NASA ACO ELECTRA QD Coupling

Final Report

In Response to:
Unfunded Space Act Agreement:
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Submitted by:
L3Harris Technologies, Inc.

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Electrically Actuated Quick-Disconnect Coupling for Cislunar and Lunar *Surface Cryogenic Propellant Transfer*

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EXECUTIVE SUMMARY

The ELECTRA QD Coupling will provide a new refueling and reuse capability for spacecraft intended for cislunar space and lunar surface operations, supporting NASA missions and the larger spacecraft servicing market.

L3Harris has designed a low leakage coupling, ELEctrically-actuated Cryogenic TRAnsfer Quick Disconnect (ELECTRA QD) Coupling, for on-orbit cryogenic fluid transfer. To further advance the Technology Readiness Level (TRL) of this design, L3Harris entered into an unfunded Space Act Agreement with NASA STMD through the Announcement of Collaboration Opportunity (ACO) program partnering with NASA Marshall Space Flight Center (MSFC). Building and testing this innovative design will make this critical technology available to newly developed CFM systems needed by NASA missions, commercial market, and government sectors. The ELECTRA QD coupling will enable crewed and uncrewed space vehicles, in cislunar space and on the lunar surface, to be refuellable and use either existing, transported, and in-situ produced propellants.

The scope of this effort included the design, fabrication, characterization, testing, and demonstration of a pair of Electrically Actuated Propellant Quick-Disconnect Couplings that demonstrate human-rated propellant transfer capability. Major milestones include Specification, Design, and Test Readiness Reviews; Performance and Demonstration Testing; and Final report. L3Harris is responsible for the design, manufacturing, and proof testing of the ELECTRA QD Coupling. Cryogenic testing is performed at NASA-MSFC Component Development Area (B4656) while dynamic mate/de-mate demonstrations are performed at NASA-MSFC Flat Floor Robotics Laboratory.

1. INTRODUCTION

The Electrically Actuated Propellant Quick-Disconnect (QD) Coupling is a very low leakage fluid coupling that has broad application for in-space and Lunar surface refueling and enables the development of a vehicle On-Orbit and/or On-Surface Cryogenic fuel transfer/refueling capability. ELECTRA QD leverages L3Harris's expertise in several technology development areas including material selection for cryogenic propellant compatibility, space environments, crew-rated hardware, and additive manufacturing. Multiple components are additively manufactured (AM) to produce a sophisticated design that is not easily machined using conventional means. The design includes two independent (male and female) dual-sealing housings designed for cryogenic propellant compatibility; a coupling mate/de-mate geared rotary actuator; mated, open and close position sensors; and an optional extend/retract linear actuator system. The ELECTRA QD Coupling has been engineered and designed to meet the demands of a crew-rated coupling for in-space use with large volume, high flow rate cryogenic propellants (i.e. liquid Oxygen (LOX); liquid Hydrogen (LH^2); liquid Methane (LCH^4)). Current analysis shows that this coupling is scalable from 1.5inch to 8-inch diameters, specifically in support of large volume flow rate cryogenic propellants. Table 1 lists some of the technologies incorporated into the design to support ELECTRA QD Coupling becoming the preferred NASA and industry standard.

Table 1. ELECTRA QD Coupling Design

Technology	Design Element
Human Rated	Dual seal against external leakage in mated and de-mated positions.
In-space coupling for fuel transfer operations	All dynamic controls reside on female coupling half: extension/retraction for mating controls with rotary electrical actuator for flow control.
Fluid pressure and dynamic load reaction	Designed to react to loads and final docking misalignments between spacecraft and refueling station. Axial loads are designed to be applied to the coupling housing to prevent separation.
Remote controlled locking/unlocking and actuation/de-actuation, which can be automated	The ELECTRA QD Coupling design includes an electric rotary actuator, which is mounted on the lower female coupling housing, and uses a gear set, a cam and mechanical linkage within the female coupling half to provide a remotely controllable housing locking and unlocking function and a dual poppet translating actuation and de-actuation function.
Fail-safe operation modes for human rating and in-space application	Couplings are remotely electrically actuated with two back up manual modes, performed by Extravehicular Activities (EVA) astronaut or robotic arm. Instrumentation and visual indications monitor operation, position, and health of coupling.

2. DESIGN

The ELECTRA QD Coupling (shown in Figure 1) incorporates a robust design for in-space cryogenic refueling applications which led to a number of design elements for challenging low leakage and material compatibility. Fundamentally, the coupling comprises of two unique and compatible halves with 3-inch internal diameter that are electrically mated and actuated via a controller. This section will describe the coupling design.

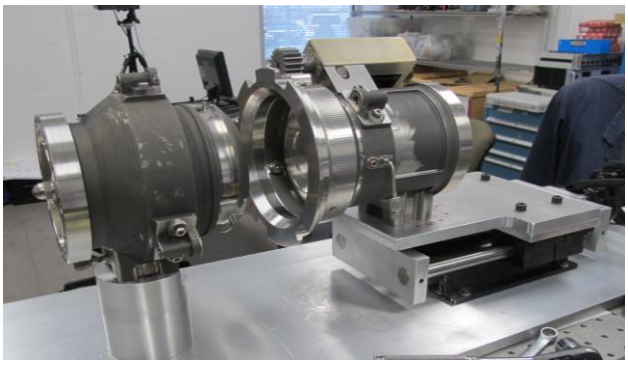

Figure 1. 3" ELECTRA-QD Assembly w/Fixed Mount

The ELECTRA QD Coupling is additively manufactured from Nickel Alloy 718 which is a relatively high-density material but is preferred for compatibility with cryogenic materials such as

liquid Hydrogen and liquid Oxygen. The Female coupling mass (22 lbm) is greater than the male coupling half (16 lbm) given the mounted electrical actuator that extends and retracts the internal poppets to open and close the fluid flow paths.

