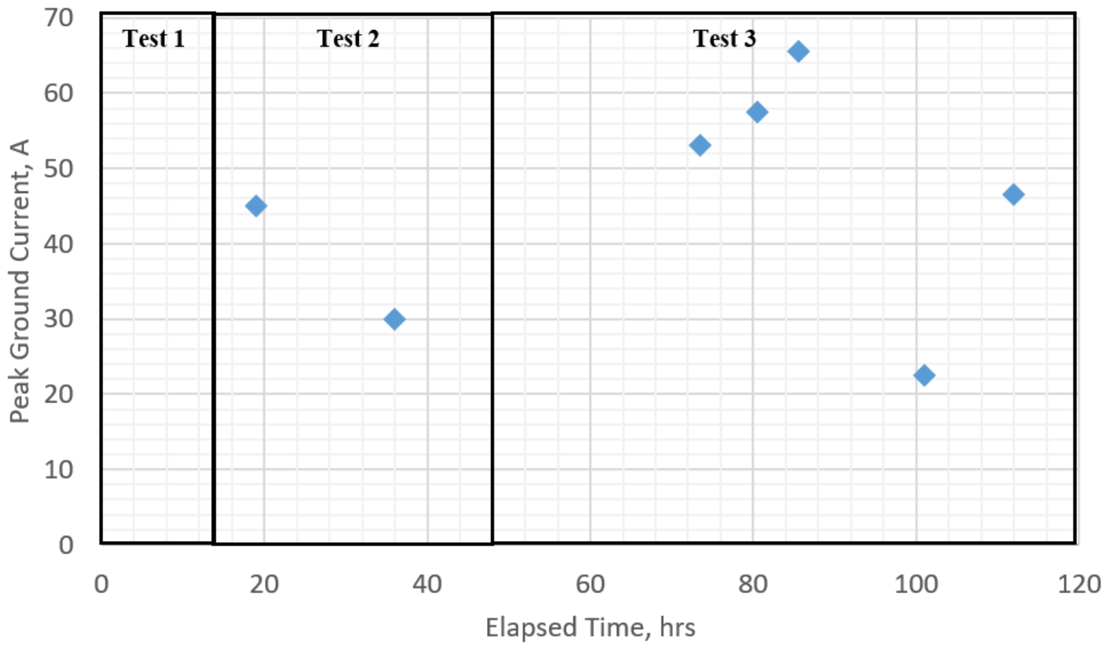
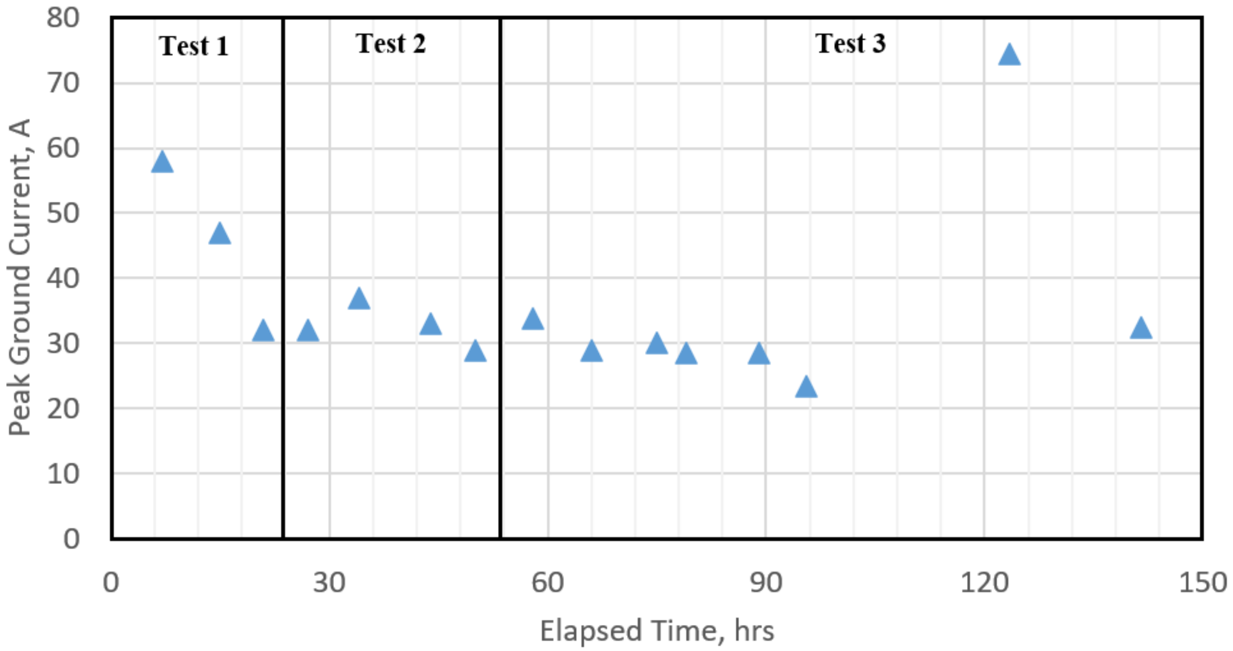
PEAK CHASSIS CURRENTS

