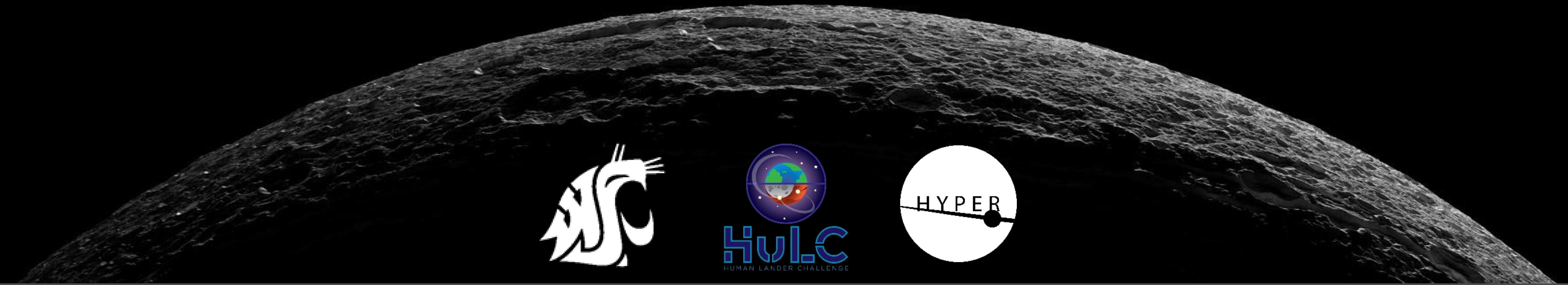
CYPRESS

CrYogenic Performance REfueling Safety System

Washington State University, HYPER Center

Professor Jacob Leachman

Alexis Williams, Reagan Dodge, Justin Godin, Kelson Peters, Adam Berg



OUR TEAM

Jacob Leachman
Professor: Mechanical Engineering
HYPER Center Director, Advisor

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Senior: Mechanical Engineering
Team Lead

Reagan Dodge
Senior: Mechanical Engineering
Heat Transfer Lead

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Magnet Lead

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Senior: Mechanical Engineering
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Senior: Mechanical Engineering
Communications Lead

PRESENTATION CONTENTS

01 Problem Statement

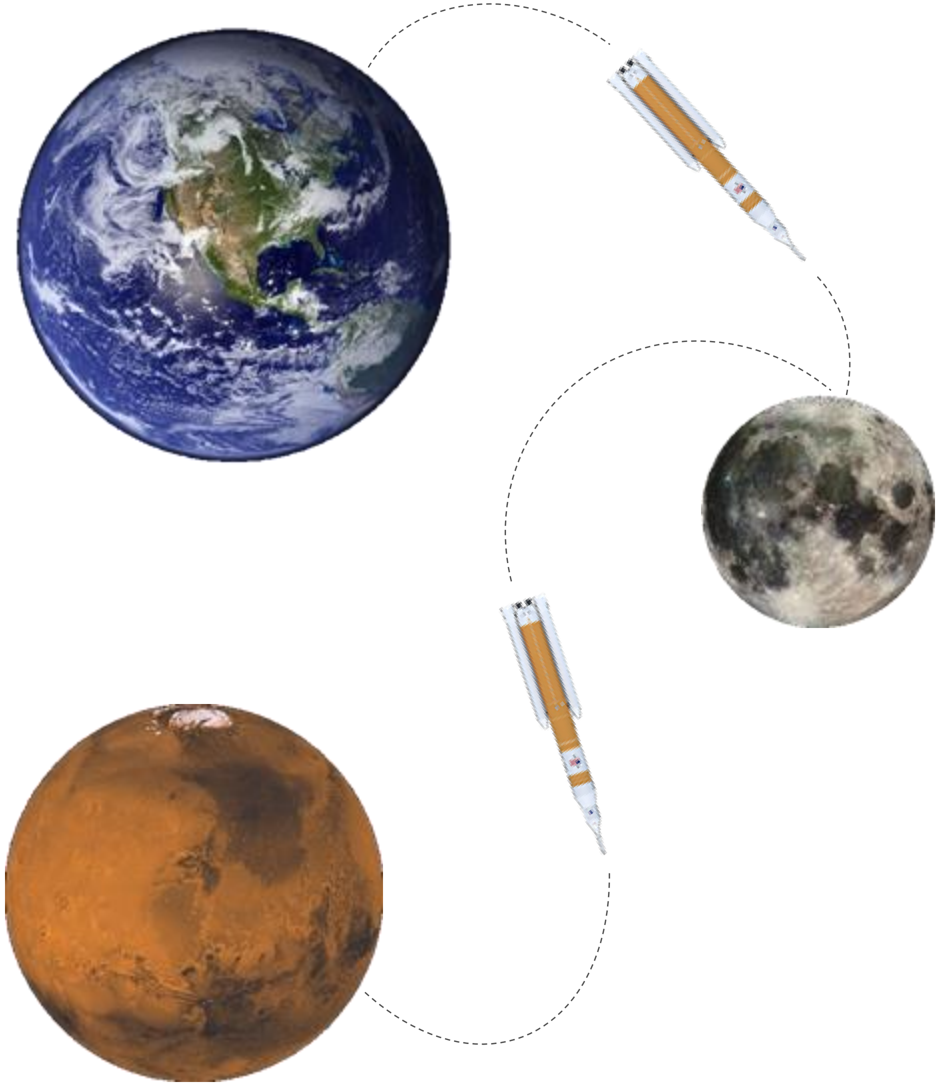
02 Design Review

03 Technology Validation

04 Development Plan

05 Conclusion

LH2 BACKGROUND



*Not to scale

Cryogenic fuel, specifically liquid hydrogen, is crucial to upcoming lunar missions and Mars exploration. LH2 is favorable for efficient propulsion due to high energy density and can be produced in-situ.

A standard boiling temperature of 20.3 K limits material selection and introduces unique challenges to LH2 fluid management systems.

Autonomous cryogenic transfer couplers for use in terrestrial, lunar, cis-lunar environments enable Artemis mission directives and pave the way for long term human travel.

Current couplers are heavy, expensive, and unreliable. Excessive amounts of fluid leak and cryogen boiloff inhibit transfer and introduce safety concerns.

PRIMARY CONSIDERATIONS

Weight
< 10 lbs

Automation & Integration

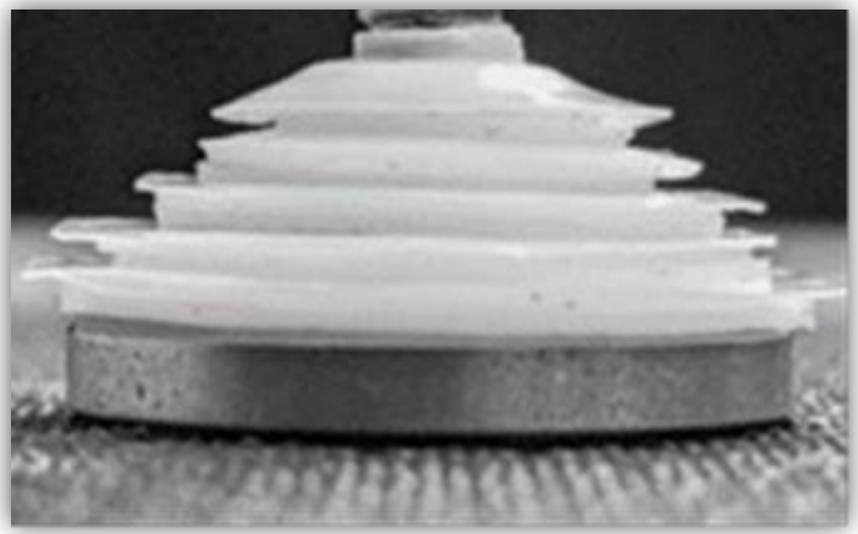
Production Cost
< $25,000

Heat Ingress & Ice Formation
< 9 W

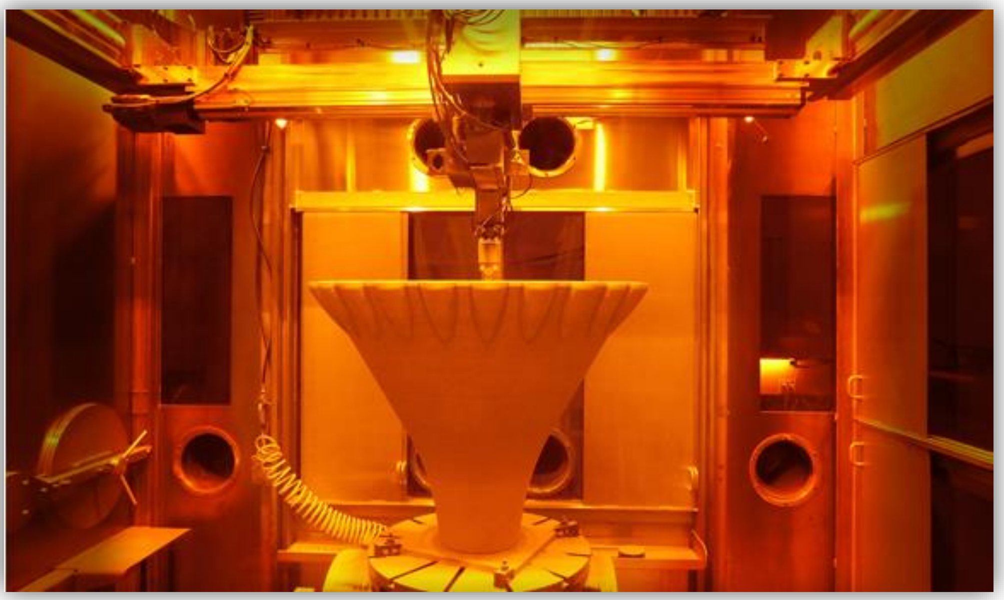
Fluid Leakage
< 0.15 sccm

Cryogenic Sealing

- Multi-layer PTFE seals remain flexible at 20 K
- Previous testing in PRVs supports FOD resistance and decreased leakage than COTS valves