The Female coupling half has all the coupling dynamic functional control although the coupling is designed for bi-directional flow capability. Figure 2 shows a model of the female and male coupling half without insulation (right).

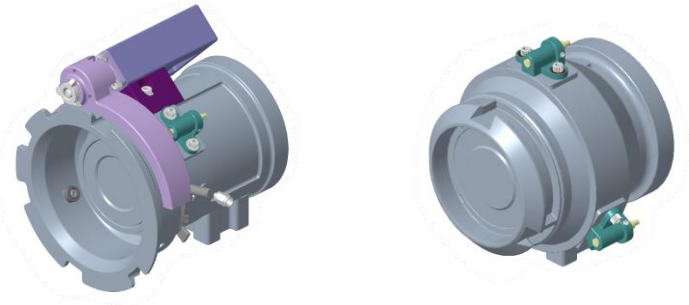

Figure 2. ELECTRA-QD Coupling Halves w/o Insulation: Female (Left) and Male (Right)

The female coupling half includes internal design features (see Figure 3 Left) that drive the female internal poppet forward and back to open and close the fluid flow path when the upper female housing is rotated relative to the lower female housing. Dual spring activated seals are used to prevent internal and external leakage. The Tri-dual roller assembly positions the poppet shaft as the rollers travel along the helical track of the upper female housing. The 28V dc rotary actuator is mounted to the exterior of the lower female housing and includes a pinion gear that rotates the sector gear on the upper female housing resulting in movement of the internal poppets. A gear set guard is included to protect from foreign object debris. The female coupling half can be operated manually as well via manual manipulation of the pinion gear with the Manual Actuation Fitting or the open and close post located on the targe plate. Proximity sensors mounted on the exterior of the lower female housing sense the target plates to provide information to the controller for the poppet position.

The ELECTRA-QD male coupling also has bi-directional flow capability, and spring activated poppet positioning. This device inherently desires to close and seal, when upstream fluid pressure is present, even in the event of compression spring compromise. The male housing is designed to receive the pin-rollers from the female housing through the inter-locking keyway. Three external radially spaced proximity sensors detect the upper female housing interface to provide mating information. Figure 3 (Right) shows a cross-section of the male coupling. Many of the internal design features of the male coupling target the control and positioning of the poppet. Dual spring activated omni-seals are positioned around the poppet head and prevent leaks via the threaded in poppet seat. C-seals prevent leaks around the poppet seat.

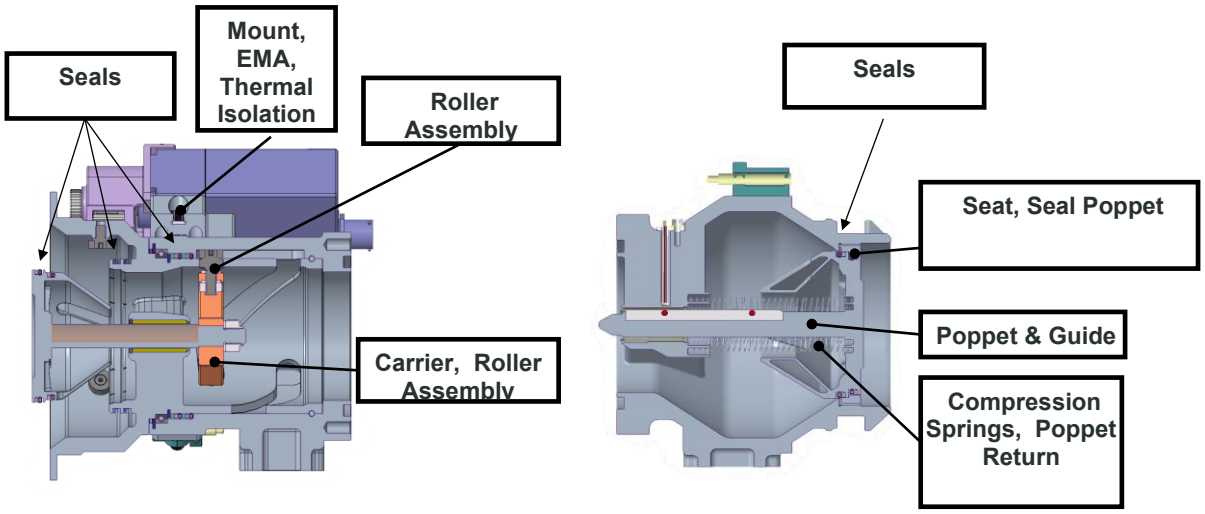

Figure 3. Coupling Cross-Section Female (Left) and Male (Right)

The base mounting design for both the male and female housings are the same. The mounting base has a 4 common bolt hole pattern. The backside of each coupling half has a common 12 bolt flange with a single static seal gland sized for a spring energized Omni-Seal. The rotary actuator mounted to the female coupling has an electrical connector which mates with a 10ft cable to the controller. The linear actuator uses a stepper motor connecting to 10ft. power and control cable.

