

National Aeronautics and
Space Administration



Space Technology Mission Directorate Game Changing Development Program

Michael Doherty | Wesley Johnson | FY20 Cryo Fluid Technologies Annual Review Presentation | 09.16.20

Michael Doherty: Aerospace Engineer, NASA Glenn Research Center, 21000 Brookpark Rd. Cleveland, OH, 44135, Mail Stop 162-4

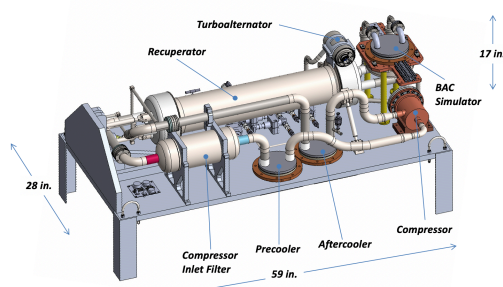
Wesley Johnson: Aerospace Engineer, NASA Glenn Research Center, 21000 Brookpark Rd. Cleveland, OH, 44135, Mail Stop 86-12

CFT Technology Overview

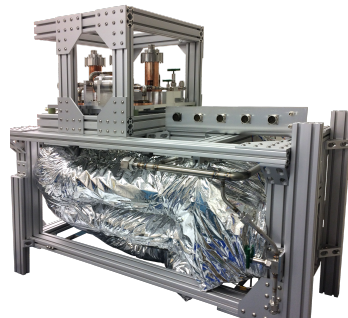


➤ Technology Product Capability

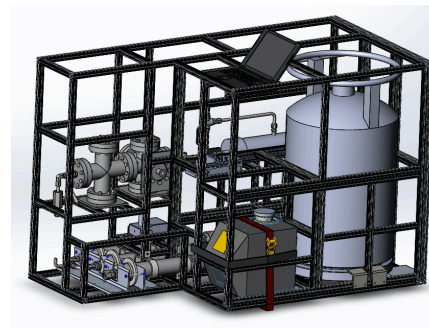
- The Cryogenic Fluid Technologies (CFT) Project is focused on the maturation of cryogenic fluid management (CFM) technologies essential to NASA's future missions in science and exploration which utilize both chemical and nuclear thermal (NTP) in-space propulsion, surface landers, and in situ resource utilization.



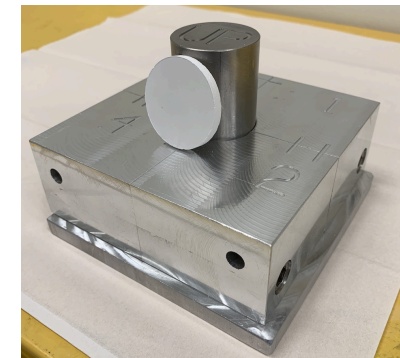
**150W/ 90K Cryocooler
Conceptual Design**



**20W 20K Cryocooler
in Cleanroom**



**RGCT Transfer Line
Chilldown Test**



**One Inch Diameter Yttrium
Oxide (Y2O3) Rigid Tile Sample
Sitting on Sample Mold**

Mission Infusion & Partnerships



➤ Contributing partners and/or stakeholders

- **Creare, LLC:** Creare LLC is providing technology development for 90K and 20K Reverse Turbo-Brayton type cryocoolers. This technology is required for maintaining cryogenic propellants for extended periods of time to enable NASA's planned long duration missions.
- **University of Florida:** The University of Florida is providing experimentation, analysis, and modeling of optimized approaches to cryogenic line chilldown, including conduct of parabolic flight tests to better understand the gravitational sensitivity of heat transfer in a line. This understanding is critical to efficient transfer of cryogenic fluids in space to enable refuelability of in-space stages, landers, and aggregation/ depots.

➤ Infusion/transition plan (**on-going**, **planned**, or **potential**)

- Deliver first prototype hardware of High Capacity 90K Cryocooler directly to ISRU Liquefaction prototype testing at GRC (**planned**)
- Provide direct cryo fluid management technology infusion to HLS Appendix H vendors - SpaceX, Blue Origin, Dynetics – via government task agreements (**on-going**)
 - The 20K and 90 K cryocooler technology has been particularly attractive to HLS vendors
- Proposal to a US company in support of a Tipping Point, proposing Y2O3 spray-on coating for covering cryogenic tanks (**potential**)
- Wide dissemination of results from this technology development effort to a larger audience through conferences, technical publications, and showcases with industry (**on-going**)



150W/ 90K Cryocooler

150W/ 90K Cryocooler – Alternate Approach

- NASA realized that reliance on multiple companies for high capacity 90K cryocooler technology was prudent, and that there were large aerospace contractors who likely had the capability to develop these 150 W at 90 K cryocoolers.
- NASA proposed to contract with these companies for conceptual designs of such a system.
- Two awards were made in February 2019, one to Lockheed Martin (LM) and one to Northrop Grumman Aerospace Systems (NGAS).
 - Both LM and NGAS both proposed and then successfully completed Conceptual Design Review(s) in the October/November 2019 timeframe, based upon **Pulse-Tube cryocoolers**
 - Both submitted non-proprietary final reports
 - While Lockheed has a higher mass and power value, their conceptual system is more thought out from a system level.

150W/ 90K Cryocooler – Alternate Approach (cont.)