Previously demonstrated seal

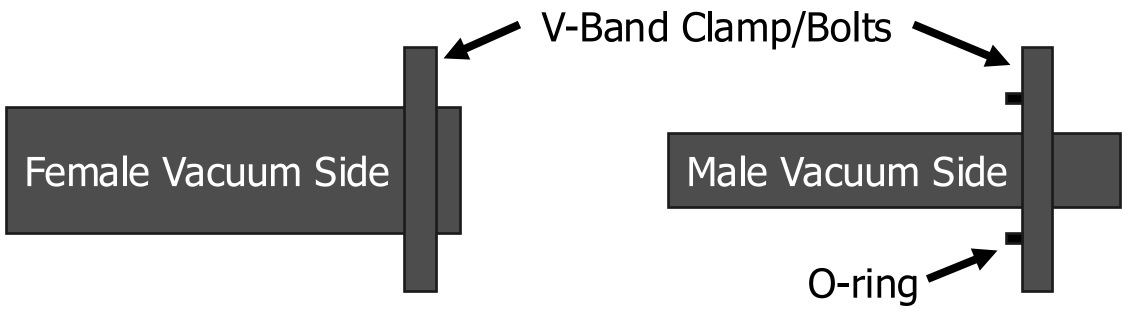


LPDED process

Additive Manufacturing

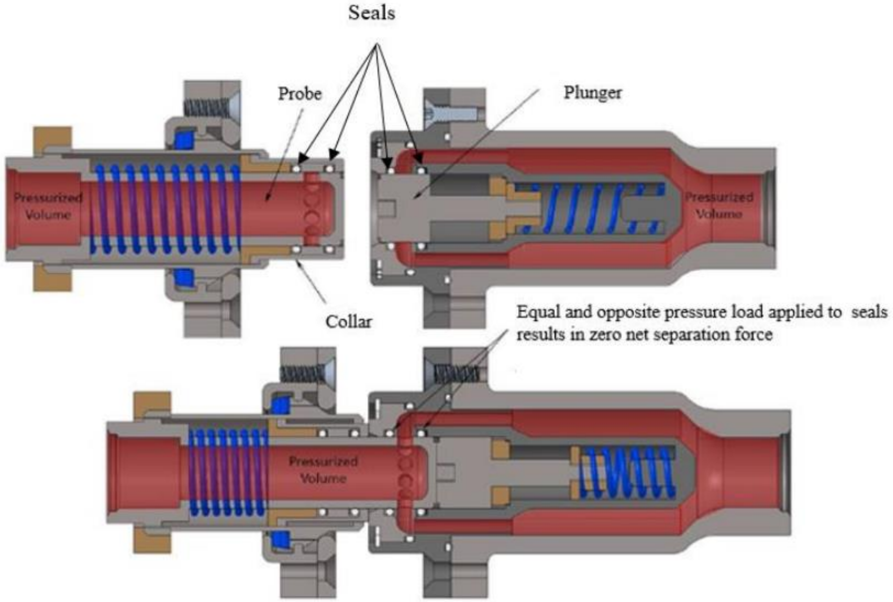
- Al6061-RAM2 alloy manufactured via LPDED
- Complex geometries at lower costs
- Thermal conductivity like SS316 at 20 K
- 1/3 density of SS316 for weight and component cool-down savings

PRESENTATION CONTENTS



Traditional Bayonet Coupling

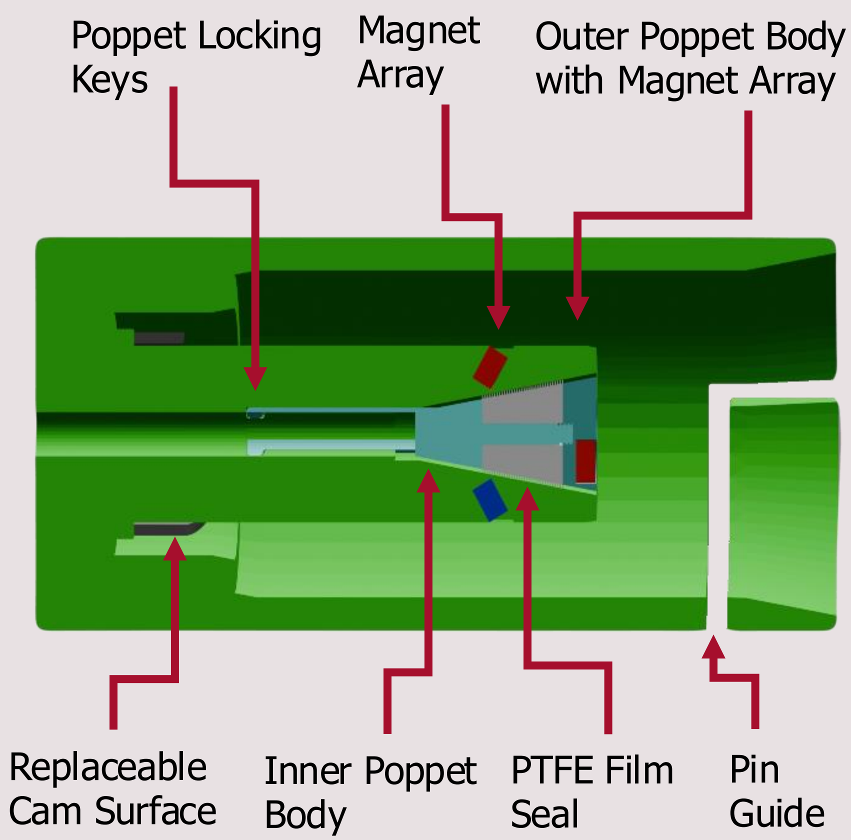
- Longer-term connection
- Requires purging of entire line
- Low heat ingress of 8.8 W at 10 in x 12 in
- O-ring at ambient conditions
- Vacuum jacketing



