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Scroll Compressors for Mars Atmospheric Acquisition

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Revision 06

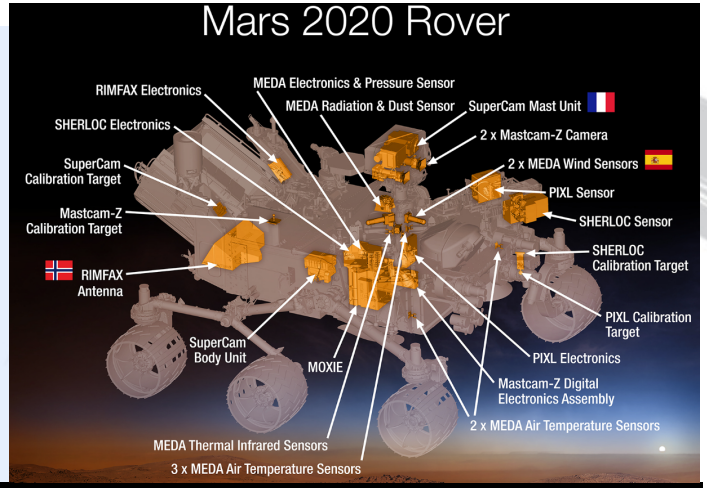
Air Squared Background

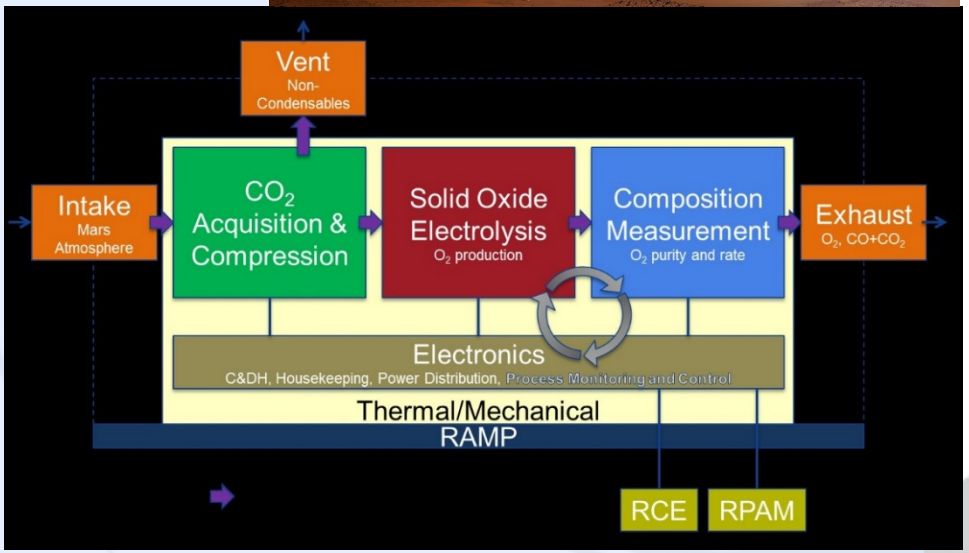
- Air Squared is a commercial scroll compressor company
  - Design custom solutions for
    - Medical
    - Aerospace
    - Fuel Cell
    - Energy Generation
- Had not ventured into the space business until a NASA SBIR came up that was a perfect fit
  - Mars Oxygen In Situ Experiment (MOXIE) focused on oxygen generation
    - Estimated to reduce the landed dry mass from 100 metric tons to 70 metric tons for a human mission

https://mars.nasa.gov/mars2020/mission/instruments/

MOXIE System

- CO2 Acquisition and Compression
- Intake
  - Brings in Martian atmosphere
  - 95% carbon dioxide
  - Filtered through HEPA filters
- Solid Oxide Electrolysis
  - 800°C temperature
  - Thermally isolated
- Composition Measurement
  - O2 exhaust
  - CO2/CO exhaust
- Other Components
  - Rover Avionics Mounting Panel
  - Electronics