- CFT submitted a white paper on 1/31/20 discussing status of 150W/90K cryocooler development, and recommendations for follow-on efforts to meet the Sustainable Lunar presence end goal that is currently in development as a part of the Human Landing System, as well as to meet the NTP development plan for missions as early as 2028 (not the first flight), including:
 - Issue separate contract for Reverse Turbo Brayton (RTB) cycle power electronics
 - Accelerate 90K Reverse Turbo Brayton (RTB) cycle cryocooler for 6-7 month earlier delivery supporting timely infusion to AES Cryogenic Fluid In-situ Liquefaction for Landers (CryoFILL) prototype unit.

150W/ 90K Cryocooler Technology Goals & Project Objectives



Technology Goals

Goal #1	Design, build, and demonstrate a 150 W/90 K RTB cryocooler with a specific mass of 0.4 kg/W and a specific power requirement of 8.0 W/W.
----------------	--

Project Objectives

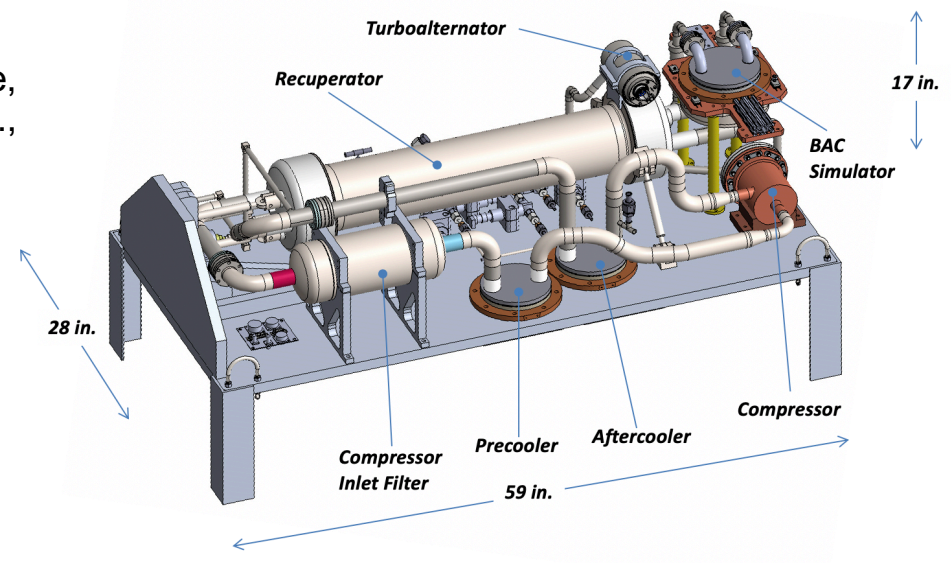
Objective #1	Design, build, and test component hardware for the 150 W/90 K RTB Cryocooler.
Objective #2	Complete brassboard acceptance testing Cryocooler components with recuperator, turbo-alternator, and previously built compressor.
Objective #3	Complete build of 150 W/90 K RTB Cryocooler with recuperator, turbo-alternator, and previously built compressor.
Objective #4	Conduct acceptance and vibration testing of 150 W/90 K RTB Cryocooler to validate system performance and confirm its structural integrity in an operational environment.
Objective #5	Deliver the validated cryocooler system to GRC (for infusion to CryoFILL liquefaction testing).

Accomplishments



Cryocooler System Design

- Held successful Initial Design Review on June 29, 2020.
 - Reviewables consisted of an extensive slide package, supported by formal documentation deliverables (e.g., Software Mgmt Plan, Quality Plan, ICD).
 - Creare covered cryocooler mechanical, electrical, control electronics and software design, turbo-alternator and recuperator component fabrication status, cryocooler brassboard and prototype test plans, and the plans for verification of compliance to NASA requirements.
 - Six Request For Actions (RFAs) assigned to Creare, and closure of all six RFAs is now complete; In addition, the Project has accepted actions, including: define SMiRF interfaces/ test configuration.
- Status to Date: Continuing with final design and analysis of cryocooler



150W/ 90K Cryocooler Preliminary Design

Cryocooler rendition courtesy of Creare

Accomplishments (cont.)



Component Level Design and Fab

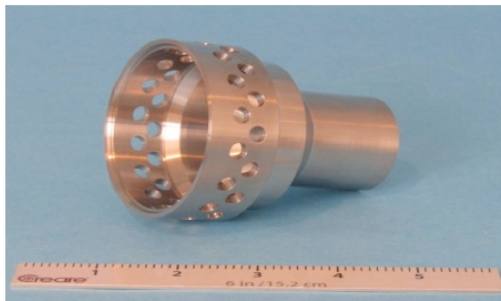
- Held successful Component Final Design Review for the Recuperator and Turbo-Alternator in January 2020, focusing on the design of the Recuperator and Turbo-Alternator.
 - The predicted Key Performance Parameters (Specific Mass and Specific Power) expected to be considerably better than NASA's goals
- Recuperator (status to date):
 - Completed fabrication of weld trial parts to qualify weld for inner tube assembly and performed trial welds
 - Mezzo (Sub-contractor) has ordered material for the mid-plates and tube-sheets.
- Turboalternator (status to date): Completed fabrication of stator laminations and housing, and assembled stator
- Brassboard cryocooler test (status to date):
 - Determined cryocooler component layout inside existing test facility
 - Completed specification of harnesses (size, length, heat leak) and pass-thru assignments and specifications for all signals and fluid interfaces