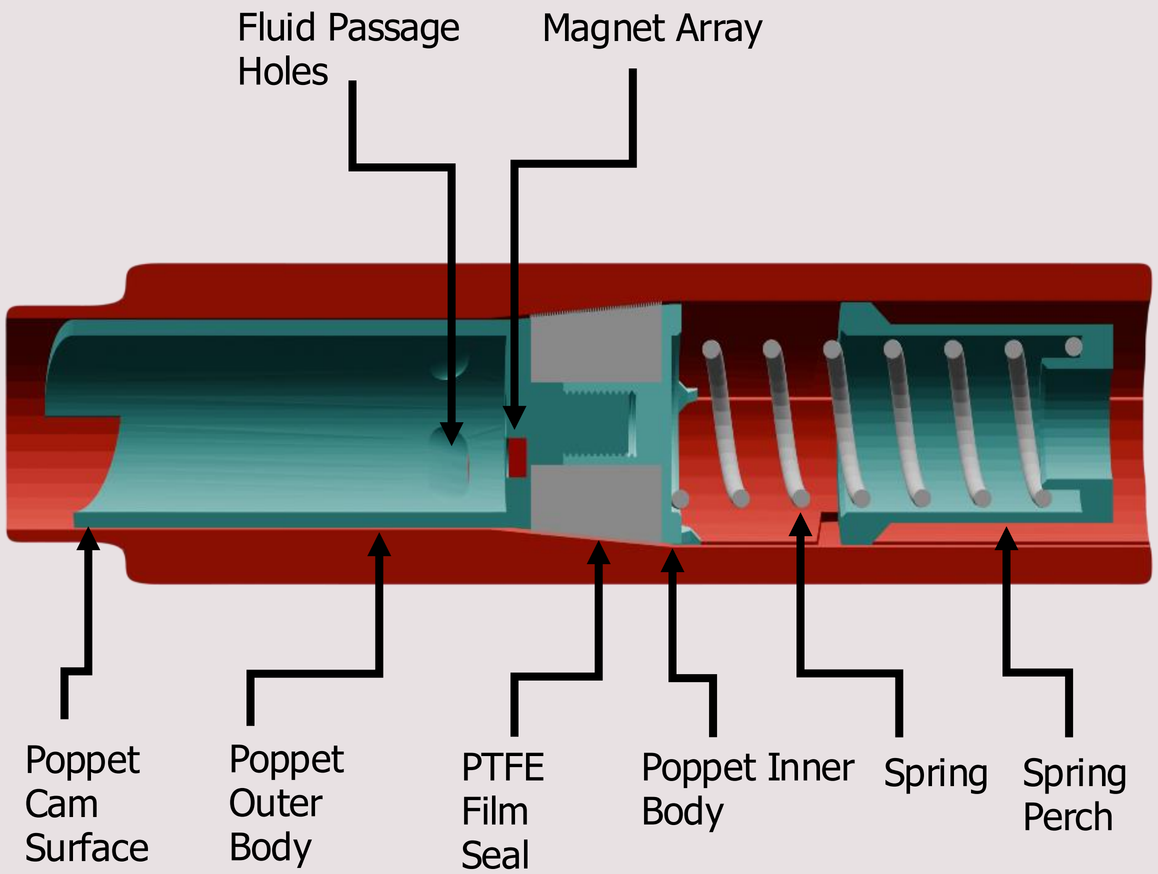
NASA CryoMag

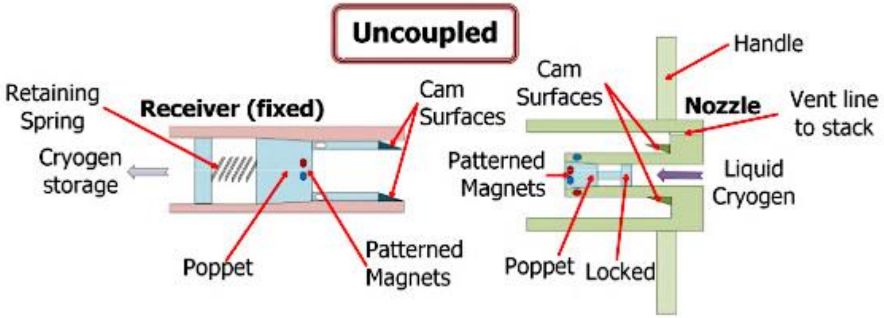
- Magnetic alignment with Low Force Disconnect Coupler
- Spring energized O-rings
- No insulation

Nozzle

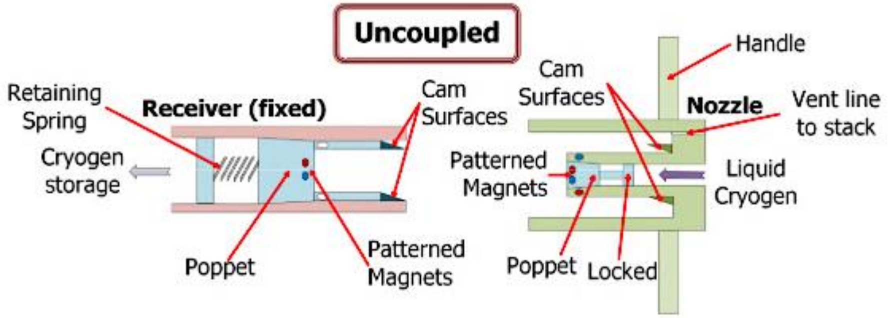


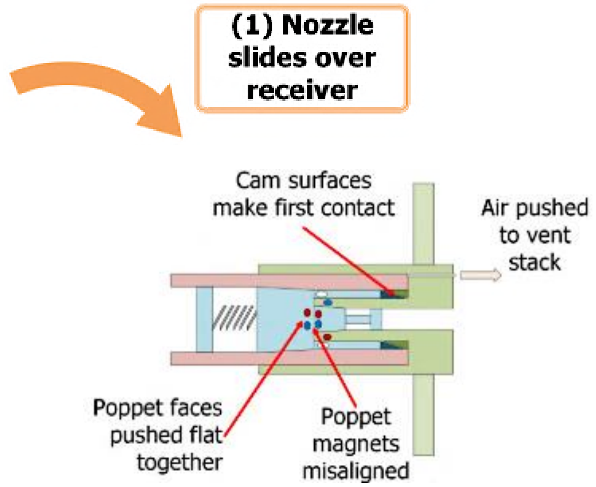
Receiver





Sequential Coupler Actuation





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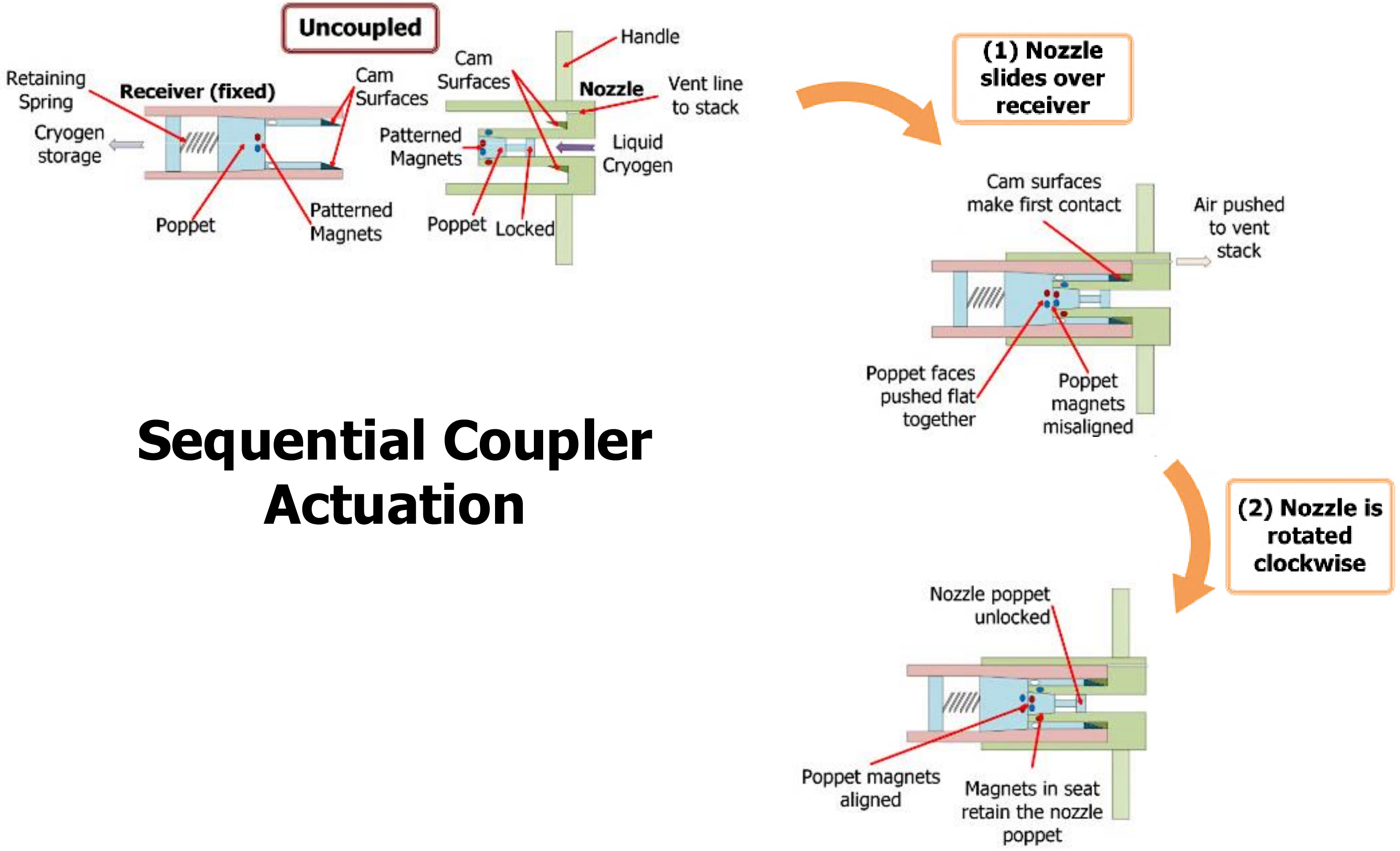

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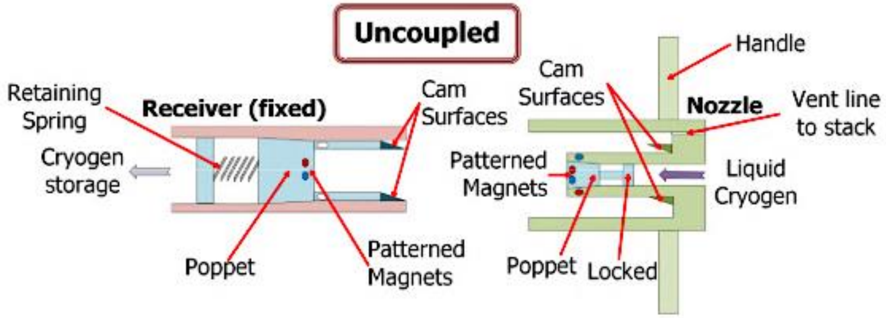