https://mars.nasa.gov/mars2020/mission/instruments/moxie/for-scientists/

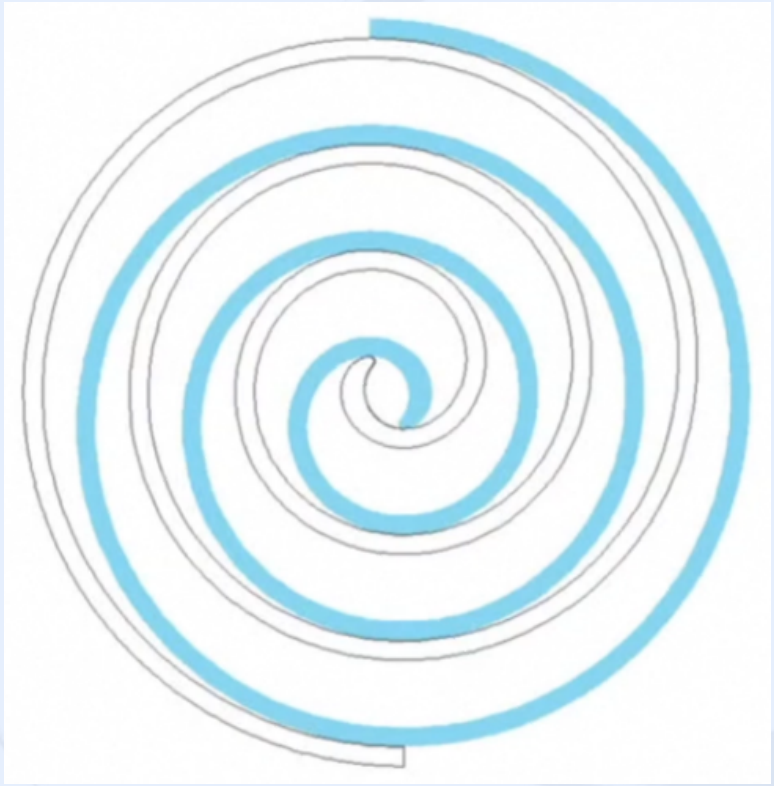
MOXIE System Requirements

- Inlet
  - 4 – 7 Torr
  - -45°C to +55°C
- Outlet
  - 540-760 Torr
  - Pressure varies with inlet density, speed
    - Viscous Flow Control Device (VFCD) sized based on mass flow
  - Minimum flow requirement of 60 g/hr, under worst case conditions
- Flight system compressor envelope
  - Limited by MOXIE box and SOXE stack
    - 150 mm length, 96 mm width, 175 mm height

Compressor Mechanical Requirements	
Dimensions [mm]	150 x 96 x 175
Mass [kg]	1.96
Compressor Performance Requirements	
Gas Inlet Pressure Range [Torr]	4 to 7
Gas Inlet Temperature Range [°C]	-45 to +55
Gas Outlet Pressure [Torr]	540 - 760
Mass Flow Rate Minimum [g/hr.]	60
Life [hrs.]	60

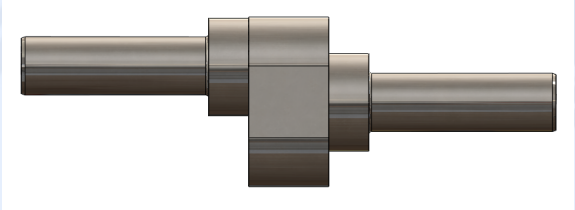
Why a Scroll Compressor?

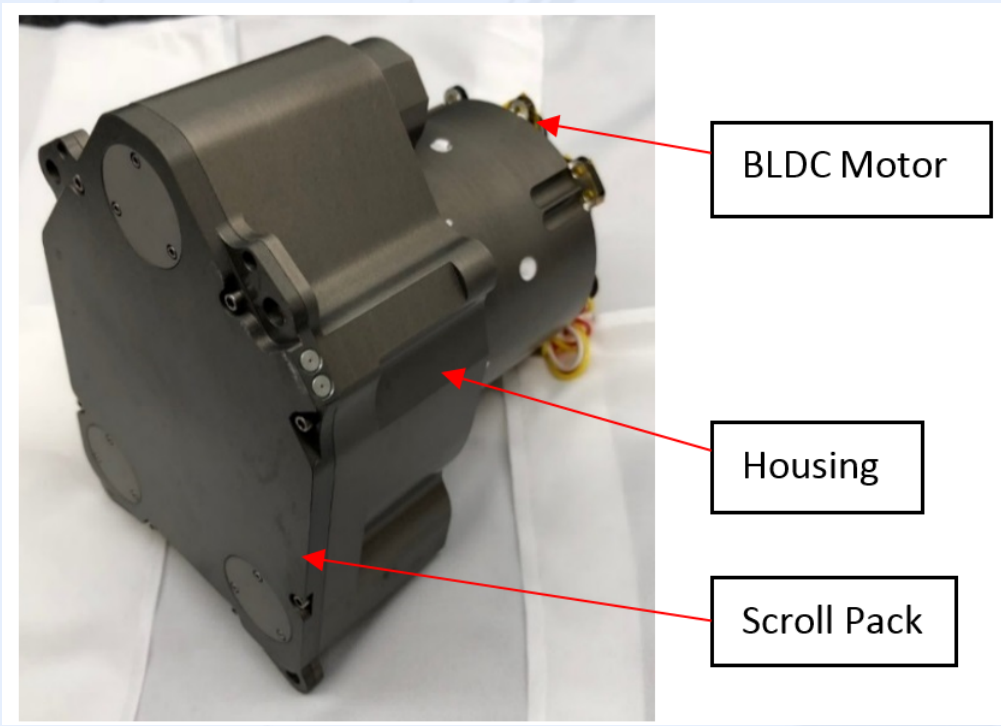
- Scroll compressor dates back to 1905 (Leon Crux)
  - Laid dormant for nearly 70 years due to tolerances
- Benefits of scroll compressors
  - Light weight
  - Low vibration
  - High efficiency
  - High reliability
  - Oil free



Main Components

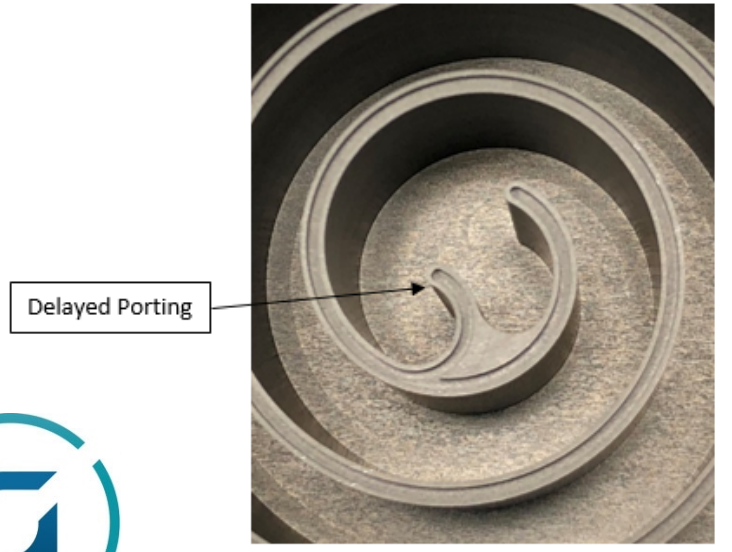
- Scroll Pack
  - Orbiting Scroll (1)
  - Fixed Scroll (1)
  - Idler Shafts (3)
- Housing
- Motor
- Crankshaft
- Bearings
- Tip Seals