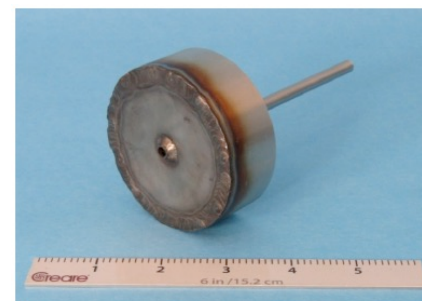
TA Bellows



TA Stator



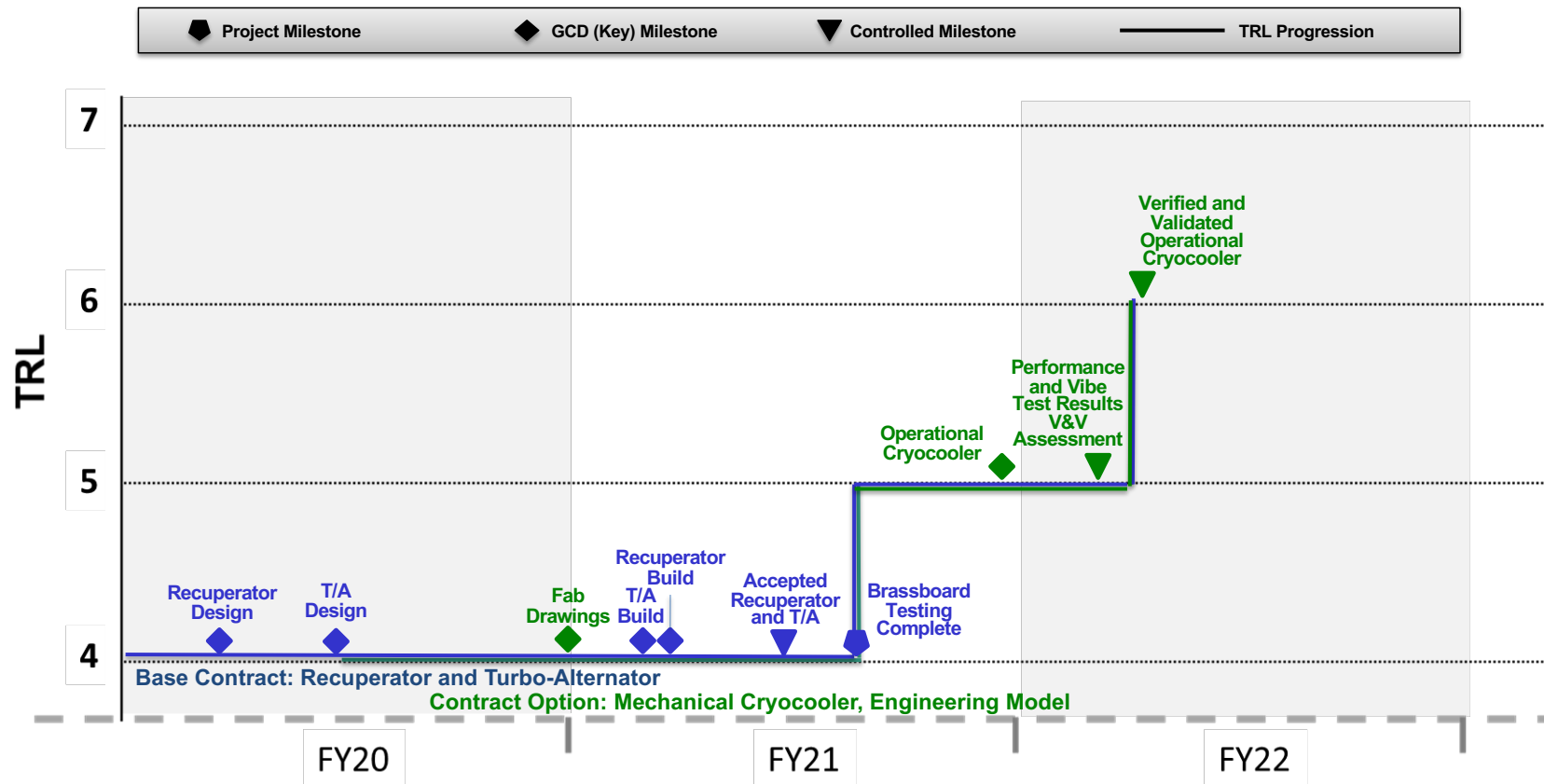
Recuperator Inner Header



Recuperator Header Weld Trial

Images courtesy
of Creare

150W/90K RTB Cryocooler Lifecycle Milestone/Maturity Schedule



Technical Assessment



Technical Elements	TRL				AD ²	
	Entry	Current ¹	Exit	TRL Verification	Entry	Current
Compressor	5	5	6²	Milestone ID# C3	6	6
Recuperator	4	4	6²	Milestone ID# C3	6	6
Turbo-Alternator	4	4	6²	Milestone ID# C3	6	6
¹ Date of last TA was May 1, 2019 ² As microgravity does not play a dominant role in the performance of the Reverse Turbo-Brayton Cycle cryocooler, successful completion of system performance and vibration testing will yield a TRL 6.						