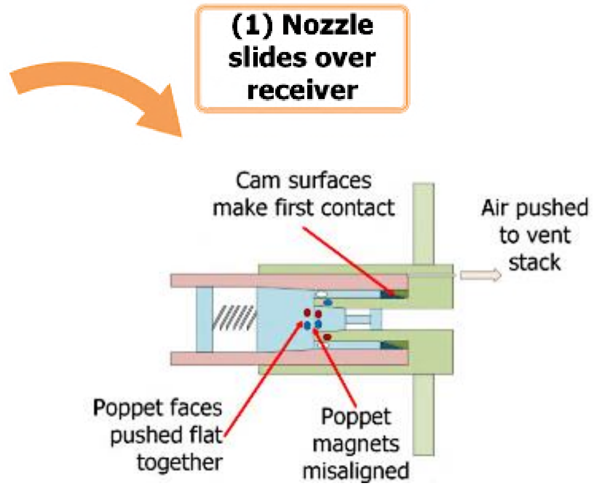

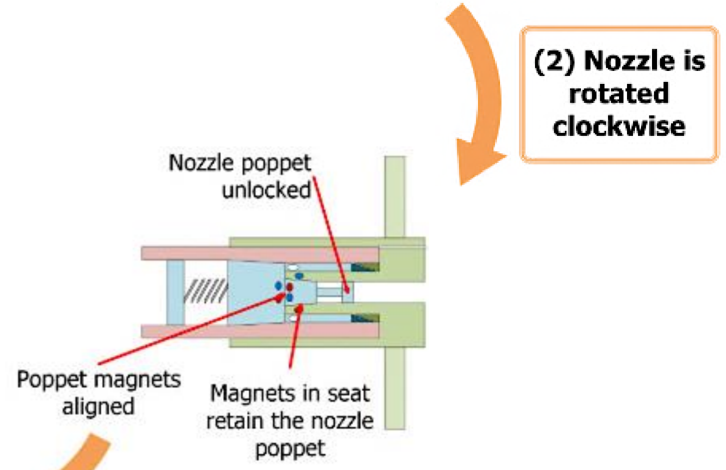

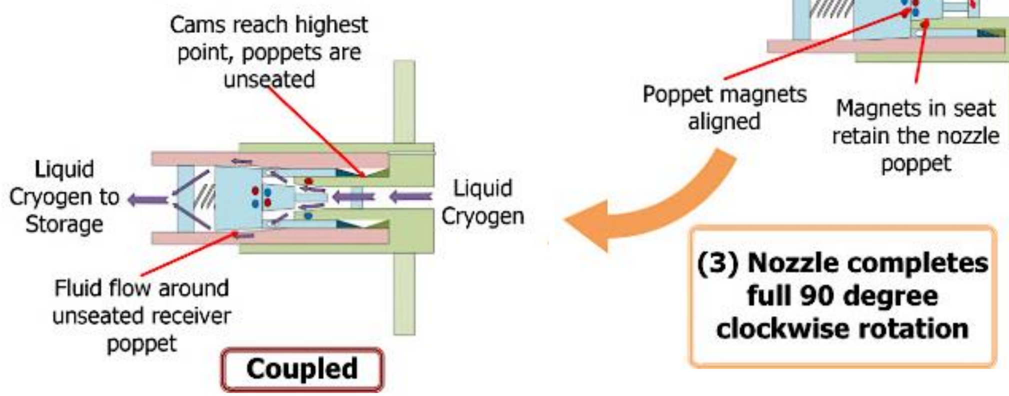

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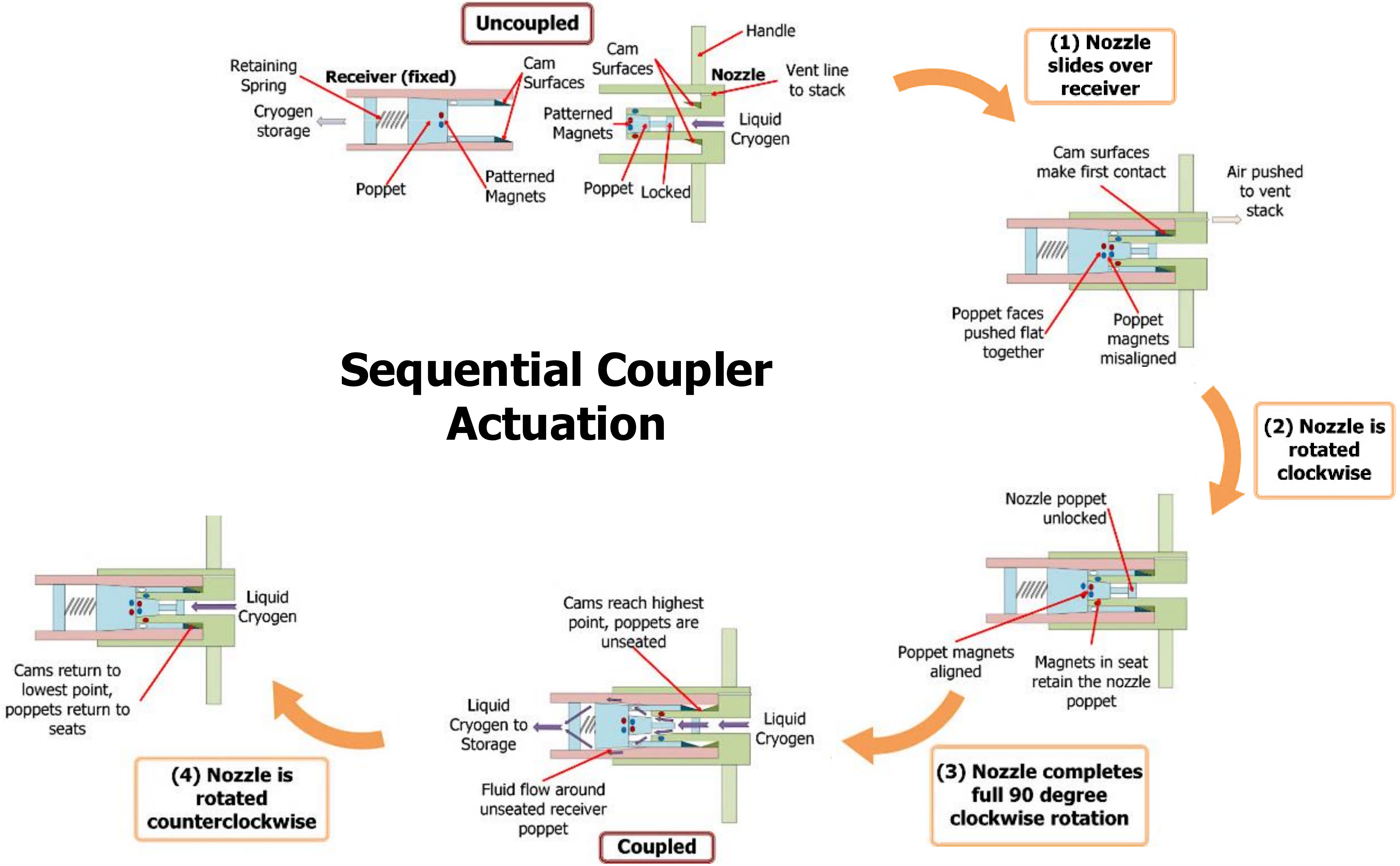