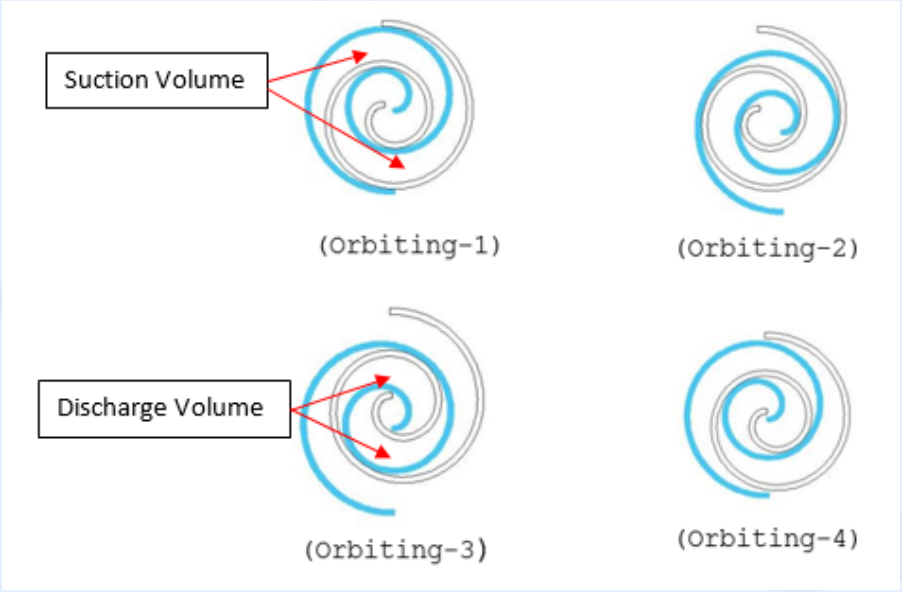




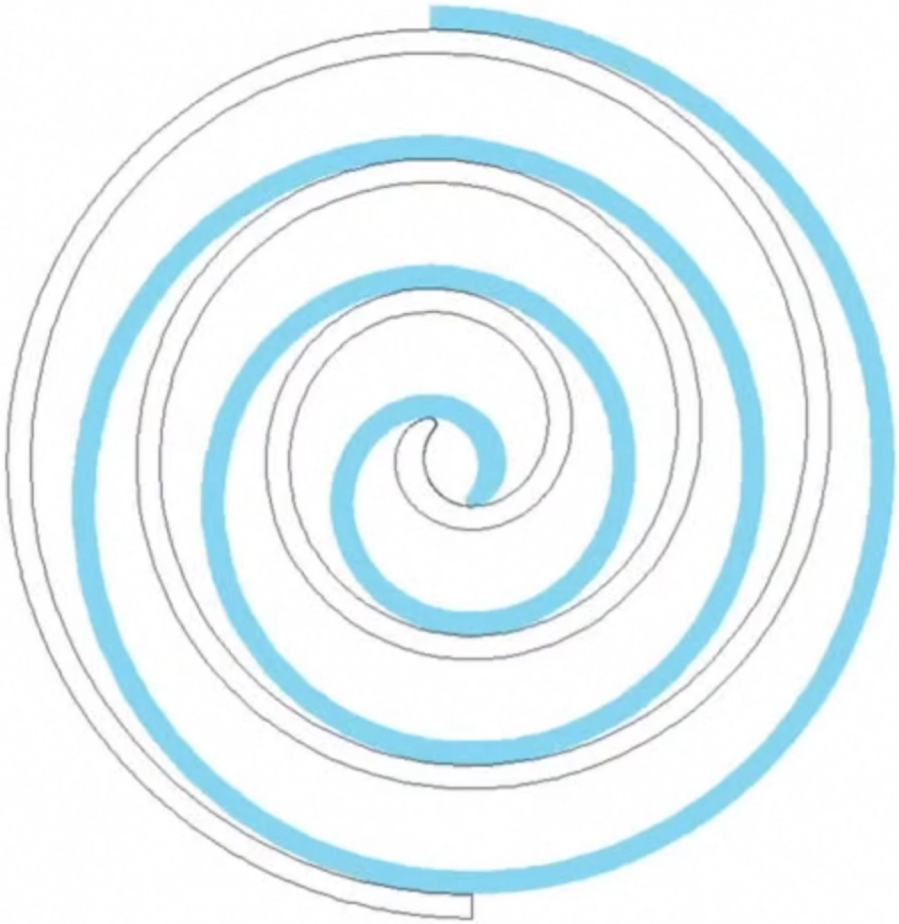
Scroll Geometry

- Two important characteristics of geometry
  - Suction volume
  - Volume ratio
- Patented delayed porting