150W/ 90K Cryocooler Key Performance Parameters (KPP) Status



Key Performance Parameters ⁽¹⁾

Parameter	Units	State of the Art (SOA)	Threshold Value	Project Goal	Current Value To Date	Current Value: Technical Basis of Estimate	Expected Exit Value	Exit Value: Technical Basis of Estimate
1) Lift Capacity	Watts	20	120	150	174	Estimated	174 ⁽³⁾	Estimated
2) Specific Mass	kg/Watt	1	0.8	0.4	0.44 ⁽²⁾	Estimated	0.44 ⁽³⁾	Estimated
3) Specific Power	Watt/Watt	15	15	8	7.4	Estimated	7.4 ⁽³⁾	Estimated

Notes:

⁽¹⁾ All KPPs assume a fully integrated cryocooler operating at an environmental temperature of 300 K and are established based on a 90K design point, and do not include the mass and inefficiency of the drive electronics.

⁽²⁾ Includes several items which may not be needed for a flight system

⁽³⁾ Expected Exit Values are based on current predicted performance. There is no basis for expecting different values until hardware is characterized through testing, and predictions are updated.



20W 20K Cryocooler

20W 20K Cryocooler Technology Goals & Project Objectives



Technology Goals

Goal #1	Design, build, and demonstrate a 20 W/20 K Reverse Turbo-Brayton (RTB) cryocooler with a specific mass of 4.4 kg/W and a specific power requirement of 60 W/W.
----------------	--

Project Objectives

Objective #1	Build and inspect rotor and bearing components for 20 W/20 K RTB Cryocooler compressors
Objective #2	Assemble and test the 20 W/ 20K RTB Cryocooler compressors.
Objective #3	Complete the build of the 20 W/20 K RTB Cryocooler.
Objective #4	Conduct acceptance testing of the 20 W /20 K RTB Cryocooler to validate system performance in an operational environment.
Objective #5	Conduct characterization testing of the 20 W /20 K RTB cryocooler performance over a broader range of expected operating conditions
Objective #6	Deliver the validated cryocooler system to NASA

Accomplishments

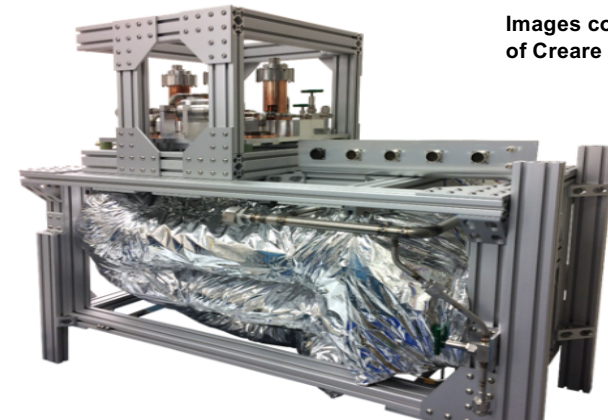


Technical Accomplishments FY20

- Developed inspection procedures for the rebuilt bearings, rotors, and coating evaluation.
- New journal bearings and rotors were manufactured in lots, then subsequently inspected at both Creare and MSFC.
- A characterization and morphology analysis was completed on the tungsten carbide coating at GRC.
- Compressor 2 rebuild started in July with accepted bearings and rotors.