The ELECTRA QD Coupling is additively manufactured from Nickel Alloy 718 which is a relatively high-density material but is preferred for compatibility with cryogenic materials such as liquid Hydrogen and liquid Oxygen. The Female coupling mass (22 lbm) is greater than the male coupling half (16 lbm) given the mounted electrical actuator that extends and retracts the internal poppets to open and close the fluid flow paths.

The ELECTRA QD Coupling is electrically actuated and controlled using a simple controller with a rotary actuator and linear actuator. The controller requires three power inputs to power the controller and each actuator. In order to maintain flexibility during testing an open loop system is applied to the control architecture to allow for user oversight and control at this stage in the coupling development. Proximity sensors and current limits provide indication for determining when the linear extension motor and rotary motor have reached their destination. A laptop computer communicates with the controller using Universal Asynchronous Receiver/Transmitter (UART) protocol. The computer displays a graphic user interface (GUI) allows the user to set which actuator to operate, direction, duty cycle, and distance.

3. TESTING

Initial testing of ELECTRA-QD Coupling Assemblies were completed in Canoga Park, CA at the Los Angeles Test Operations Component Test Center (CTC). Three initial tests were performed at CTC: basic mechanical and electrical functional testing, proof testing, and leak testing. Following the testing at L3Harris CTC the coupling was shipped to NASA Marshall Space Flight Center (MSFC) for cryogenic flow characterization, leak testing, and dynamic testing.

Five proof cycles were successfully conducted holding at pressure for 30 seconds using gaseous Helium while in both the de-mated and mated configurations. Proof pressures were determined at 1.5 times the maximum expected operating pressure (MEOP).

The Component Development Area (CDA), managed by the Valves, Ducts, and Actuators Branch (ER14) at NASA's Marshall Space Flight Center (MSFC) in Huntsville, Alabama, is a specialized propulsion engineering facility located in Building 4656. This lab delivers rapid-turnaround technology advancement, hardware inspections, and anomaly troubleshooting to maximize the safety, operability, and reliability of vital rocket components—with a primary focus on deep-space and cryogenic valve systems. Cryogenic flow characterization and leak testing are performed at CDA.

The Flight Robotics Laboratory (FRL), commonly known as the Flat Floor Robotics Lab (FFRL), is a premier simulation facility at NASA's Marshall Space Flight Center (MSFC) in Huntsville, Alabama. The lab serves as a crucial validation ground for autonomous rendezvous, proximity operations, satellite servicing, and structural assembly technologies for both NASA missions and commercial aerospace partners. Demonstration testing was performed at the MSFC Flat Floor Robotics Laboratory using the NASA docking system with both active and passive rings representative hardware. Misalignment testing is conducted to demonstrate ambient mate/de-mate performance with specified angular and radial misalignments between the docking interfaces.

3.1 Leak Testing

Low leakage is critical for in-space cryogenic refueling because the transferred fluids, such as liquid oxygen or liquid hydrogen, are stored near their boiling points and can be lost rapidly through even very small leaks. In orbit, every kilogram of propellant is mission-critical, so leakage directly reduces available delta-v, shortens mission life, and can prevent successful rendezvous, transfer, or departure burns. Escaping cryogens can also create thermal, contamination, and safety hazards by inducing unwanted forces and torques on the vehicle or accumulating in confined areas where they may affect sensors, insulation, seals, or nearby systems. In addition, low leakage is essential for maintaining pressure control, transfer efficiency, and accurate mass accounting during docking and refueling operations, where precise fluid management is required. For long-duration architecture such as depots, lunar missions, or deep-space transportation, minimizing leakage is therefore a key enabler of reliability, safety, and overall mission economics.

The primary location for potential leakage is through overlapping surfaces. There are several points where leakage can occur in the ELECTRA QD Coupling design. Overlapping surfaces exist at the mating interface between the male and female coupling, between the poppets and coupling half housings, as well as between the upper and lower female housing

The leakage testing is first performed at L3Harris CTC in Canoga Park, CA using gaseous He and a Mass flowmeter with 0-4 SCCM range at ambient temperatures. Leak testing is performed on each individual housing in the de-mated configuration as well as in the mated configuration. Effectively, no leakage is detected during this testing.

Leak testing is then performed at NASA MSFC Component Development Area at ambient and cryogenic temperatures. Leak testing is again performed using gaseous helium. Leak rate

measurements were taken once the system reached a steady state where the leak rate remained constant for approximately 1 minute.

Leak testing on the ELECTRA QD Coupling is performed in the mated condition first. The coupling was tested with the internal poppets open at three pressures (25, 75, and 125 psig). Negligible to no leakage was detected. Mated leak testing was performed prior to testing at the Flat Floor Robotics Lab.

Leak testing of the mated coupling assembly is repeated at cryogenic temperatures using LN_2 chilling with helium leak detection, to demonstrate performance. Similar to the ambient testing, leak checks were performed at 3 pressures (25, 75, and 125 psig). There are some cases where the dwell time is reduced to 1-2 min or if leak rate already reached a stable rate due to time and temperature constraints. Leakage at the lower pressures was 1 scim or less at the inter-seal locations (Figure 4). Leakage at 125 psig was detected at 16.3 and 10.2 scim respectively for the male and female inter-seal locations (Figure 4). Unfortunately, external bagged sniff testing was not performed to say how much leakage translated past the second seal.