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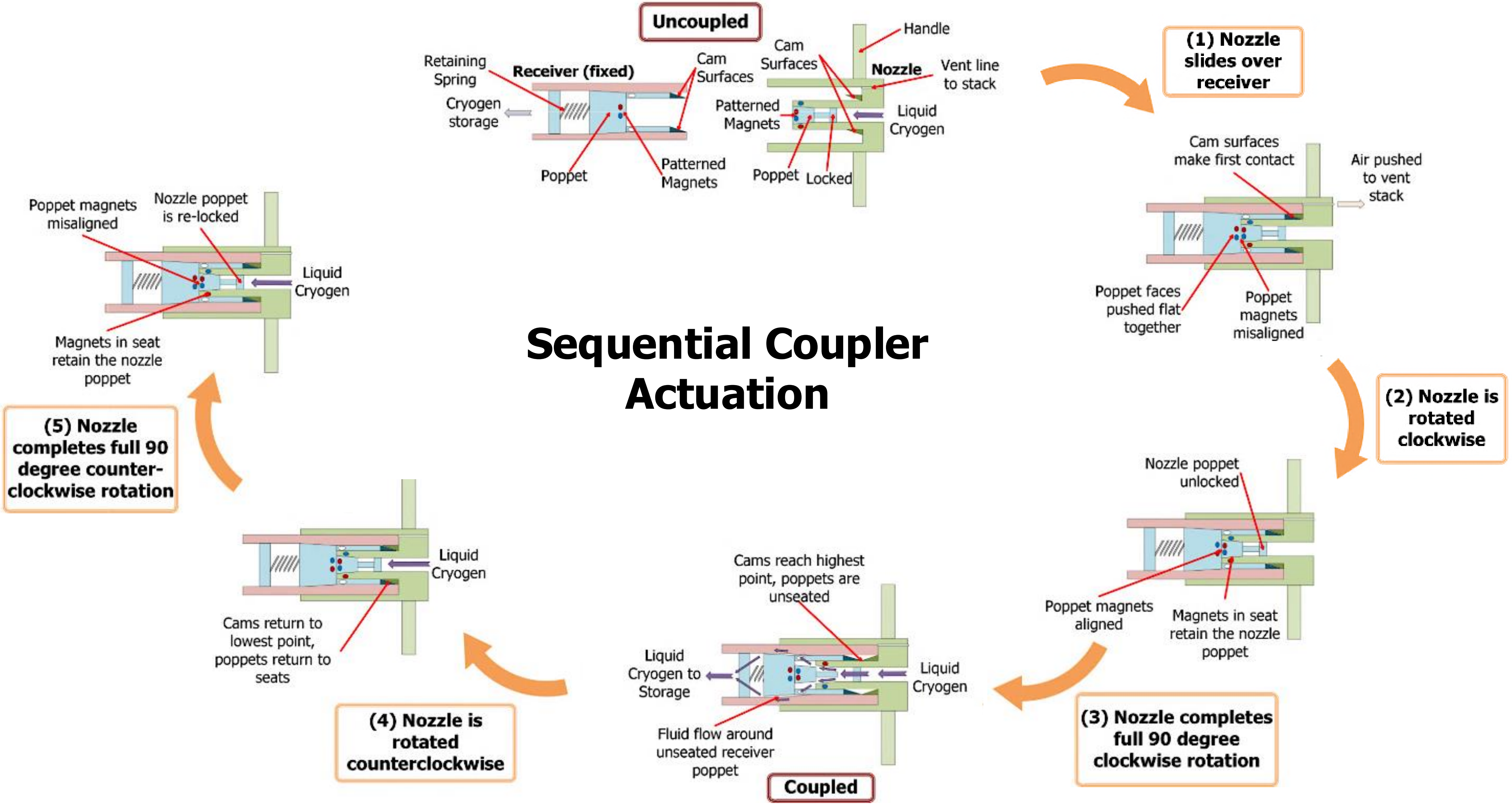
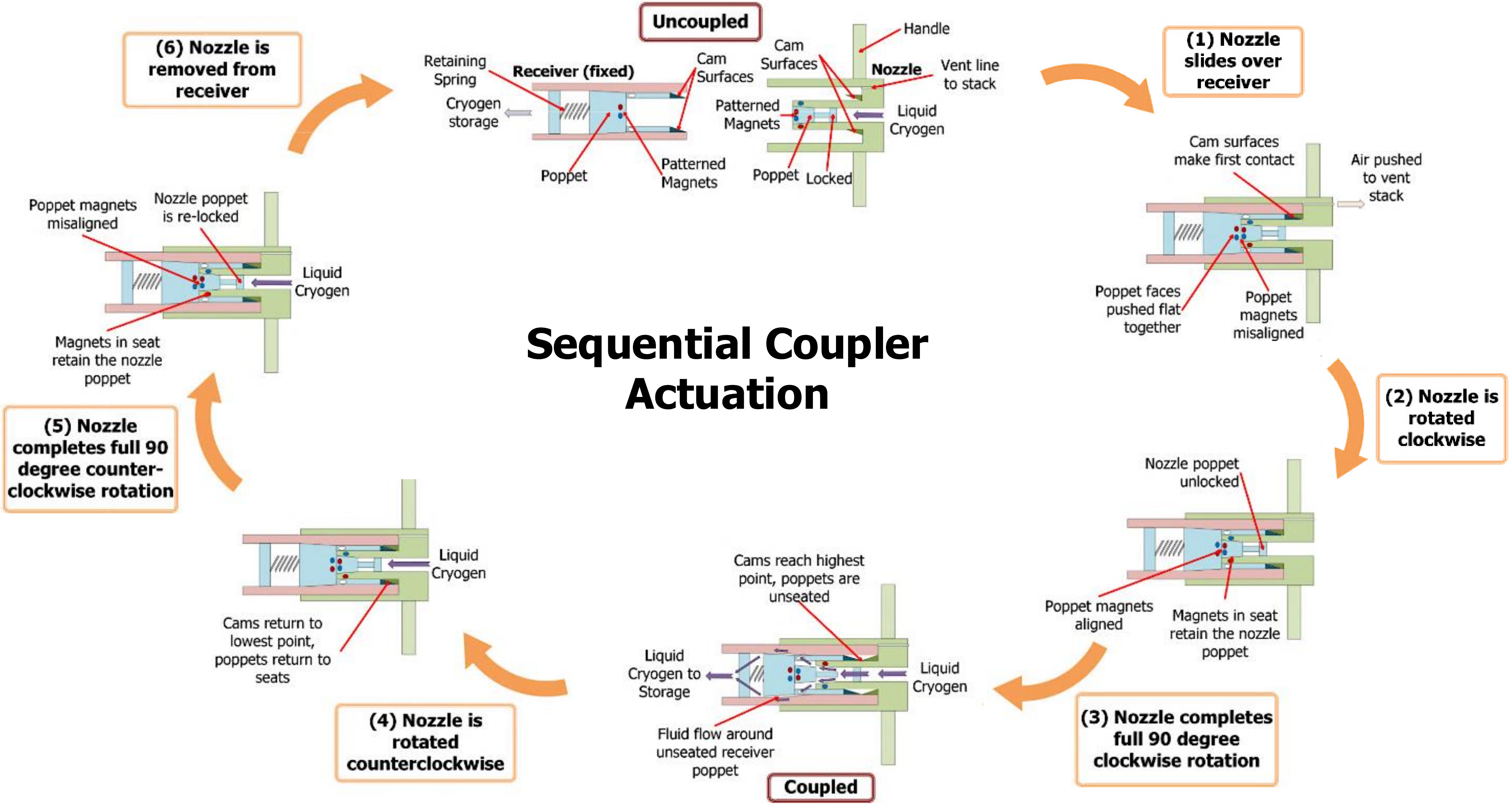



Sequential Coupler Actuation
Uncoupled
Retaining Spring
Receiver (fixed)
Cam Surfaces
Cryogen storage
Poppet
Patterned Magnets
Handle
Cam Surfaces
Nozzle
Vent line to stack
Patterned Magnets
Liquid Cryogen
Poppet
Locked
(1) Nozzle slides over receiver
Cam surfaces make first contact
Air pushed to vent stack
Poppet faces pushed flat together
Poppet magnets misaligned
(2) Nozzle is rotated clockwise
Nozzle poppet unlocked
Poppet magnets aligned
Magnets in seat retain the nozzle poppet
(3) Nozzle completes full 90 degree clockwise rotation
Cams reach highest point, poppets are unseated
Liquid Cryogen to Storage
Liquid Cryogen
Fluid flow around unseated receiver poppet
Coupled
(4) Nozzle is rotated counterclockwise
Liquid Cryogen
Cams return to lowest point, poppets return to seats
(5) Nozzle completes full 90 degree counter-clockwise rotation
Poppet magnets misaligned
Nozzle poppet is re-locked
Liquid Cryogen
Magnets in seat retain the nozzle poppet
(6) Nozzle is removed from receiver

Motions required for full actuation

- Linear extension/retraction to connect
- Rotation of Nozzle to open and close flow

Integration

- Can be built isolated from existing systems with a dedicated linear and rotary actuator
- May be integrated with existing docking systems for alignment and connection, negating the need of a dedicated linear actuator and support structure
- Coupler can open and close while docked

6DoF Test of the NDS

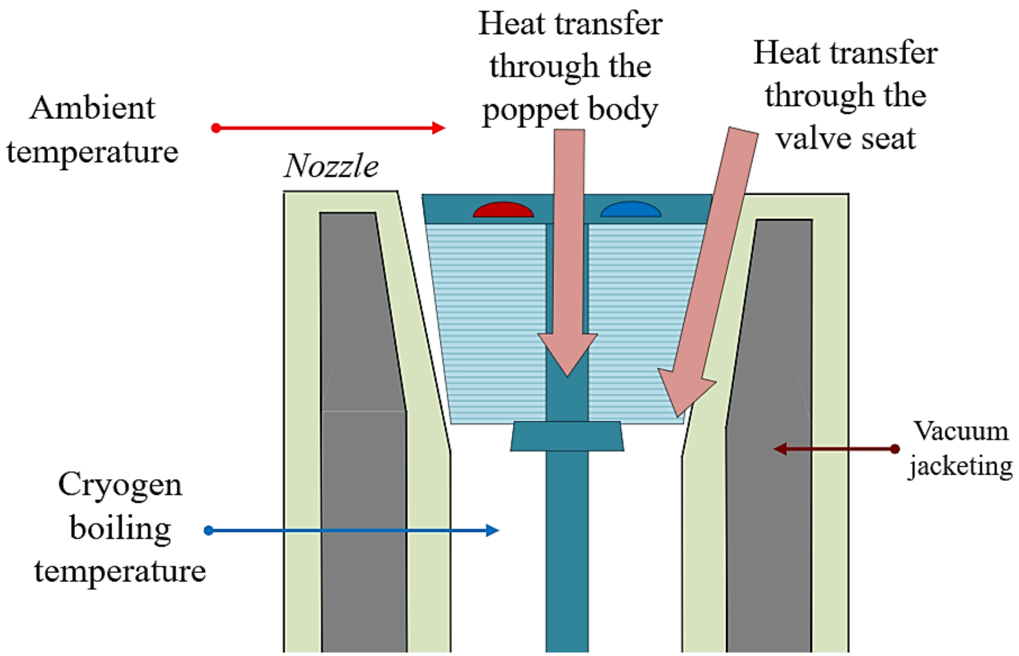
Icing Prevention

- Thermal standoffs and vacuum jacketing incorporated
- Shortest paths of heat transfer (shown below) were considered to determine dimensions of poppet and poppet seat