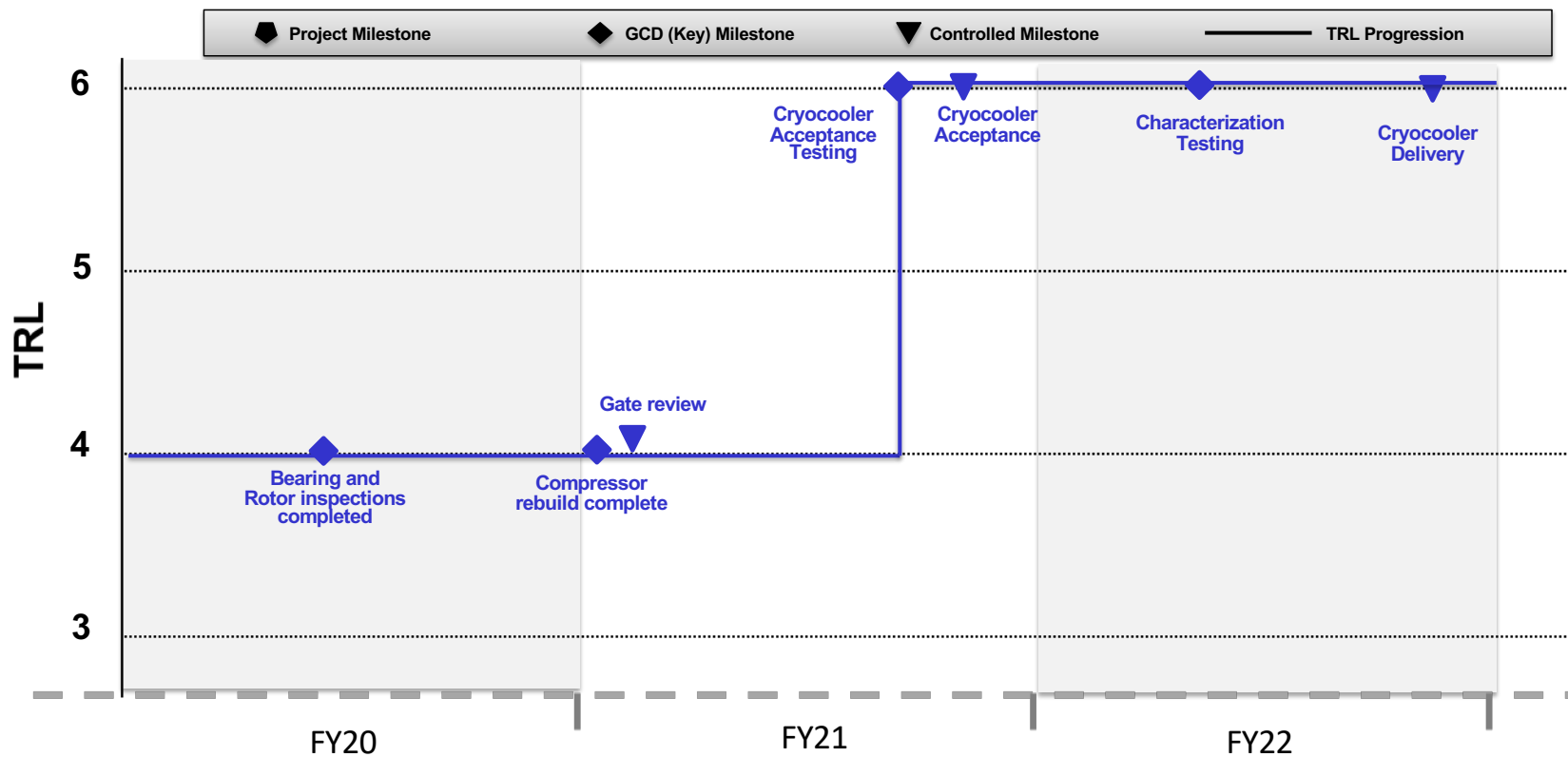
Compressor Rotor



Images courtesy of Creare

20W 20K Cryocooler in Creare's Clean Room

20W 20K Cryocooler Lifecycle Milestone/Maturity Schedule



Technical Assessment



Technical Elements	TRL				AD ²	
	Entry	Current ¹	Exit	TRL Verification	Entry	Current
Compressor	4	4	6	20W 20K Cryocooler Acceptance	6	6
Recuperator	4	4	6	20W 20K Cryocooler Acceptance	5	5
¹ Date of last TA was May 1, 2019						

20W 20K Cryocooler Key Performance Parameters (KPP) Status



Key Performance Parameters

Parameter	Units	State of the Art (SOA)	Threshold Value	Project Goal	Current Value To Date	Current Value: Technical Basis of Estimate	Expected Exit Value	Exit Value: Technical Basis of Estimate
Lift Capacity	W_{therm}	1	17	20	19.1 ⁽¹⁾	Correlated model	19.1 ⁽¹⁾	Correlated model
Specific Mass	$\text{kg}/W_{\text{therm}}$	18.7	5.5	4.4	5.3	Correlated model	5.3	Correlated model
Specific Power	$\frac{W_{\text{elec}}}{W_{\text{therm}}}$	370	80	60	95 ⁽²⁾	Correlated model	95 ⁽²⁾	Correlated model

Notes:

Performance Parameters for Cooling Capacity @ 20K

At 40 psi, T_{sat} is 24.2K, the 20-20 cryocooler lift is 28.4W at 50W/W (1420W input power)

⁽¹⁾ This value represents the as-delivered Engineering model. The flight model is predicted to be 20 W.

⁽²⁾ This value represents the as-delivered Engineering model. The flight model is predicted to be 71 W/W.



Reduced Gravity Cryogenic Transfer

Reduced Gravity Cryogenic Transfer Technology Goals & Project Objectives



Technology Goals

Goal #1	Develop methods and approaches to reduce cryogen propellant mass loss due to line and receiver tank chill down during transfer operations and validate them through analysis and testing.
----------------	---

Project Objectives

Objective #1	Line Chillover: Modify an existing flightworthy cryogenic testbed for experimentation of reduced gravity transfer line chill down
Objective #2	Line Chillover: Demonstrate reduction of propellant mass consumed through the application of a pulse flow technique on line chill down during reduced gravity liquid cryogenic transfer
Objective #3	Line Chillover: Characterize chill down performance improvements in reduced gravity through the application of thermal coating on inside diameter of liquid cryogenic transfer lines
Objective #4	Line Chillover: Develop, verify, and validate numerical models to design future reduced gravity transfer line architectures
Objective #5	Tank Chillover: Design, build, and verify a versatile flightworthy cryogenic testbed for experimentation of reduced gravity cryogenic tank to tank transfer experiments
Objective #6	Tank Chillover: Evaluate three alternate receiver tank chill down methods to demonstrate the performance improvement on transfer rate and mass savings
Objective #7	Tank Chillover: Design and build alternate tank injectors and demonstrate the chill down and fill performance improvements for transfer rate and mass savings
Objective #8	Tank Chillover: Demonstrate (collect data) feasibility of tank to tank transfer (achieving tank chillover) of cryogenic fluid at reduced gravity for up to three operational concepts
Objective #9	Tank Chillover: Develop, verify, and validate numerical models to design future reduced gravity tank to tank transfer architectures