Mated Cryogenic Leak						
Male Intermediate Port (HOV-4)	Test Pressure (psig)	Tube Scale	Leakage SCCM (gHe)	Leakage SCIM (gHe)	Rotameter #	Notes
	25	Off Scale Low	<1	<.1	3	Less Than Small Range Flowmeter. (At -192°F)
	75	Off Scale Low	<1	<.1	3	Less Than Small Range Flowmeter. (At -175°F)
	125	46	268	16.3	2	(At -212°F)
Female Intermediate Port (HOV-3)	Test Pressure (psig)	Tube Scale	Leakage SCCM (gHe)	Leakage SCIM (gHe)	Rotameter #	Notes
	25	35	16.6	1.0	3	(At -204°F)
	75	Off Scale Low	<1	<.1	3	Less Than Small Range Flowmeter. (At -172°F)
	125	30	168	10.2	2	(At -201°F)

Figure 4. Mated Cryogenic Leak Check Result

Leak testing on the ELECTRA QD Coupling halves are also performed in the de-mated condition. It is noteworthy to say this testing occurred following functional testing at the Flat Floor Robotics Lab. It is also to be noted that the seals on the ELECTRA QD Coupling were not replaced prior to returning to the Component Development Area for more leak testing and have experienced 3-4 days of exercising the seals in a dry environment. Due to the extremely low leakage detected at ambient temperatures at both L3Harris CTC and in the mated condition at CDA, only cryogenic testing was performed on the coupling halves.

There are several leak paths to be checked in for each coupling half. Figure 5 shows the test articles during test for both the Male coupling half and the Female coupling half respectively. Leak testing is performed at the same three pressures as the mated leak tests (25, 75, and 125 psig). Again, there are some cases where the dwell time is reduced to 1-2 min or if leak rate already reached a stable rate due to time and temperature constraints.





Figure 5. De-mated Leak Test Female (Left) Male (Right)

The male coupling cryogenic leakage results (Figure 6) show improved performance at higher pressures for each of the locations that were tested. It is assumed that the increased pressure is creating an improved sealing environment by applying a force to the back of the poppet face into the poppet seat. The leakage results at 25 psig are consistent with the leakage values measured at the inter-seal location during the mated cryogenic leakage testing. Leakage levels remain well below the Goal value for this program at less than 20 scim at any location.

MALE COUPLING DE-MATED CRYOGENIC LEAKAGE						
Closed Poppet Leakage	Test Pressure (psig)	Tube Scale	Leakage SCCM (gHe)	Leakage SCIM (gHe)	Rotameter#	Notes
	25	14	258	15.7	1	
	75	16	76	4.6	2	
	125	61	39	2.4	3	
Male Coupling Seal Surface Leakage	Test Pressure (psig)	Tube Scale	Leakage SCCM (gHe)	Leakage SCIM (gHe)	Rotameter #	Notes
	25	42	234	14.3	2	
	75					Less than the FM-3 low range, could not pull vacuum with mass spec due to no adapter/TA interface seal.
	125					Less than the FM-3 low range, could not pull vacuum with mass spec due to no adapter/TA interface seal.
Threaded Seat Seal Leakage	Test Pressure (psig)	Tube Scale	Leakage SCCM (gHe)	Leakage SCIM (gHe)	Rotameter #	Notes
	25	47	277	16.9	2	
	75	7	48	3	2	
	125	7	48	3	2	

Figure 6. De-mated Male Coupling Cryogenic Leak Check Results

The female coupling cryogenic leakage results (Figure 7) shows less than 1 scim at all the locations for tests at all three pressures. Increased pressure on the back of the poppet face again shows improved leakage trend. Consistent to the mated testing, increased pressure resulted in increased leakage at inter-seal locations. Leakage levels remain well below the Goal value for this program at less than 1 scim at any location.

FEMALE COUPLING DE-MATED CRYOGENIC LEAKAGE					
Female Coupler De-Mated Cryogenic Leak (Poppet Closed)					
	Test Pressure (psig)	Mass Spec. (SCCS)	Leakage SCCM (gHe)	Rotameter#	Notes
Closed Poppet Leakage	25	1.60E-02	0.96	n/a	3.2 Torr on Mass Spec. in gross mode. Poppet closed for Cryo-conditioning.
	75	1.40E-02	0.84	n/a	3.1 Torr on Mass Spec. in gross mode. Poppet closed for Cryo-conditioning.
	125	1.30E-02	0.78	n/a	3.1 Torr on Mass Spec. in gross mode. Poppet closed for Cryo-conditioning.
Female Coupling De-Mated Ambient Leak (Poppet Open)					
	Test Pressure (psig)	Mass Spec (SCCS)	Leakage SCCM (gHe)	Rotameter#	Notes
Intermediate Seal Female Housing/ Rotary	25	1.80E-02	1.08	n/a	3.2 Torr on Mass Spec. in gross mode. Limited troublehsooting tm.
	75	1.50E-02	0.90	n/a	3.2 Torr on Mass Spec. in gross mode. Limited troublehsooting tm.
	125	1.00E-01	6.00	n/a	3.2 Torr on Mass Spec. in gross mode. Limited troublehsooting tm.
	Test Pressure (psig)	Mass Spec (SCCS)	Leakage SCCM (gHe)	Rotameter#	Notes
Intermediate Seal Female to Male Housing Seal	25	1.70E-02	1.02	n/a	3.1 Torr on Mass Spec. in gross mode. Limited troublehsooting tm.
	75	2.70E-02	1.62	n/a	3.2 Torr on Mass Spec. in gross mode. Limited troublehsooting tm.
	125	4.60E-02	2.76	n/a	3.8 Torr on Mass Spec. in gross mode. Limited troublehsooting tm.
	Test Pressure (psig)	Mass Spec (SCCS)	Leakage SCCM (gHe)	Rotameter#	Notes
Dual Seal Female to Male Housing Seal	25	1.30E-02	0.78	n/a	3.2 Torr on Mass Spec. in gross mode. Limited troublehsooting tm.
	75	1.40E-02	0.84	n/a	3.4 Torr on Mass Spec. in gross mode. Limited troublehsooting tm.
	125	1.20E-02	0.72	n/a	3.2 Torr on Mass Spec. in gross mode. Limited troublehsooting tm.
External Couping De-Mated Ambient Leak					
	Test Pressure (psig)	Tube Scale	Leakage SCCS (gHe)	Rotameter#	Notes
External Sniff	125	n/a	0.00004	n/a	Used Mass Spec. Sniff Probe Inside bagged Joint.
					1. The higher Torr was due to a leak in test setup that was not found until the following test day during De-mated Male coupler leak testing. 2. Checked smallest flow range meter as well for the various leak tests above and did not observe any measureable leakage.