- Chassis currents during grid-to-grid recycles was 5-15 A
- Chassis currents during high voltage to chassis recycles ranged from 20-70 A
  - a significant fraction (up to 80%) of output current from the beam supply traveled through the neutralizer; this may be a ground test effect

Standard throttle conditions (Jb ≤ 3.52 A)

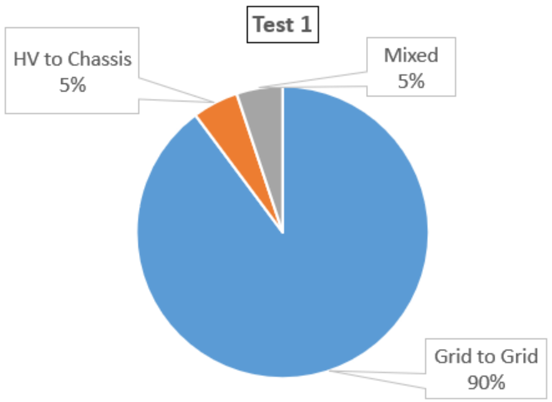


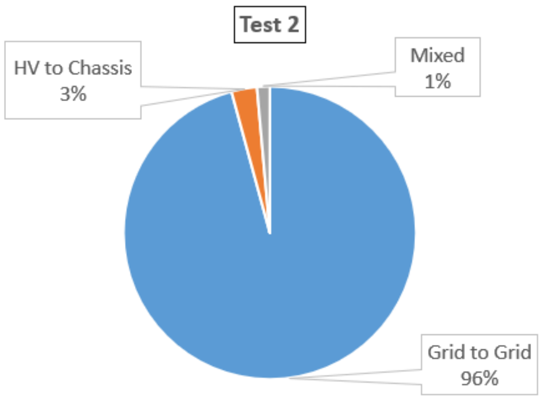
High thrust-to-power conditions (Jb > 3.52 A)