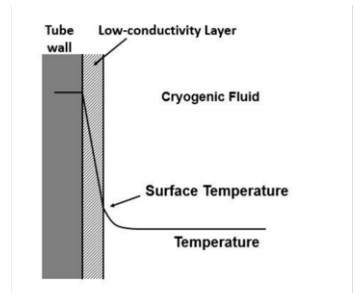
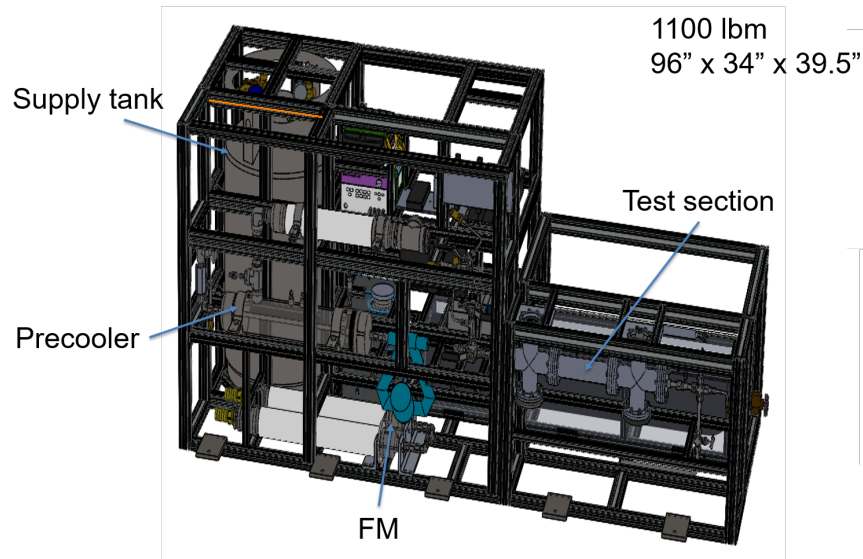
Accomplishments



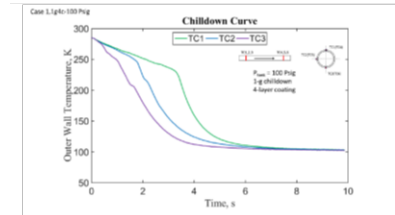
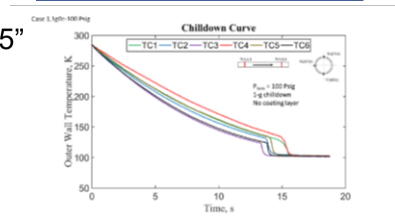
Technical Accomplishments FY20

➤ Line Chilldown

- Demonstrated 1-g performance gain of Teflon coatings on the transfer line. Optimized thickness needs to be determined though.
- Analytical model developed for optimizing thermal coating material and coating type on transfer line.
- Modified and flight qualified a test rig to obtain low-g line chilldown data
- **Plan was to conduct parabolic flight tests on-board the Zero-G aircraft in March 2020**
 - Flights delayed due to COVID



Temperature profile of coated transfer line



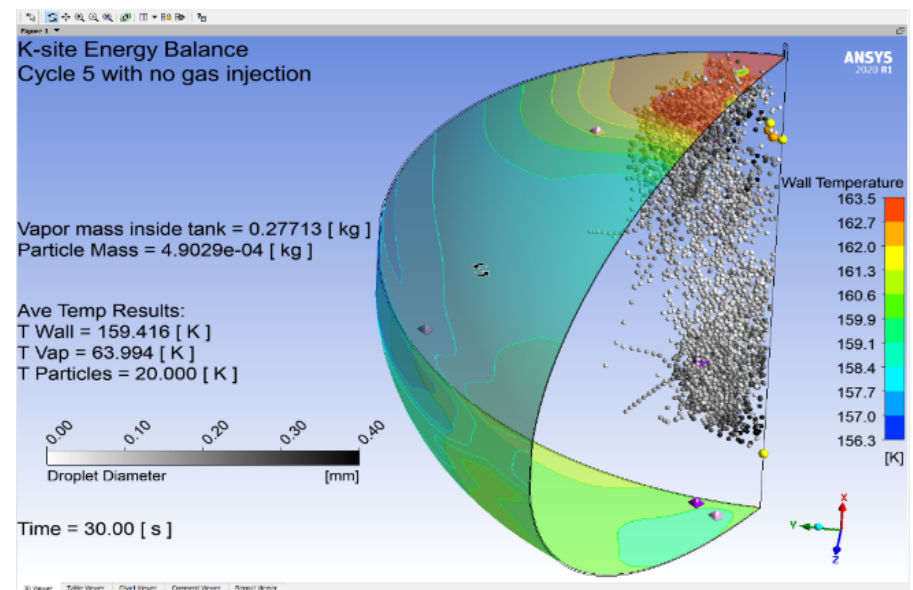
Effect of thermal coatings on chilldown time

Accomplishments (cont.)