$$Q_{conv} = hA_{surface}\Delta T$$

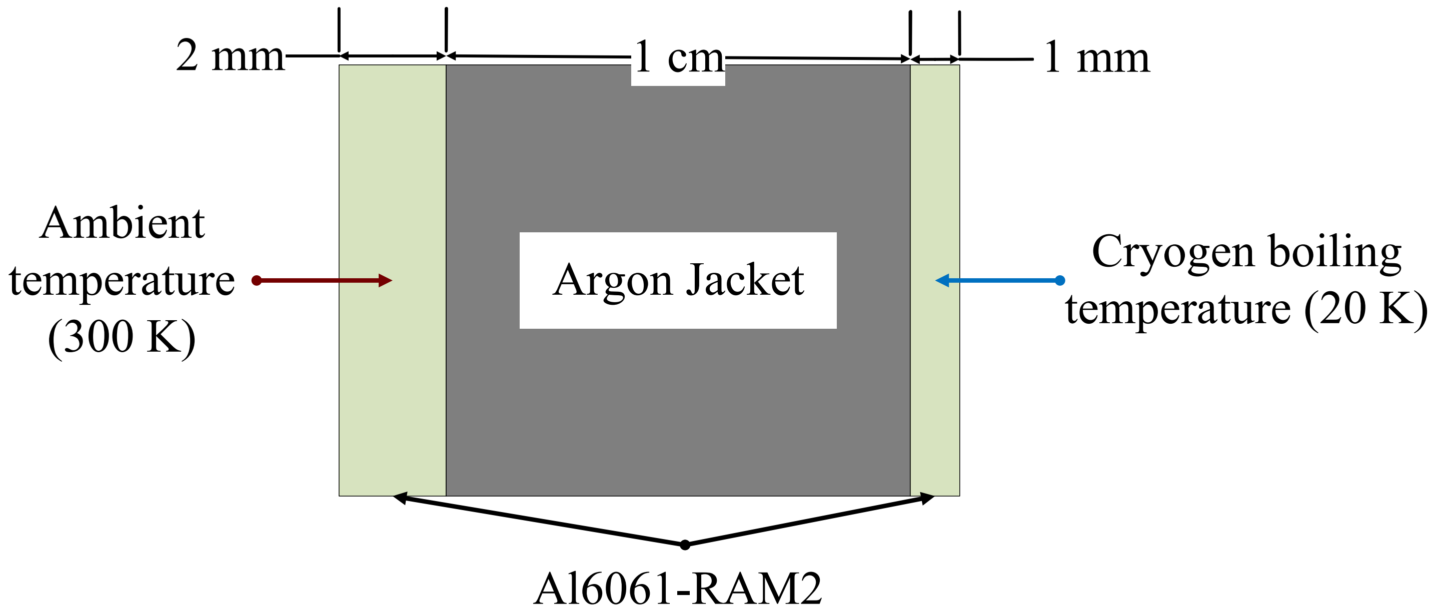
$$Q_{cond} = \frac{kA_{avg}\Delta T}{L}$$

$$Q_{conv} = Q_{cond}$$



Vacuum jacketing

- Voids in housing filled with argon during printing process
- Argon solidifies at 83.81 K, yielding a pressure lower than 10^{-5}Pa at 20 K
- Vacuum effective thermal conductivity of 10 mW/m-K
- Thermal resistance network (shown below) analyzed to determine heat leak of approximately 7.8 W per uncoupled



Opening Distance

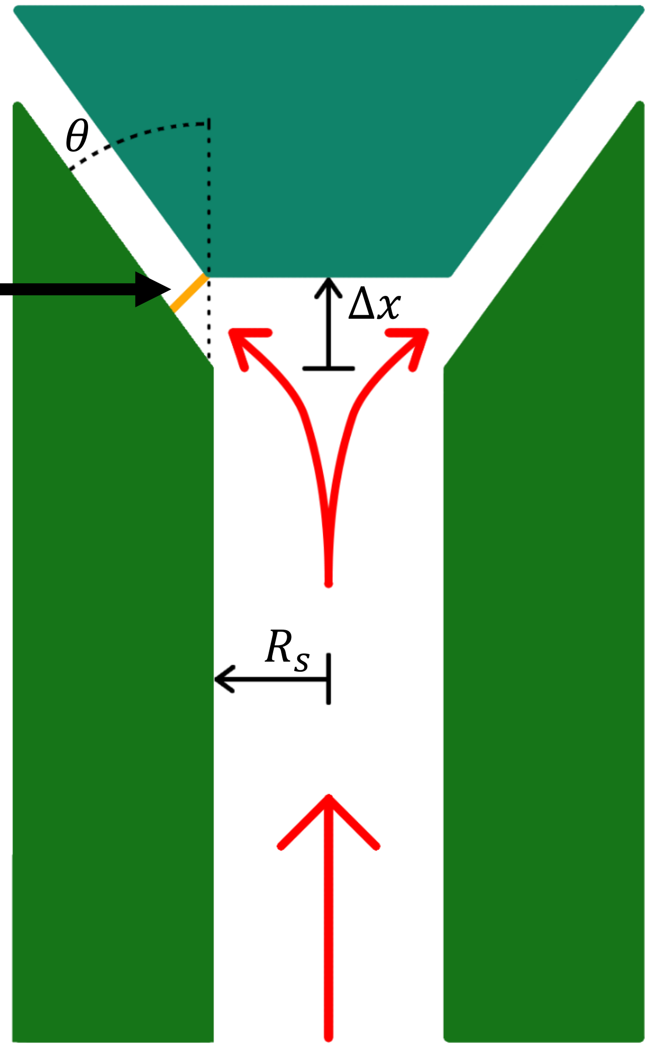
- Area for flow through valve must never be less than the inlet area to minimize flow restriction
- The smallest area for flow is at the nose of the poppet
- With valve geometry determined via heat transfer calculations, opening distance can be found

$$\Delta x = \frac{R_s\left(\sqrt{\cos(\theta)+1}-1\right)}{\cos(\theta)\sin(\theta)}$$

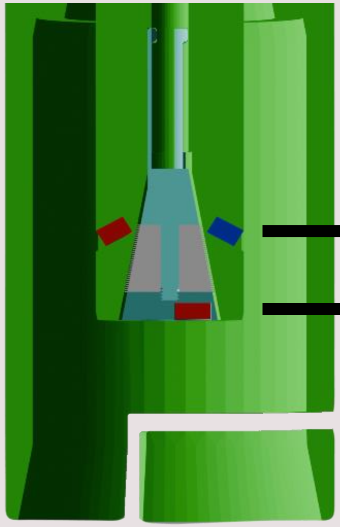
- Informs the decision of positioning with magnet opening system

Most restricted flow area, A_r

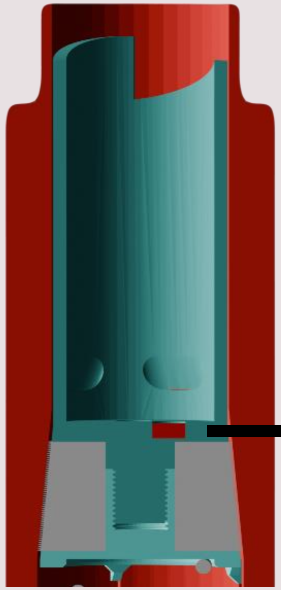
$$A_i = A_r = g(R_s, \theta, \Delta x)$$

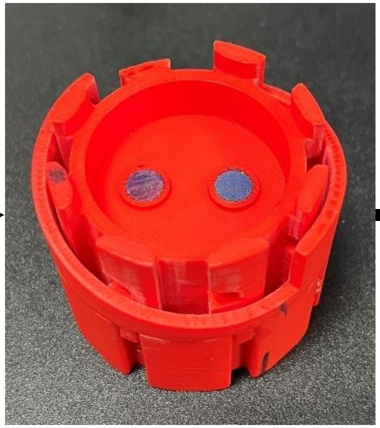


Nozzle



Receiver





Nozzle

Nozzle Poppet

Receiver Poppet

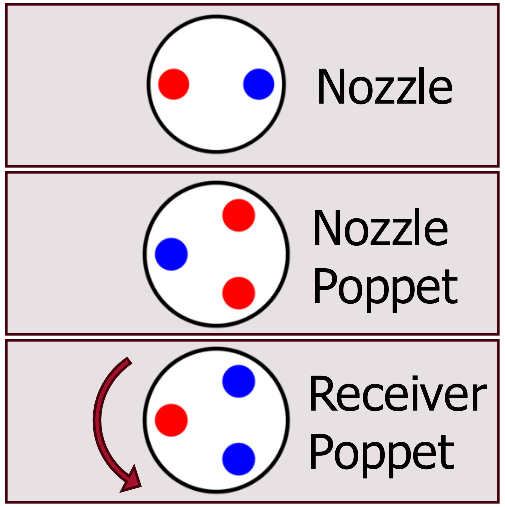
Samarium Cobalt Magnets

- Resist hydrogen embrittlement
- Perform better than Neodymium at cryogenic temperatures
- Arrays allow for rapid prototyping and cost savings

$$\frac{S_1 * S_2}{D^2} = F$$

Magnetic Force Modeling

- Axial force between each magnet is calculated both as the Nozzle is rotated and as the Nozzle poppet travels
  - Initially the two poppet arrays repel
  - Once rotated approx. 90 degrees the poppet arrays align to attract, pulling open the nozzle poppet



3D Printed Magnets

- A larger opening window
- Greater opening forces
- Greater sealing forces

Lunar regolith is abrasive, electrically charged, and ubiquitous.