Figure 7. De-mated Female Coupling Cryogenic Leak Check Results

3.2 Flow Characteristics

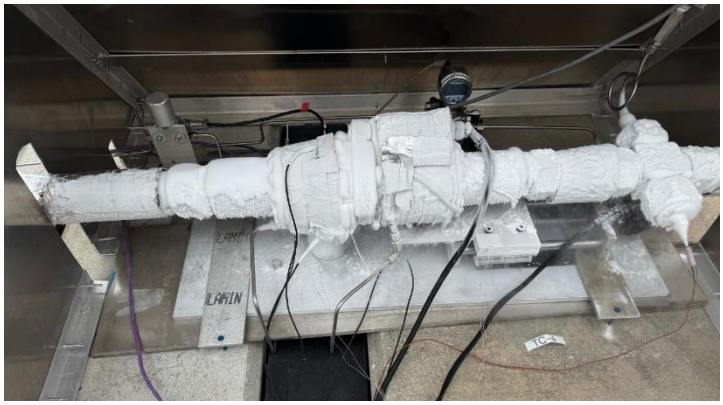

Figure 8. Cryogenic Flow Testing

Cryogenic flow testing (Figure 8) was performed at the Component Development Area (B4656) using LN_2. Testing included:

- Measurement of pressure drop (ΔP) versus flow rate across the coupled assembly over the required operating range.
- Verification of the minimum LN_2 flowrate requirement of 11.24 lbm/sec (100 gal/min).

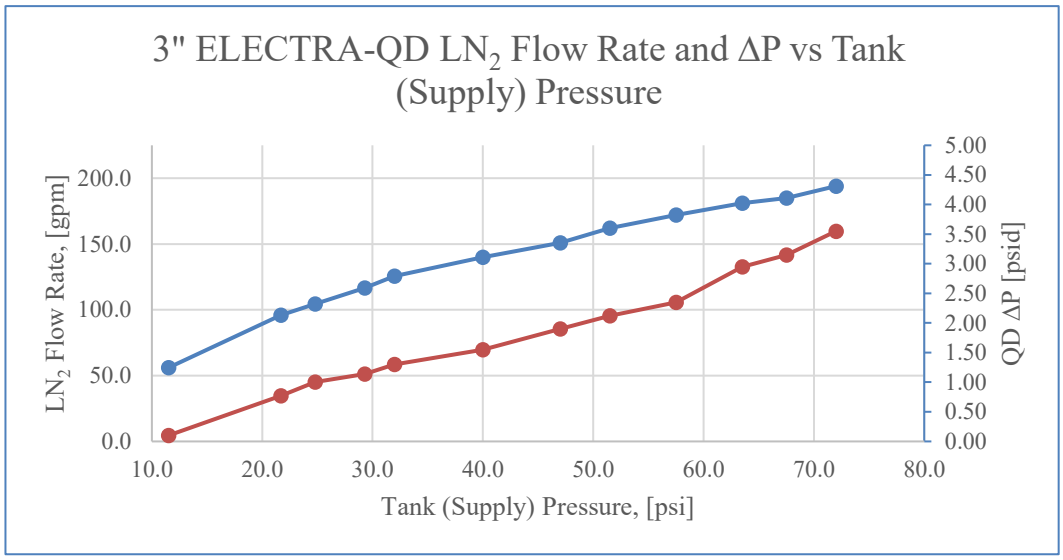

Figure 9. Pressure Drop and Flow Rate Data

Figure 9 plots in blue the LN2 flowrate in gpm versus supply tank pressure in psi units. Additionally, the pressure drop across the valve (shown in red) versus supply tank pressure in psi units is also provided. The maximum pressure drop (3.55 psid) across the valve was experienced at the maximum flow rate 194 gpm.