➤ Modeling and Analysis

- Performed CFD and lumped node code validation against two historical data sets
- Completed Thermal Desktop model validation against K-site tank chilldown data
- Developed an analytical tool to design and size optimal tank Chilldown and fill injectors



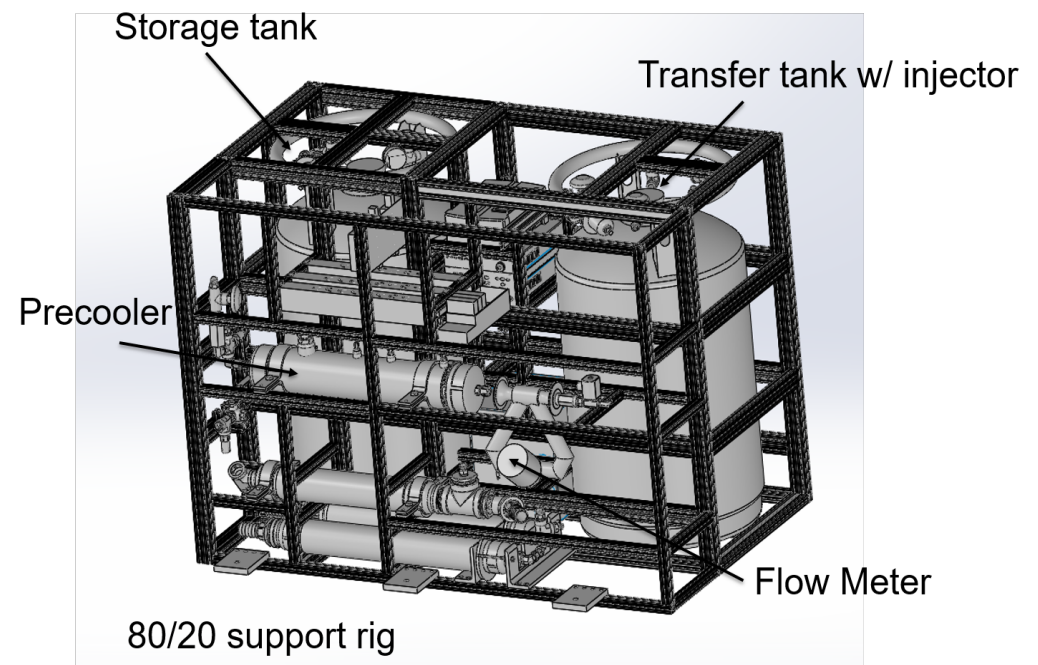
CFD Tank temperature contours and particle trajectories

Accomplishments (cont.)