Leidenfrost Dusting Effect

- Film boiling
- Previously demonstrated to remove >90% dust simulant from spacesuit material in vacuum environment
- Purge functionality removes dust just before coupling

HYPER Leidenfrost Dusting Demonstration

Removeable Dust Cap

- Physical barrier to dust contamination
- Cold end contact prevention

PRESENTATION CONTENTS

TRL 1 — Basic Principles (Prior to project)

- Teflon seals used in cryogenic applications
- Al6061-RAM2 cryogenic properties observed

TRL 2 — Technology Concept Development (Jan 25-Mar 25)

- Paradigm iterations and design review
- Final coupler design

TRL 3 — Function Proof of Concept (Mar 25-May 25)

- Polymer prototype printed to verify viability of design
- Demonstrate size, shape, design, and basic functionality

TRL 4 — LN2 Testing (May 25-Aug 25)

- Sealing capabilities, heat ingress, pressure drop, surface icing all to be tested

TRL 5 — LH2 Testing (Aug 25-Dec 25)

- Repeat LN2 testing but with LH2 flow to verify viability with hydrogen

TRL 6-9 — Flight Readiness Testing (2026-2028)

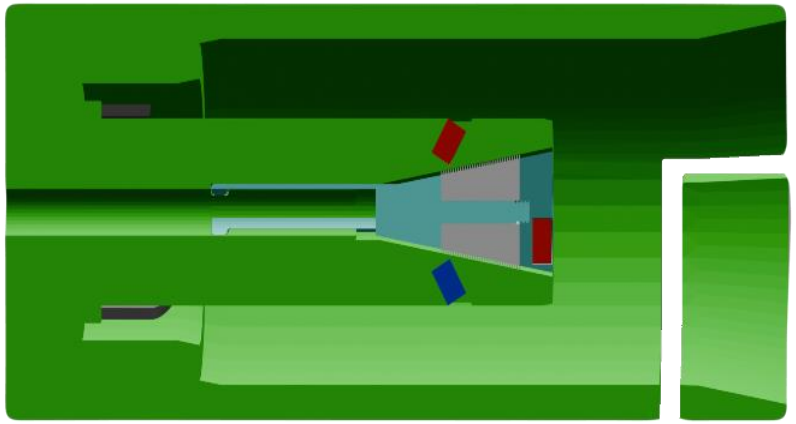
- Testing of entire system in relevant environment, including flight readiness testing
- TRL 9 achieved once system is "flight proven"

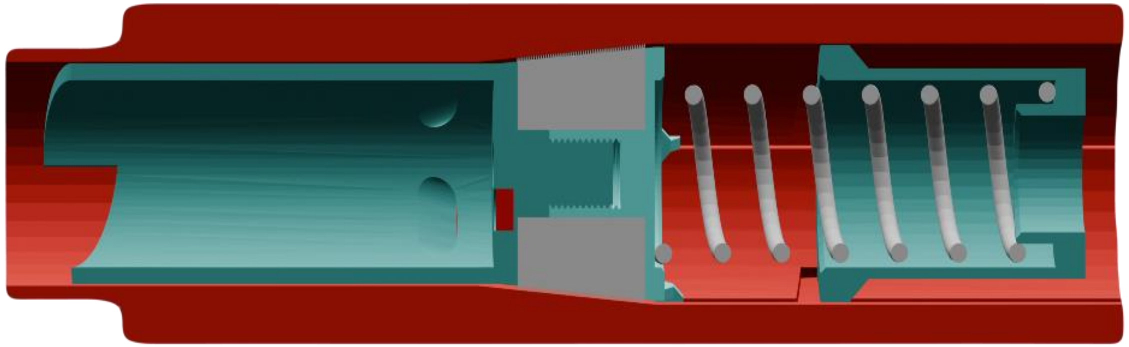
PRESENTATION CONTENTS

The CYPRESS coupler synthesizes novel cryogenic sealing and additive manufacturing technologies to enable LH2 transfers in extreme environments.

CYPRESS can be integrated into pre-existing space craft mating systems for automated cis-lunar fuel transfers without the added complexity of an EVA.

Ongoing validation testing will advance the technology through TRL 4 with plans to advance through TRL 5 in conjunction with the HYPER center.

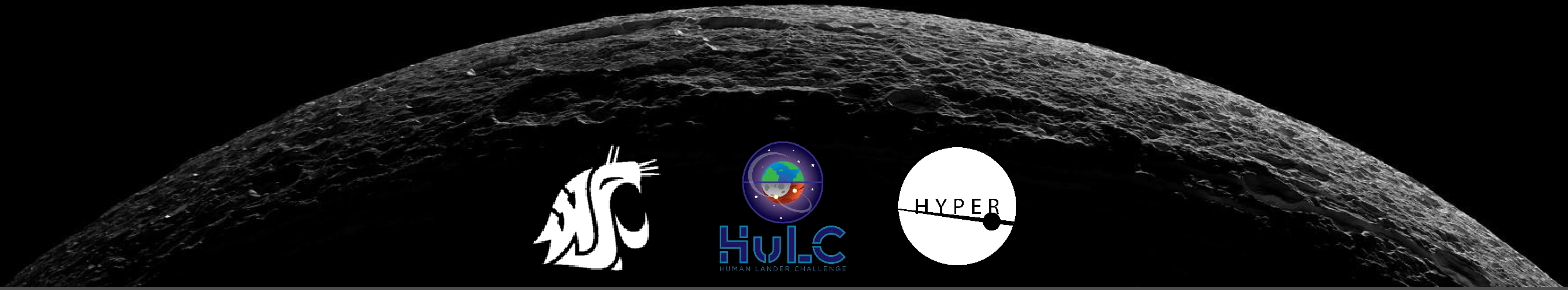




CYPRESS

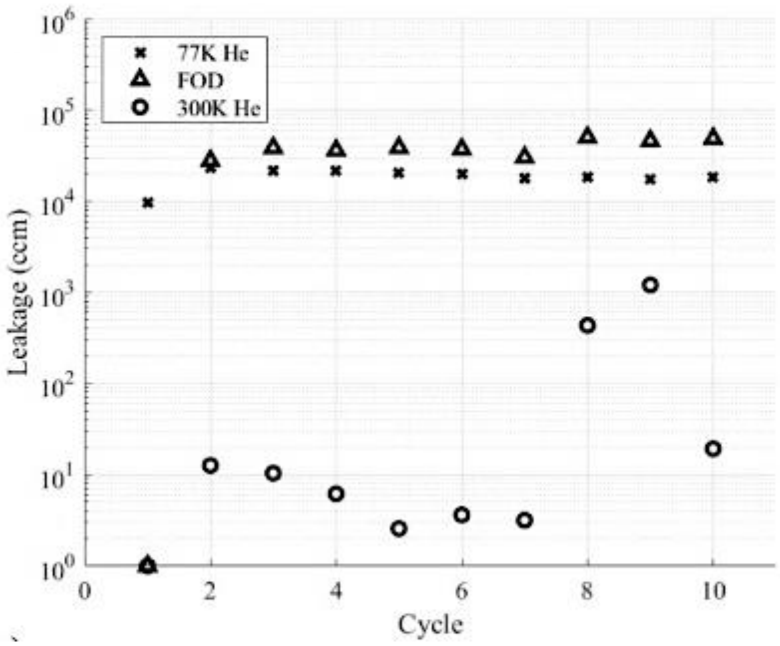
CrYogenic Performance REfueling Safety System

THANK YOU!