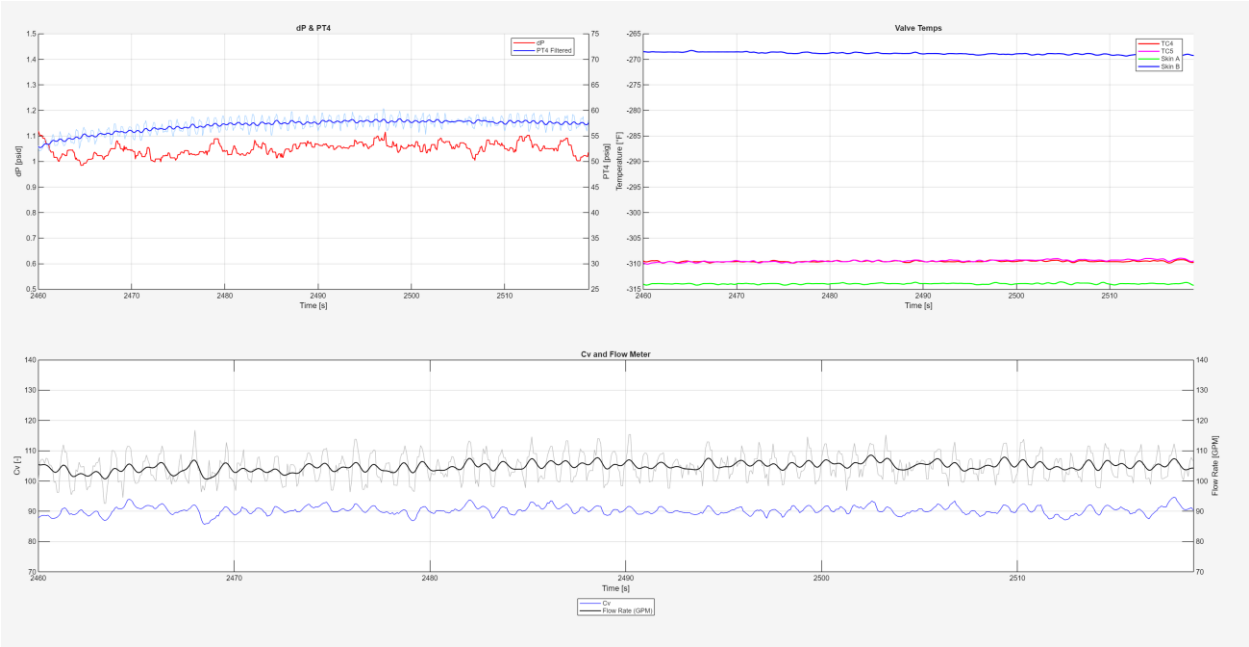

Figure 10. Three Panel Cryogenic Flow Characterization

Figure 10 shows three panels of cryogenic flow data that characterize the ELECTRA QD Coupling. In the upper left panel shows a sustained 1 psi pressure drop across the coupling during 1 minute of testing. The upper right panel shows thermocouple data demonstrating cryogenic temperatures during the test. The bottom panel shows the flow rate at approximately 105 GPM corresponding to a valve coefficient of approximately 90. This test characterizes the valve performance at the designed to minimum flow rate of 100 gpm. The flow characterization testing was only performed with flow in one direction. The ELECTRA QD Coupling is designed for bi-directional flow. Therefore, future testing will compare flow characterization in the opposite direction.

3.3 Functional Testing

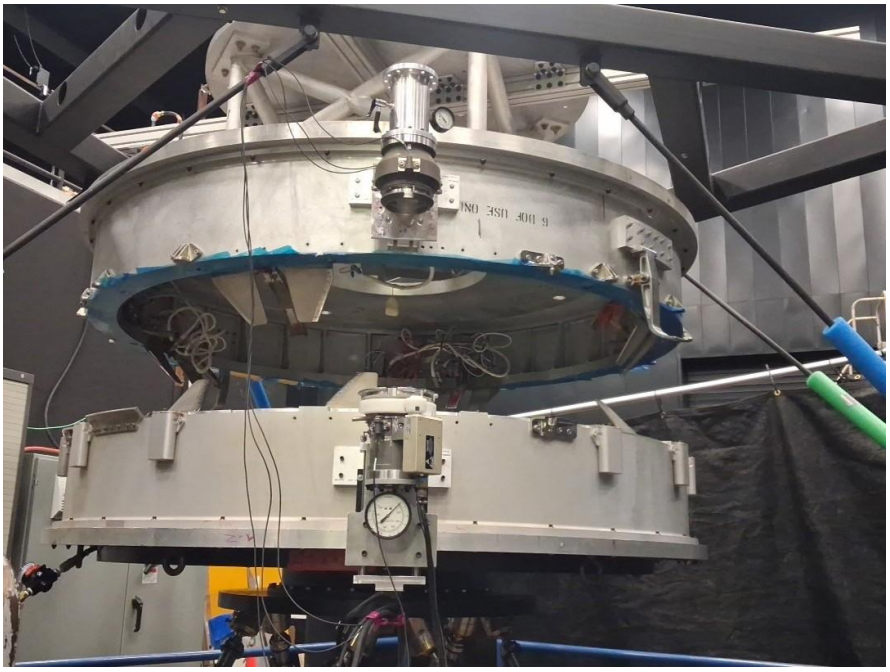

Figure 11. ELECTRA QD Coupling mounted to the Common Berthing Mechanism

Demonstration testing was performed at the MSFC Flat Floor Robotics Laboratory using the NASA docking system with both active and passive rings representative hardware. Robotically controlled hard and soft dockings were performed with electrically actuated coupling mate/de-mate cycles and demonstration of correct quick disconnect sensor logic. Additionally, follow-on demonstration of QD coupling functionality was performed, including failure mode operation (e.g., unpowered manual operation). Mis-alignment testing is performed first after mated testing at the Component Development Area. Functional testing with the Common Berthing Mechanism is performed after the misalignment testing.