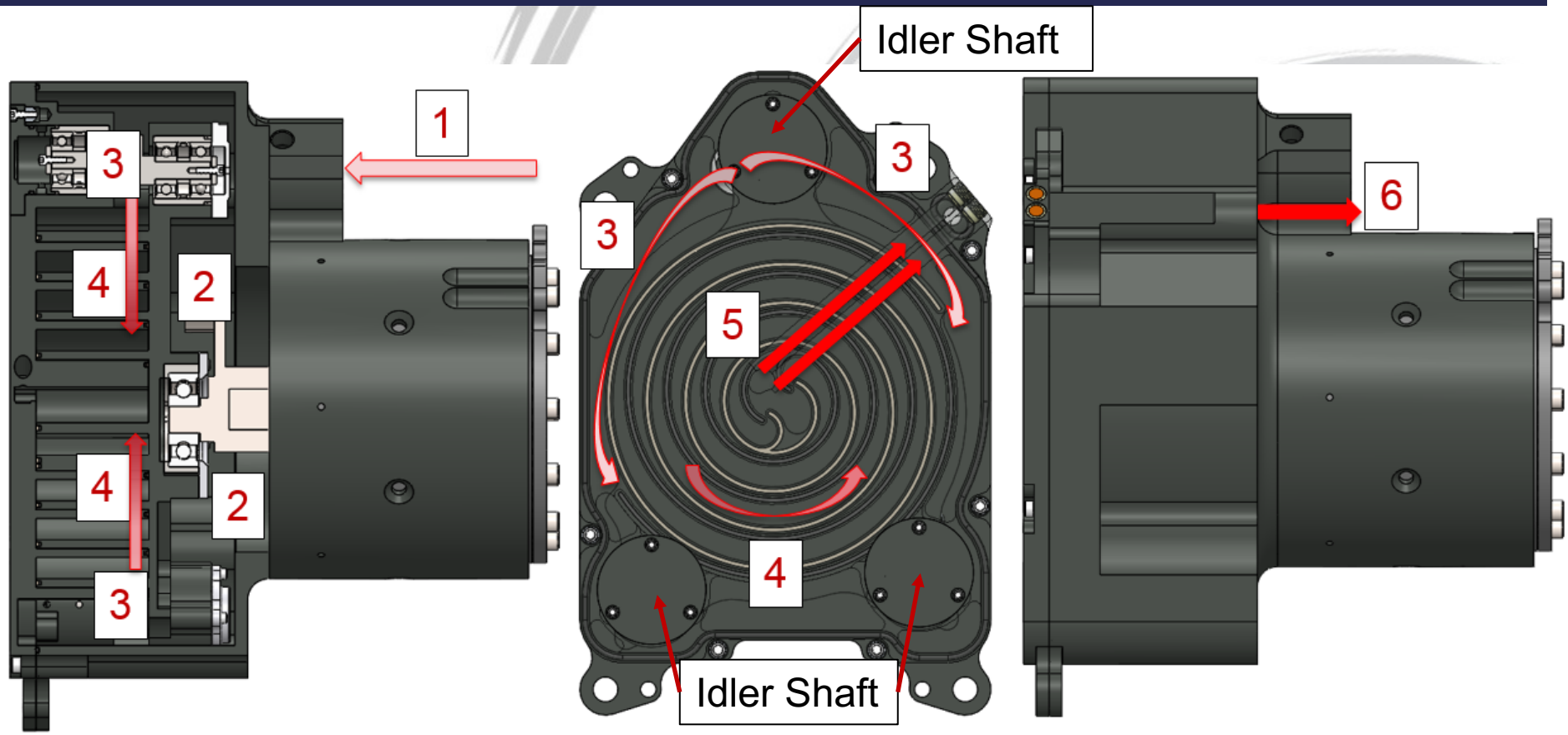


Scroll Involute Compression Process



https://www.youtube.com/watch?v=CXmFSb7TIhs

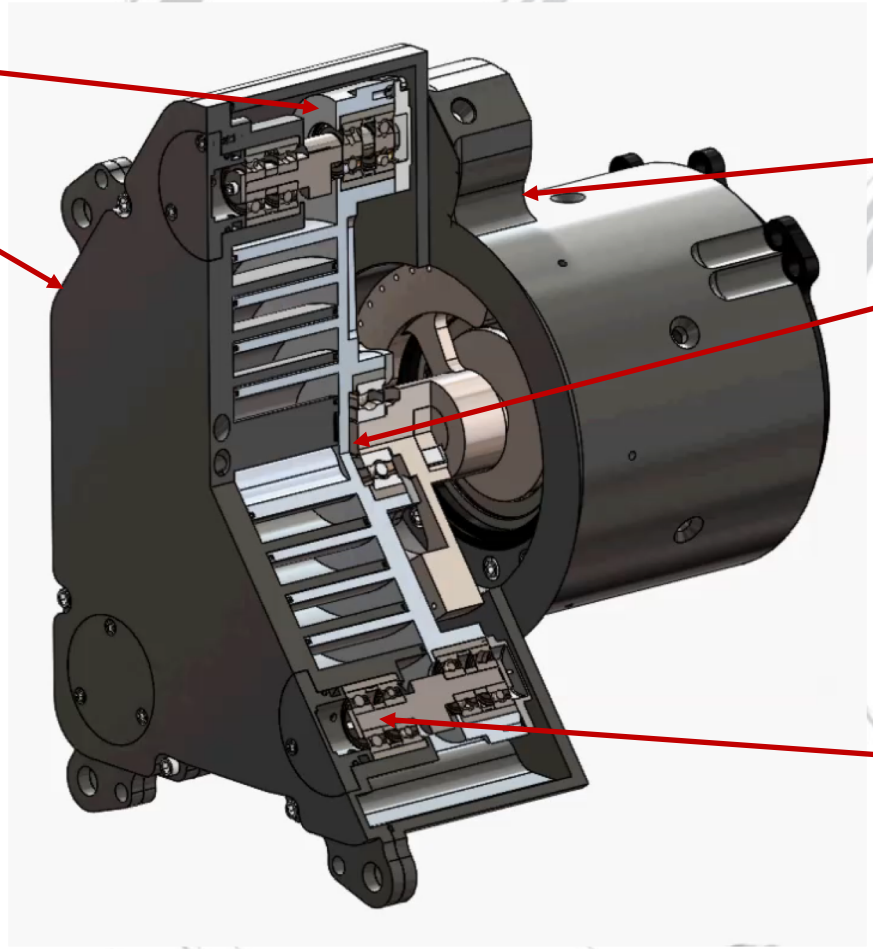
Scroll Compressor Working Principle



1. Inlet
   Fill housing with CO2
   CO2 enters scroll inlets locations
4. Single stage compression
5. Discharge through cross hole
6. Outlet flow

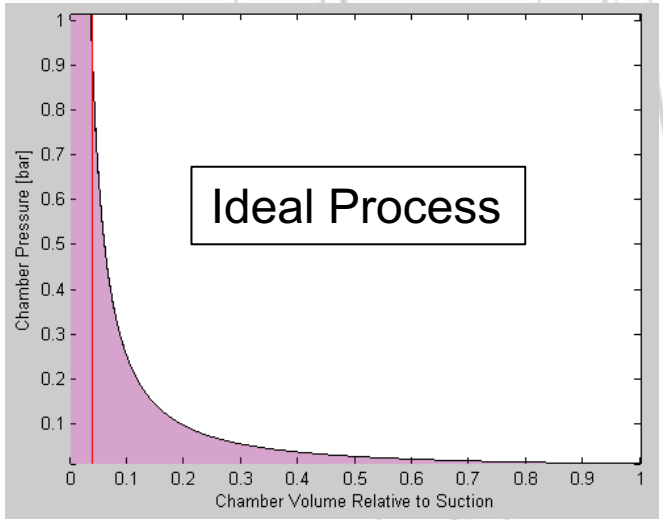
Scroll Compressor Operation