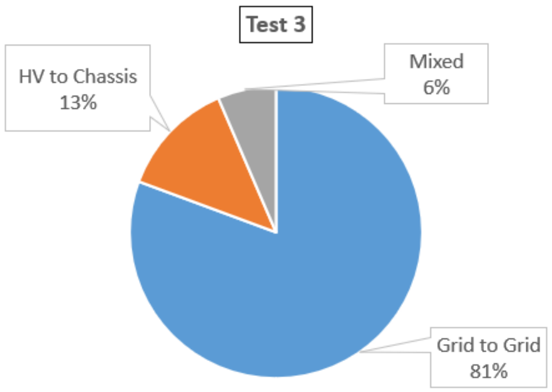


ARC TYPE PERCENTAGE

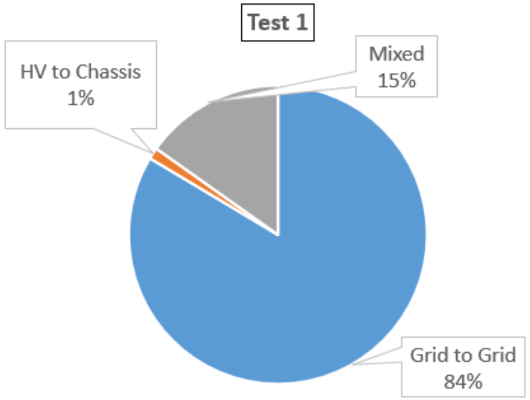
- High voltage-to-chassis arcs constituted 4-30% of the total recycle events