Figure 11 shows the ELECTRA QD Coupling mounted to the exterior of the Common Berthing Mechanism (CBM). This testing simulated coupling functionality in a simulated docking scenario. Test data recorded during this testing includes photos and video for visual inspection. It is shown in Figure 11 that the Female coupling is mounted on the stationary base while the male coupling is mounted on the dynamic top half of the CBM. This is intentional given the male coupling has

minimal electrical connections for routing cables for a dynamic operation. As a consequence, the electrical actuators are aligned with the force of gravity in this scenario.

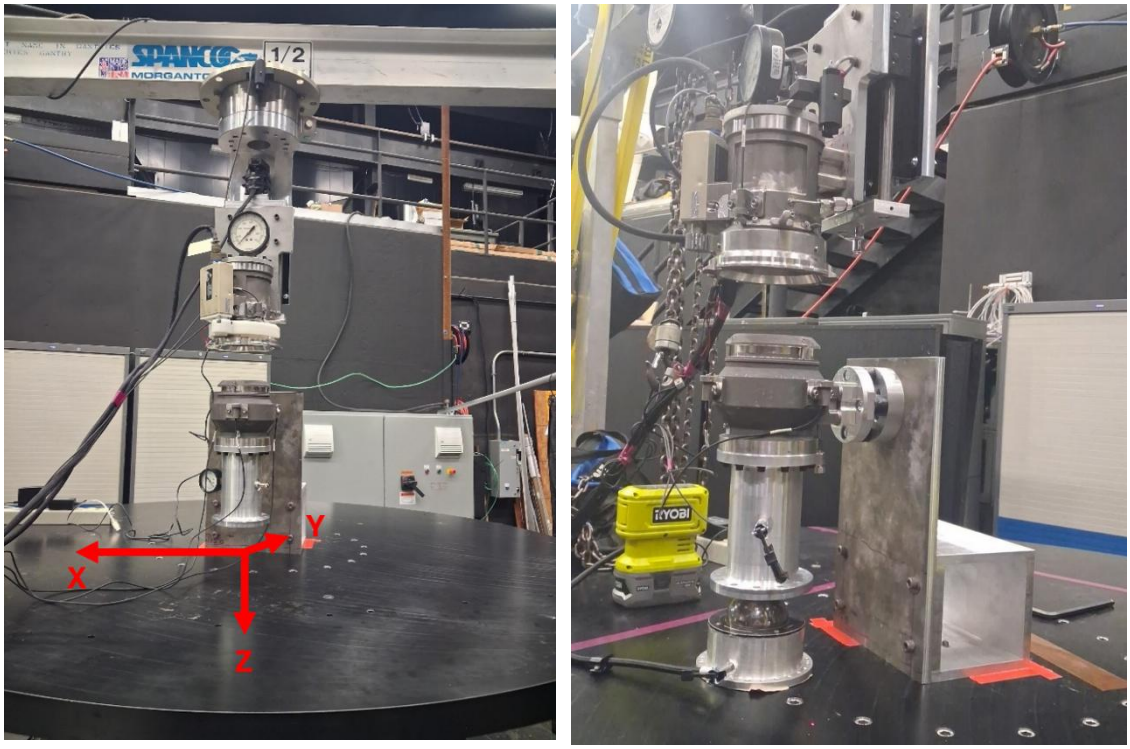

Figure 12. Misalignment Testing

Misalignment testing was conducted to demonstrate ambient mate/de-mate performance with specified angular and radial misalignments between the docking interfaces. The FFRL robotics system provided controlled relative motion and force/torque feedback to evaluate reaction loads during misaligned engagements. Additionally, during each mis-alignment test, a leak check of the external seals is accomplished during mated/open position via an installed pressure decay canister and plate test fixture, equipped with a Schrader valve and redundant pressure gages. Figure 12 shows the test set-up for testing. The coupling is mounted in the vertical direction with the dynamic female coupling on top, aligned with the force of gravity. Figure 13 shows maximum force and torque measurements from a series of tests (20 total). Maximum forces were recorded in the z-direction at an order of magnitude greater than the x and y direction. Force torques also range from 5 lbf-ft to 68 lbf-ft. Absolute mating forces were predominately higher than de-mating forces as well. Additionally, an air bearing was incorporated into the test set-up for comparison of reaction forces. Misalignments tests are conducted for a range of values in the angular (0.5-1.5 degrees), roll (0.25-1.5 degrees), yaw (0.5-1.5 degrees), and x-translational (0.03-0.125 inch) direction. After each successful mating/opening, the coupling was pressurized to 127 psig and held for 5 minutes. Visual inspection is used to check the gauge. No pressure decay was noted during any of the mis-aligned mating operations when successful mating and

opening of poppets is achieved. Additional work is needed to process the entire amount of data for comparison to analysis.