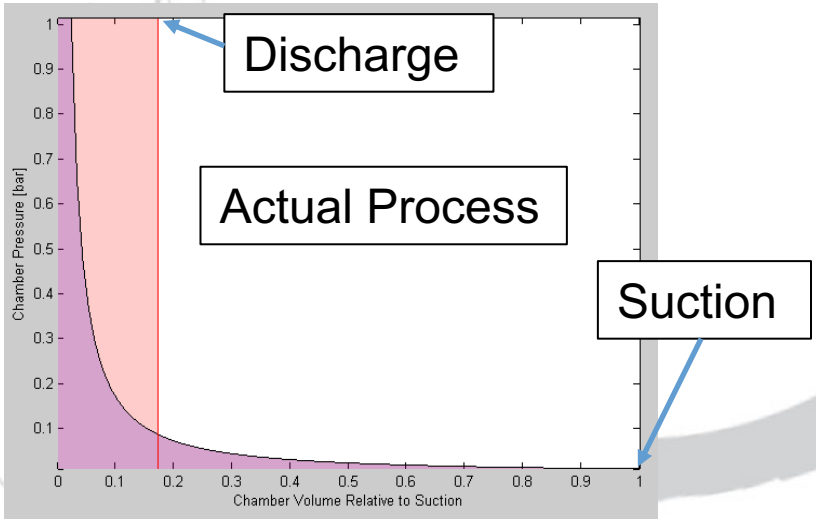
Working Principle - Isometric



Compression Process

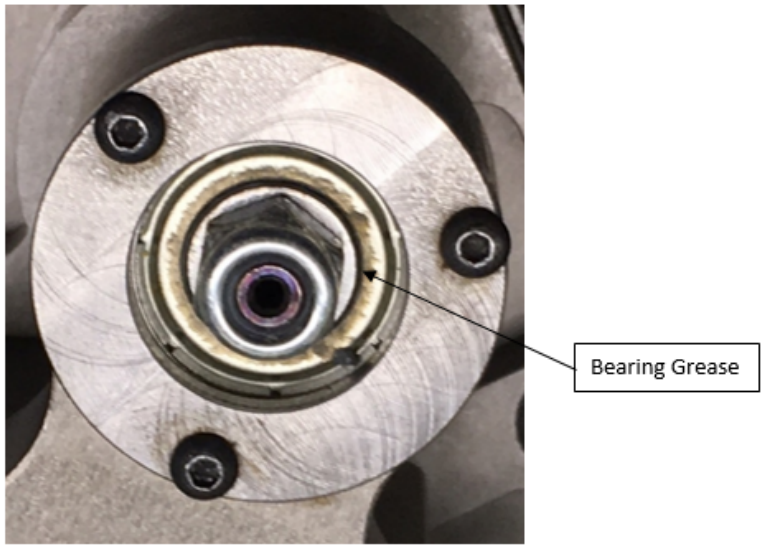
- Pressure volume curve shown below
  - Volume on x-axis
  - Pressure on the y-axis
- Suction process follows the x-axis
- Ideal compression process follows the purple curve
  - For an ideal compression process – Volume ratio is 44.2
- Pink area is off the ideal compression process