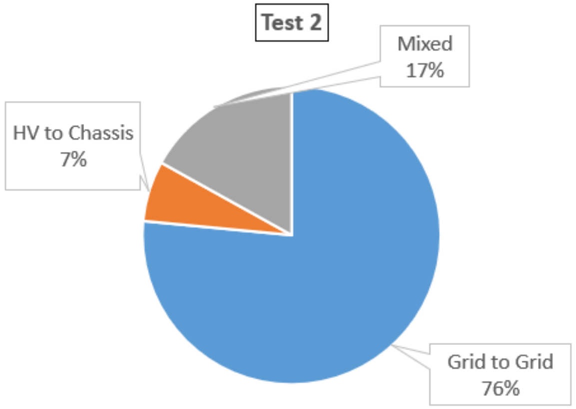


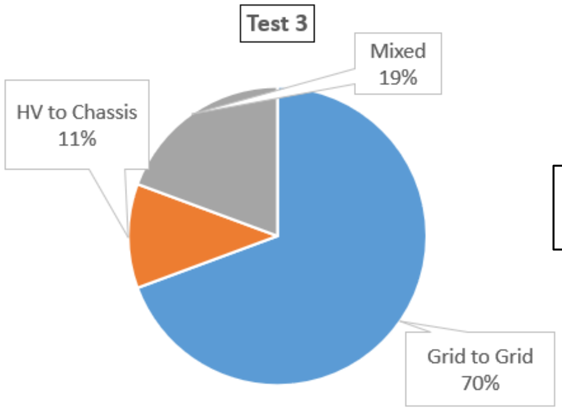




Standard throttle conditions





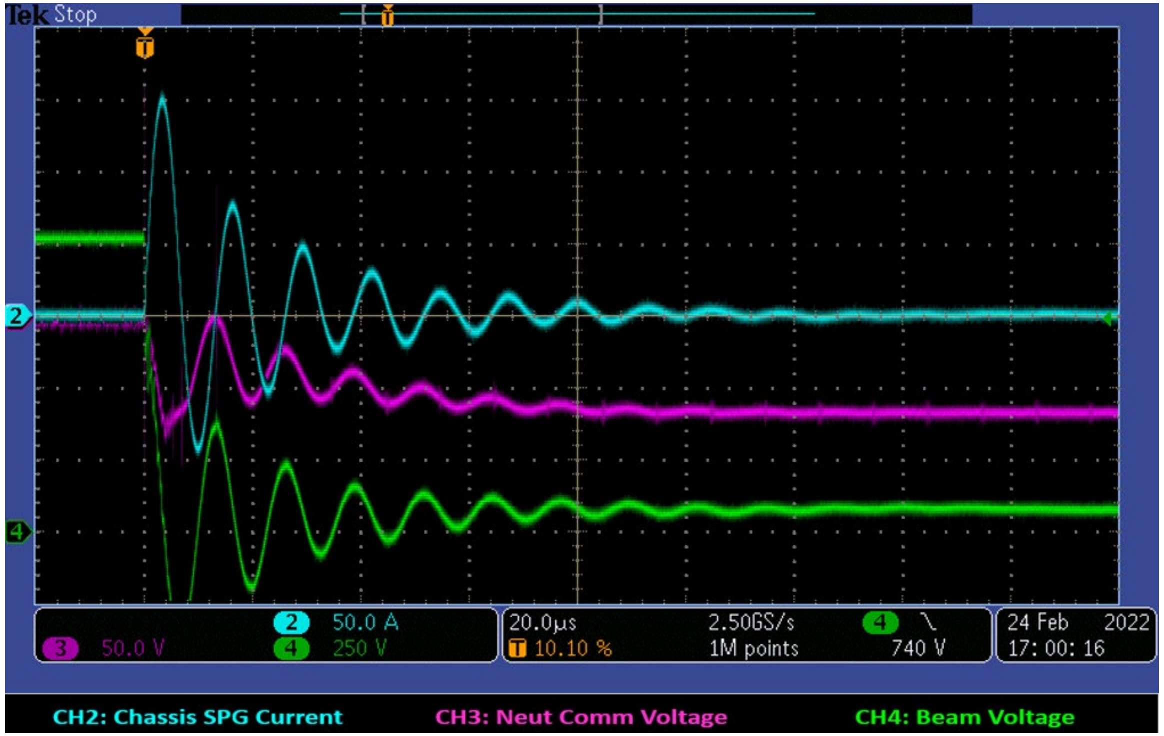


High thrust-to-power conditions

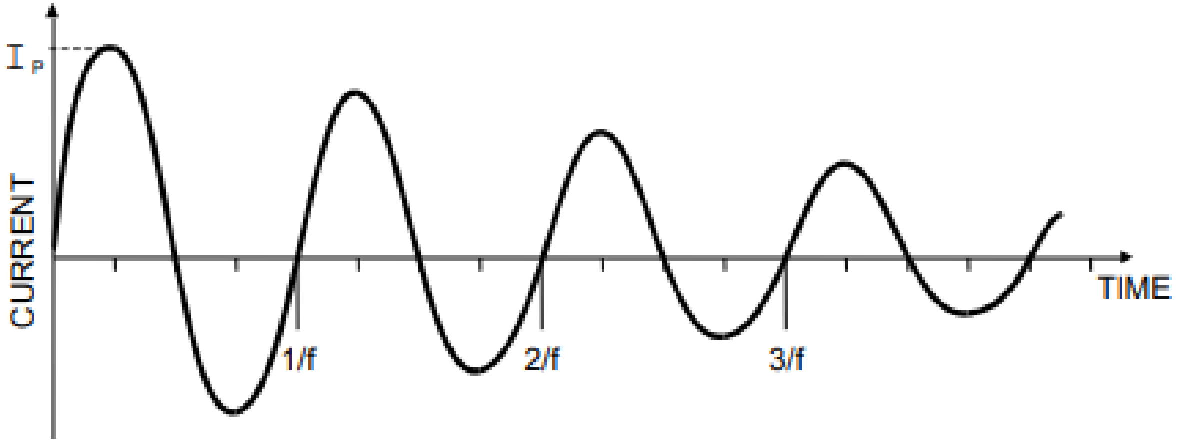
CONDUCTED SUSCEPTIBILITY TESTING

- NEXT-C team recommends that missions perform conducted susceptibility testing per CS116 per MIL-STD-461G
  - CS116 test was able replicate in-flight anomaly on spare ground test DART hardware

NEXT-C PPU current waveforms on a resistive load



CS116 test waveform (MIL-STD-461G)



SUMMARY

- Test conducted on engineering model Advanced NEXT thruster to characterize arcing behavior

- Test results indicate 4-30% of the total arcs are initiated due to a breakdown between high voltage and chassis

- Chassis currents of 25-70 A were measured across all operating conditions
  - only 10-20% of the return current was measured at chassis, the rest went through the neutralizer cathode
    - this is likely a ground facility effect, that could differ on a spacecraft

- NEXT-C team recommends that missions perform conducted susceptibility testing per CS116 per MIL-STD-461G to characterize electrical response during recycle events