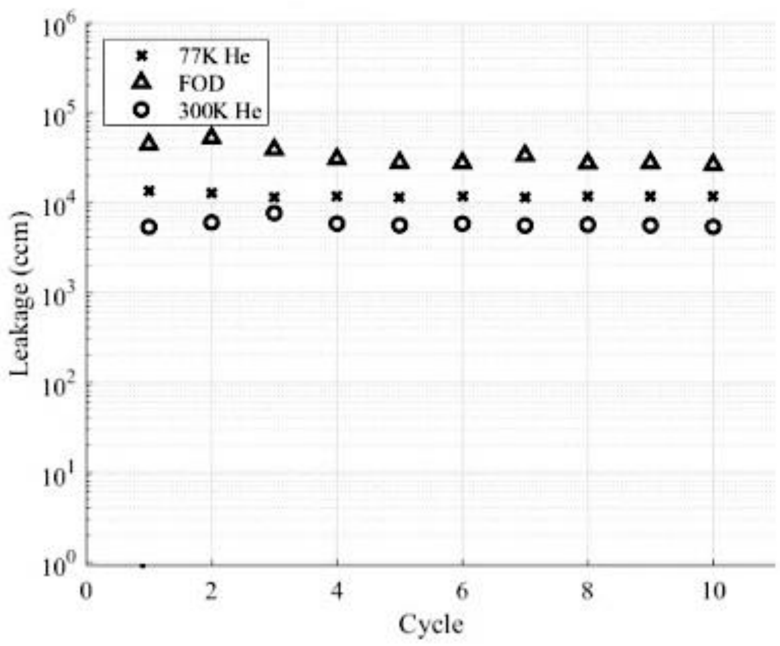


EXTRA SLIDES

Previously Demonstrated PRV Seals [5]



COTS Valve Leakage Rate per Cycle

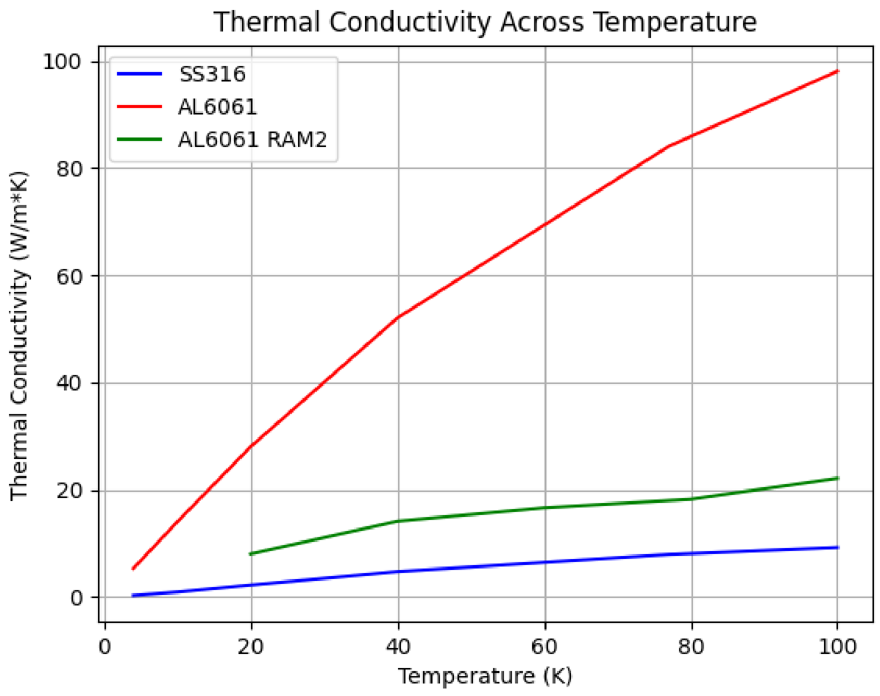


Conformable Plug Leakage Rate per Cycle

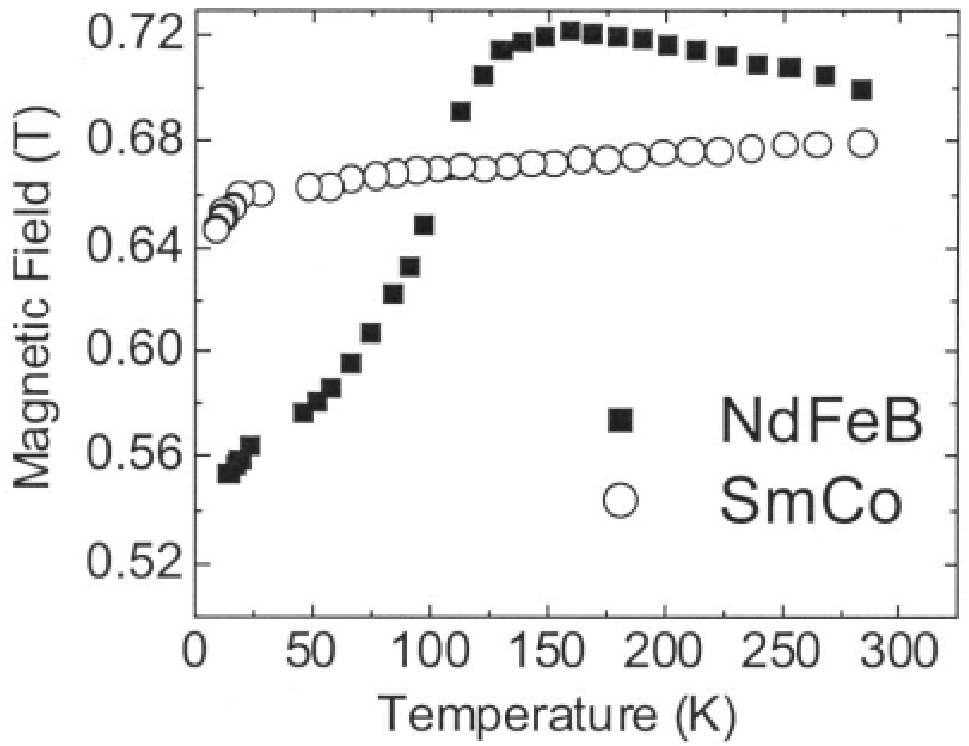
Conformable Plug Average Leakage

Test	Average Leakage per Cycle [ccm]
300K	5778
77K	11,830
FOD	33,247

AL6061-RAM2 [6]



Samarium-Cobalt Magnets [22]



Cam Surface Wear Estimate

Assumptions

- Opening/closing velocity of 10 ft/min
- 1 min cycle time
- 10,000 cycles
- Material properties equivalent to 66 Nylon + 15% PTFE

$$Wear = Motion\ Factor * Environ\ Factor * Wear\ Factor * Pressure * Velocity * Time$$

Motion Factor:	1.3
Environmental Factor:	6
Material Wear Factor:	$1.3 * 10^{-9}$

$$0.002\ in^3\ material\ worn\ away$$
$$0.002\ in\ y - displacement\ change$$

Pressure Vessel Safety Validation

- Wall stress resulting from fluid pressure and vacuum insulation
- Thin-walled pressure vessel where wall thickness t and inner radius r

$$t < 10r$$

- Hoop stress σ_h estimated using the differential pressure across the wall P

$$\sigma_h = P * \frac{r}{t}$$

- ASME BPVC VIII-1 calls for 3.5 FOS for hoop stresses
- Coupler wall at 1 mm thickness exceeds requirements with FOS of 90

Budget

PI Name(s): Jacob Leachman						PHASE 1	PHASE 2	TOTAL
						04/08/25	06/02/25	
Agency Name: NASA						06/01/25	08/08/25	
00 - SALARIES	**Pay Rate**	**# Mos.**	**% FTE**		**Salart**			
PI: Jacob Leachman	0.00	0.00	0.00%		31.30%	-		-
PI: Emily Larsen	0.00	0.00	0.00%		31.30%	-		-
01 - WAGES	**$ Per Hr.**	**Hrs/Wks**	**# Wks.**					
Student:	$0.00	0	0		**Wages**	-		-
				Benefits	2.9%	-		-
07 - BENEFITS								
					Total Salaries/Wages/Benefits	-		-
02 - PURCHASED SERVICES (Personal Services Contracts and Consultants and Computer Services)								
					Total Personal Services Contracts	-		-
03 - GOODS/SERVICES (Including Small/Attractive Items)								
Conference registration						2,600		2,600
					Total Goods/Services	2,600		2,600
04 - TRAVEL								
Travel to Competition						3,625		3,625
					Total Travel	3,625		3,625
05 - COMPUTER SERVICES								
					Total Computer Services	-		-
06 - MATERIALS AND SUPPLIES								
					Mechanism Testing Supplies	300	-	300
					Cryogenic Testing Supplies and Manufacturing	-	15,000	15,000
					Total Materials and Supplies	300	15,000	15,300
08 - SCHOLARSHIPS AND FELLOWSHIPS (SUBSIDIES/PARTICIPANT SUPPORT COSTS)								
Remaining Scholarship funds						2,725		2,725
NASA Internship Stipend (3 interns)							32,800	32,800
					Total Stipends/Subsidies/Participant Support Costs	2,725	32,800	35,525
14 - AWARD RESTRICTIONS (RESTRICTED: incl. SUBAWARDS/SUBCONTRACTS)								
					Total Subcontracts/Restricted	-		-
TOTAL DIRECT COSTS						-		-
EXCLUSIONS								
Other (Off-Site Rental & Stipends, Etc)						-		-
					Total Exclusions	-		-
MTDC BASE					**Base**	-		-
13 - FACILITIES & ADMINISTRATIVE COSTS (F&A, IDCs, OVERHEAD)				**F&A Rate:**	**0.000%**	-		-
TOTAL COSTS						9,250	47,800	57,050

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