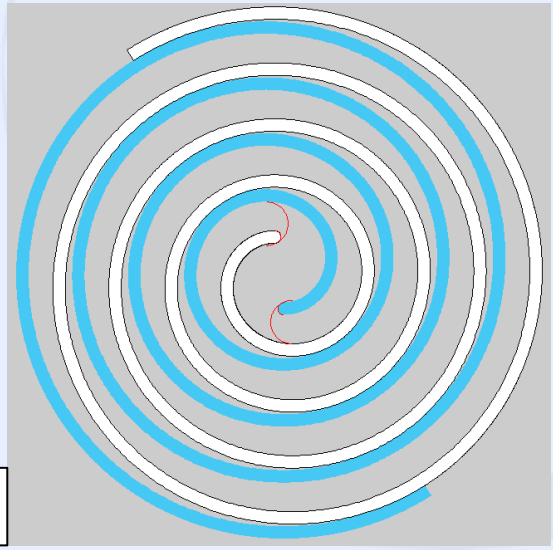
Issues Found with the Prototype

- Bearing grease seeping through the shields
  - Decomposition of grease will deactivate active sites on cathode
    - Estimate of 100 micrograms could destroy stack
- Grease seepage mainly due to pressure cycles
- Use of Krytox grease in the prototype was not preferred for the flight unit – JPL recommended Braycote
- Thermal expansion of scrolls
- Motor was not space rated



Flight Unit Development

- Flight unit development was heavily influenced by the prototype
  - Designed for launch loads – bearing loads
  - Increase operating temperature range – bearing fits
  - Motor vendor with flight heritage – motor design
- The reduction in width has significant impact on flow
  - 106 mm down to 96 mm
  - Prototype SV = 40.6 cc
  - Flight SV = 30.1 cc
- Had to increase height of involute
  - Increase risk for Air Squared



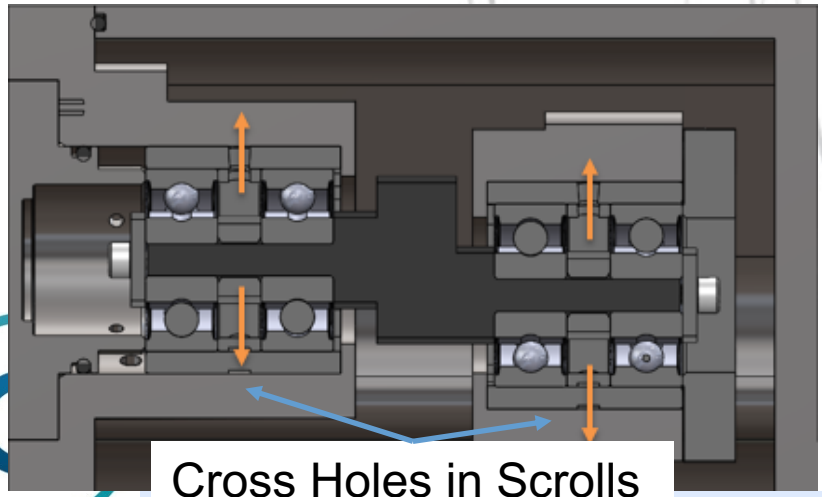
Flight Involute

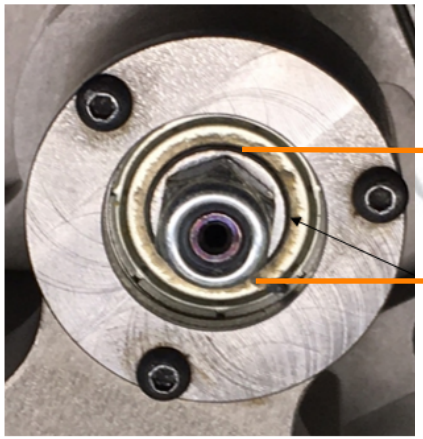
Bearing Fit Solution – Flight Unit

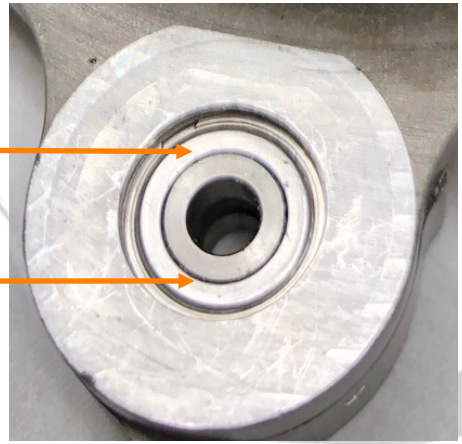
- Bearings were sleeved to prevent loss of press
  - Scrolls made of aluminum, bearings are 440c
- Machining of involutes is critical based on locations of idler bores
  - Roughed involutes and finished aluminum bores
  - Pressed roughed ID sleeve
  - Finish 440c sleeves and involute in the same operation
- Mask the bores for the anodize process

Grease Loss Solution – Flight Unit

- Prevented trapped pockets of gas from pulling through shields
  - Implemented bearing spacers to vent (left image)
- Solved the issue of bearing grease seepage
  - Left images (Prototype)
  - Right image (Flight Qualification Unit)
    - 391 hours
    - 14 pressure cycles