ELECTRA-QD COUPLING MATE/DEMATE FLEX-MOUNT MIS-ALIGNMENT FORCES & TORQUES SUMMARY							
Avg Baseline	F/T Serial Number = FT32284						
	Max. Force X (lbf)	Max. Force Y (lbf)	Max. Force Z (lbf)	Max. Torque X (lbf-ft)	Max. Torque Y (lbf-ft)	Max. Torque Z (lbf-ft)	Notes
Mating	19.08	-8.78	-134.71	-20.79	-14.37	-10.10	
Demating	-14.44	13.46	164.41	28.78	-19.34	-6.08	
1.5° Angular Mis-Alignment	F/T Serial Number = FT32284						
	Max. Force X (lbf)	Max. Force Y (lbf)	Max. Force Z (lbf)	Max. Torque X (lbf-ft)	Max. Torque Y (lbf-ft)	Max. Torque Z (lbf-ft)	Notes
Mating	17.86	-21.38	-363.15 (1)	39.19	-27.86	54.08	
Demating	14.65	-25.90	144.67	68.16	-40.03	-48.52	
1.5° Pos. Roll Mis-Alignment	F/T Serial Number = FT32284						
	Max. Force X (lbf)	Max. Force Y (lbf)	Max. Force Z (lbf)	Max. Torque X (lbf-ft)	Max. Torque Y (lbf-ft)	Max. Torque Z (lbf-ft)	Notes
Mating	24.19	11.80	-220.55 (1)	5.87	-7.14	-7.65	
Demating	-13.17	-10.00	141.47	12.27	-11.97	-5.30	
1.5° Pos. Yaw Mis-Alignment	F/T Serial Number = FT32284						
	Max. Force X (lbf)	Max. Force Y (lbf)	Max. Force Z (lbf)	Max. Torque X (lbf-ft)	Max. Torque Y (lbf-ft)	Max. Torque Z (lbf-ft)	Notes
Mating	22.06	10.83	-193.79 (1)	-4.68	-6.96	7.80	
Demating	-13.10	-9.62	149.86	11.50	-11.89	-6.42	
1/8" Pos. (X) Mis-Alignment	F/T Serial Number = FT32284						
	Max. Force X (lbf)	Max. Force Y (lbf)	Max. Force Z (lbf)	Max. Torque X (lbf-ft)	Max. Torque Y (lbf-ft)	Max. Torque Z (lbf-ft)	Notes
Mating	22.17	20.44	-289.06 (1)	42.71	22.37	15.65	
Demating	-14.97	8.17	126.94	20.09	7.61	2.84	

Note: 1. Z-Axis Forces in the mating direction are significantly higher during maximum mis-alignment cases as compared to the baseline case due in part to the test set-up of the male coupling flex mount that included the air bearing mount beneath the pressure decay test canister which minimized the z-axis movement of the male coupling.

Figure 13. Flex-mount Maximum Mis-alignment Force & Torques

4. SUMMARY

L3Harris entered into an unfunded Space Act Agreement with NASA STMD through the Announcement of Collaboration Opportunity (ACO) program partnering with NASA Marshall Space Flight Center (MSFC) to advance the TRL of the ELECTRA QD Coupling from TRL 3 to TRL 5. This program consisted of several phases of development with Specification, Design, and Test Reviews as well as manufacturing and testing the coupling for the first time.

The ELECTRA QD Coupling design includes two independent (male and female) dual-sealing housings designed for cryogenic propellant compatibility; a coupling mate/de-mate geared rotary actuator; mated, open and close position sensors; and an optional extend/retract linear actuator system. The coupling can be operated electronically through a controller or manually. The coupling has been engineered and designed to meet the demands of a crew-rated coupling for in-space use with large volume, high flow rate cryogenic propellants (i.e. liquid Oxygen (LOX); liquid Hydrogen (LH2); liquid Methane (LCH4)).

Manufacturing and assembly of the ELECTRA QD Coupling is performed by Aerojet Rocketdyne of L3Harris Technologies. The male coupling includes a spring activated poppet and qty. (3) proximity sensors for mating. The female coupling includes a rotary actuator to drive the internal poppet carried by tri-axial roller bearings traveling on a helical track. The female coupling is mounted on the linear actuator with two proximity sensors that detect the position of the internal

poppet. Testing is performed at both ambient and cryogenic temperatures. Liquid Nitrogen is used for conditioning to cryogenic temperatures and flow characterization. Gaseous helium is used for both ambient and cryogenic leak testing using a mass spectrometer. A force torque sensor is used for measurements during misalignment testing.

The ELECTRA QD Coupling proved to be a very low leakage coupling with valve coefficient of approximately 90, demonstrating 1 psid across the valve while flowing a little over 100 GPM of LN2. Maximum leakage values of less than 20 scim were measured at inter-seal locations at cryogenic temperatures. External leakage in the mated condition with poppets open was not performed at cryogenic temperatures. During individual coupling half cryogenic testing the male coupling demonstrated more leakage than the female coupling. All ambient leakage tests resulted in negligible leakage less than 1 scim.

Testing at the Flat Floor Robotics Lab demonstrated the coupling functionality using two different simulated docking setups. First, force-torque measurements were conducted during a series of misalignment tests using the 6 degrees of freedom table and an overhead A-frame. Maximum forces and torques are reported for each test. Additionally, during each mis-alignment mate/open/close/de-mate test, a leak check of the external seals was accomplished during mated/open position. No pressure decay was noted during any of the mis-aligned mating operations, as long as successful mating and opening of poppets was achieved.

Finally, a more realistic docking scenario was simulated by mounting the Coupling Assembly on the external surfaces of a (ground test) Common Berthing Mechanism (CBM) docking ring system. With the CBM docking system axis oriented in the up/down vertical direction, the Female Coupling and LAA were mounted on the lower CBM ring, with direction of travel in the vertical. The Male Coupling was mounted to the upper CBM ring. The CBM Rings were then docked. After the initial alignments were made to the Coupling positions, several additional docking operations were repeated on the CBM halves, and each time, the Female Coupling was extended/mated/opened/closed/de-mated/retracted from the Male Coupling. This docking/coupling/decoupling/undocking action was successfully repeated several times. Because of the limitations on the schedule and scope and due to the sheer quantity of recorded data, additional effort is needed to fully understand all the reported test results from this data. This will be included in the forward work plan for the ELECTRA-QD Coupling product.

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