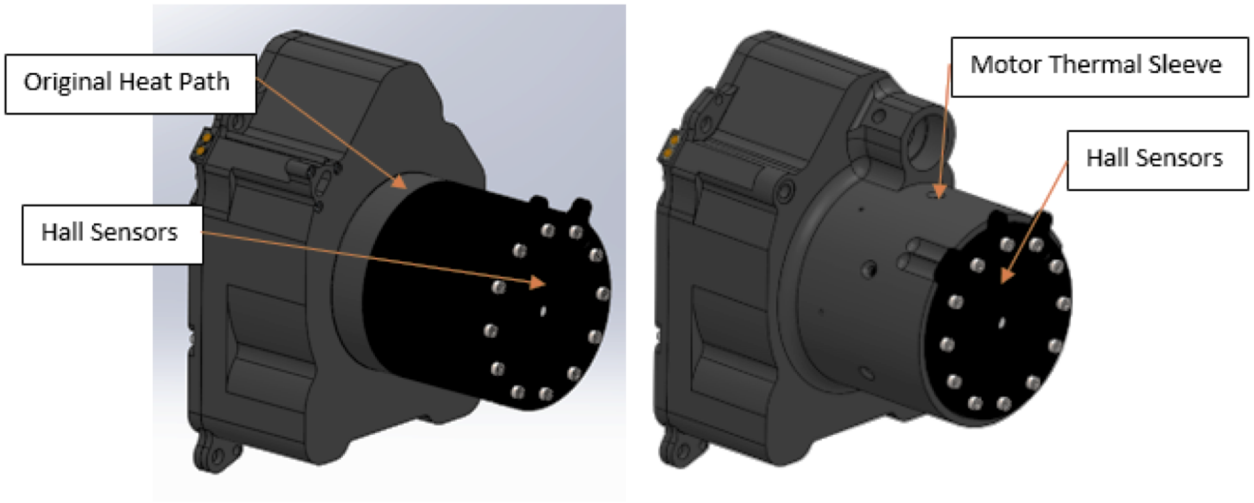






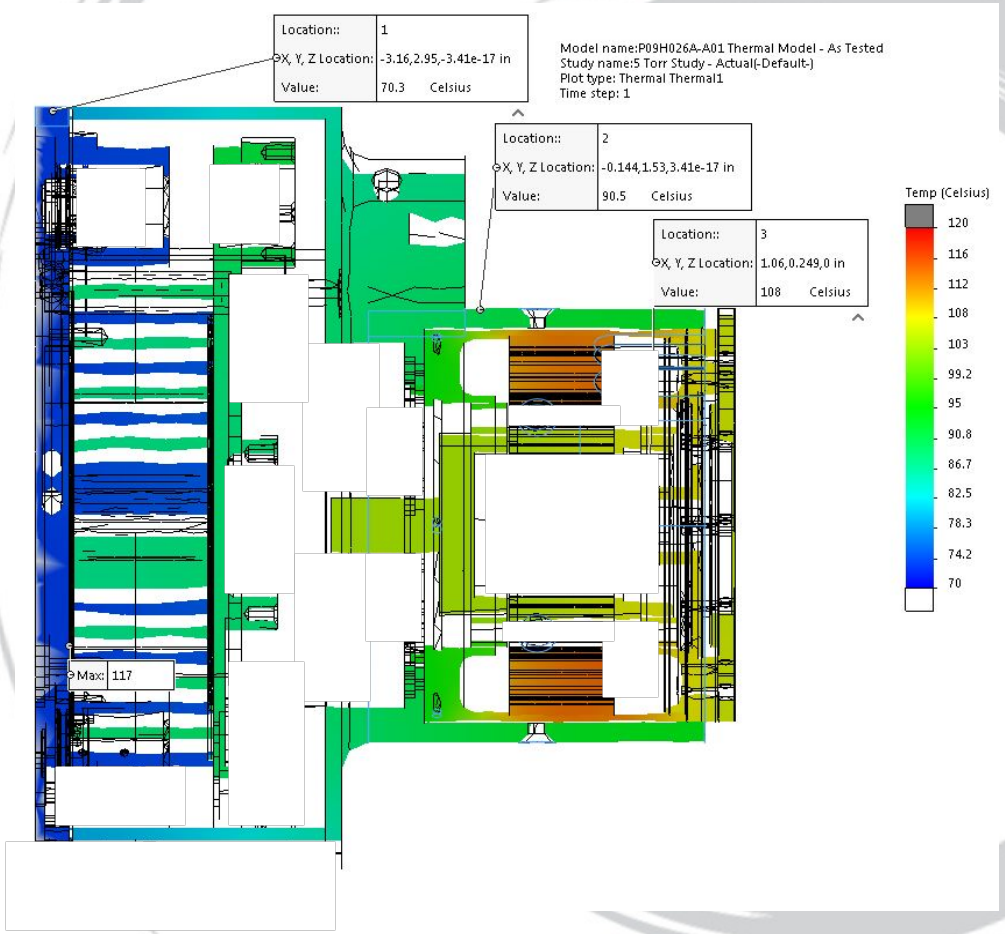
Motor and Thermal Performance

- Motor changed from prototype to flight unit
  - Needed a motor vendor with flight heritage
  - Went from frameless design to housed
  - Housed motor used stainless steel housing for CTE match
- Created issue for hall sensor temperature (De-rated to 105 C)
- After testing, had to redesign the housing – with JPL input
  - Aluminum extension to compressor housing
  - Removes heat from stator conducts to RAMP housing

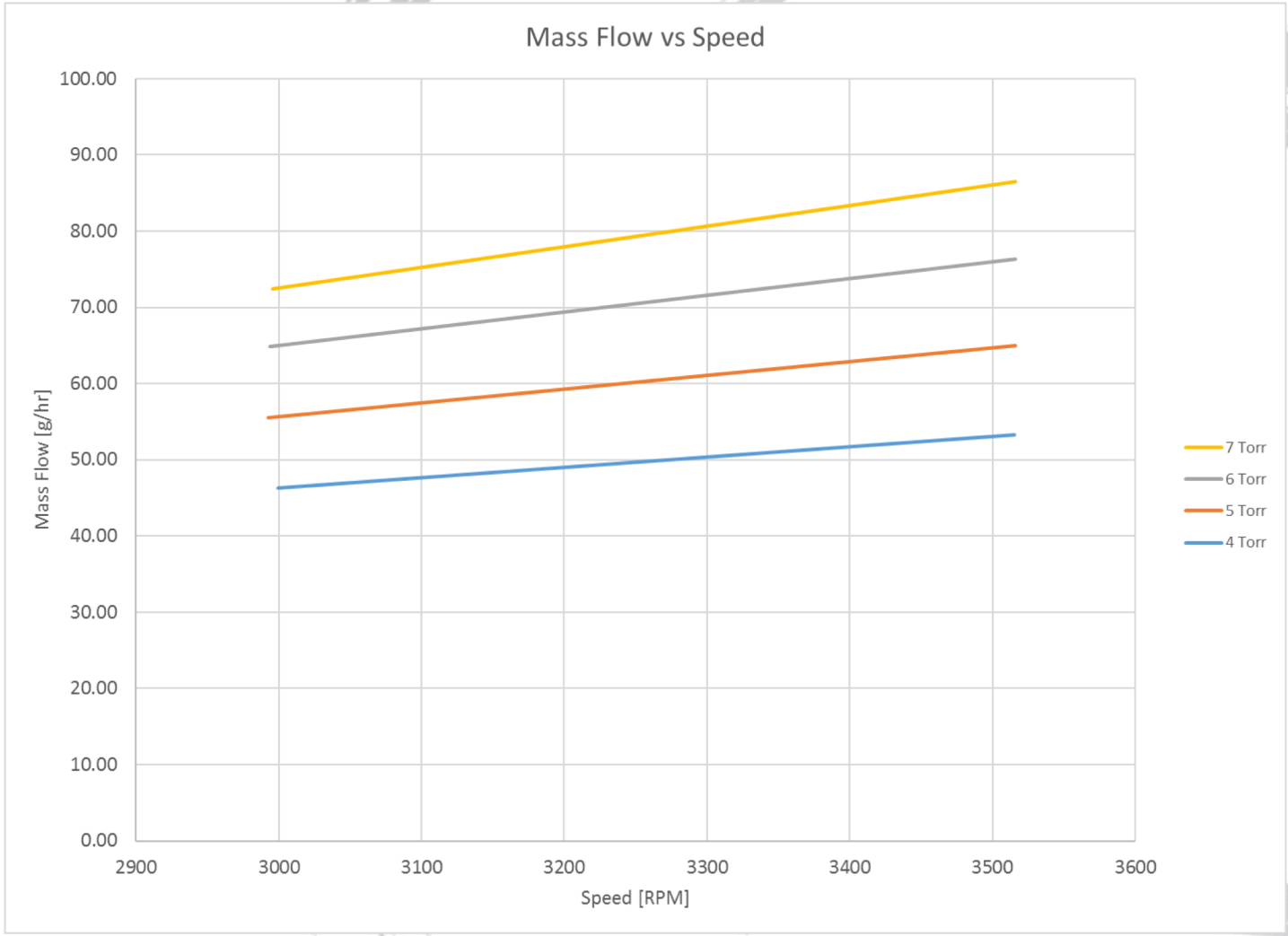


Thermal Model

- Assumptions made based on Spacecraft Thermal Control Handbook
- Temperatures verified during testing
  - Temperature stickers on orbiting scroll
- ~20°C delta from fixed to orbiting scroll
- ~35°C gradient from fixed scroll to back of motor (hall sensors) at nominal operating conditions

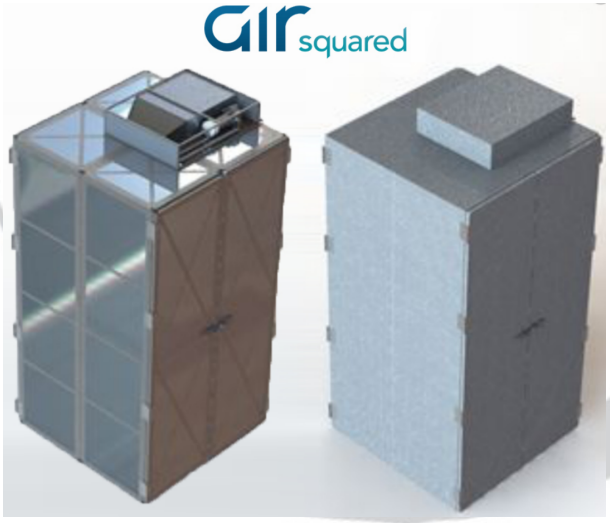


Flight Unit Varying Inlet Performance



Current Projects and Future Applications

- Larger scale compressors – human missions
  - 100x the flow rate of the MOXIE system
- Compressor for CO2 removal on spacecrafts
  - Capable of wide range of inlet and outlet pressures
    - 2 Torr inlet capability
    - 2-3 Bar outlet capability
- Cryogenic Pump
  - Propulsion systems
- Zero Gravity Refrigeration Systems



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