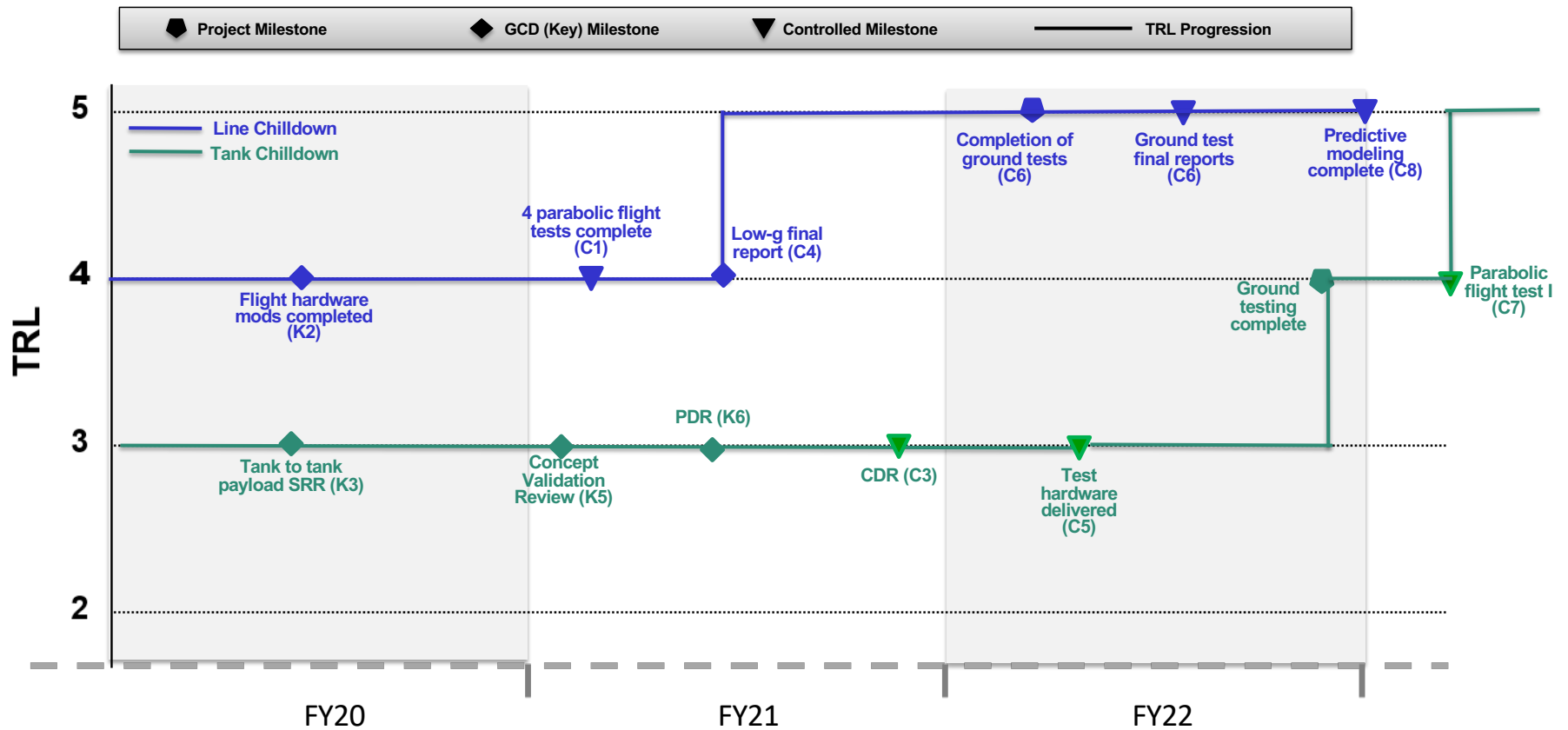


➤ Tank-to-Tank Parabolic Flight Rig Design

- Successful System Requirements Review for NASA flight rig
- Developed injector concept designs
 - 24 concepts paired down to 8 concepts for Concept Validation Review (scheduled in 10/2020) using the Analytical Hierarchy Process
- Developed multiple concept of operations for different chilldown methods;
- Developed Qty=3 Tank Chilldown Concepts for final selection



RGCT Lifecycle Milestone/Maturity Schedule



Technical Assessment



Technical Elements	TRL				AD ²	
	Entry	Current ¹	Exit	TRL Verification	Entry	Current
Line Chill Down Coatings	4	4	5	C6 1-g Final Report	5	5
Line Chill Down Valve Duty Cycle	4	4	5	C6 1-g Final Report	5	5
Tank Chill Down Injection Method	3	3	5	C10 Final Report Flight Test Data Analysis	6	5
Tank Chill Down Method	3	3	5	C10 Final Report Flight Test Data Analysis	6	5
¹ Date of last TA was June 5, 2020						

RGCT Key Performance Parameters (KPP) Status



Key Performance Parameters

Parameter	Units	State of the Art (SOA)	Threshold Value	Project Goal	Current Value To Date	Current Value: Technical Basis of Estimate	Expected Exit Value	Exit Value: Technical Basis of Estimate
1) Vented nitrogen mass reduction for achieving line chill down using pulse flow in low-g	%	Continuous Flow	30	50	50	Preliminary ground test data ³	50	Estimated ⁴
2) Vented nitrogen mass reduction for achieving tank chill down using alternate methods in 1-g ¹	%	Vented Chill/ Vented Fill	50	70	50	Estimated ⁵	70	Estimated
3) Demonstrate operational concept to achieve tank chill down to target temperature during parabolic flight ²	Quantity	0	1	3	0	Requires parabolic flight system testing	3	Estimated

Notes:

- 1) Chill down valve cycling approaches combined with injection methods will be basis for overall reduction in vented nitrogen mass
- 2) Chill down operation will be conducted continuously over multiple parabolic cycles during a test flight.
- 3) Ground test data on coated tube sections gathered in Q4FY20 shows promise to meet the KPP in reduced gravity flights currently scheduled for Q2FY21
- 4) There is a known reduction in heat transfer in reduced gravity due to lack of buoyancy force, so the flight based performance is based on projecting ground based performance
- 5) Based on thermal equilibrium based models



Cryo Thermal Coating (Solar White)

Cryo Thermal Coating (Solar White) Technology Goals & Project Objectives



Technology Goals

Goal #1	Develop technology to manufacture solar reflector tile of Yttrium Oxide (Y ₂ O ₃) with solar absorption levels between 1% and 0.3% capable performing in deep space environments on future space vehicles.
Goal #2	Develop technology to use Y ₂ O ₃ as a spray-on solar reflector coating that can be readily applied to large structures with solar absorption levels between 6% and 3%.

Project Objectives

Objective #1	Develop the optimal process to manufacture Y ₂ O ₃ tiles that meet the desired performance standards. This includes optimization of parameters such as sintering temperature, thickness, and metallic coating to balance high solar reflectivity with tile breaking strength.
Objective #2	Develop a high performance spray-on coating based on Y ₂ O ₃ with uniformity, minimal thickness and flake generation, while maximizing solar reflectance.
Objective #3	Construct and verify operation of simulated deep-space environmental chambers for quantifying solar reflectivity.
Objective #4	Test to quantify tile and spray-on-coating performance in deep-space environmental chambers and spectrophotometers.
Objective #5	Test to quantify tile degradation due to interactions with atomic oxygen.

Accomplishments

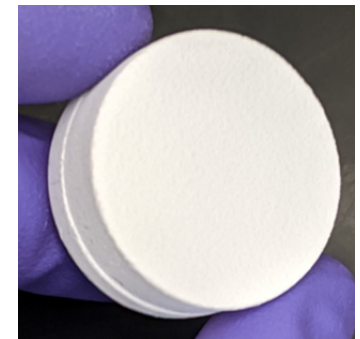


➤ Technical Accomplishments FY20

- Installation of new Spectral Reflectometer and acquisition of NIST traceable reflectance standards (see photo).
- Familiarization with the new spectrometer and the measurement of spectral absorptivity. Numerous runs were made to understand the impact of sample alignment, sample gaps, scan speed, humidity, and sample tilt on absorptivity measurements.
- Collaboration with several industries on the development and evaluation of material samples
- Systematic Study of High Reflection Yttrium Oxide (Y_2O_3)-Based Spray on Coating. Three different formulations were applied to aluminum, steel, silver, and multilayer insulation. We achieved our project goal of 3% solar absorptivity by spraying on a smooth surface of 7075 aluminum (2.8%)—see the photo to the right.
- Spray on test samples are being constructed for testing at GRC, for incorporation in an LSP funded cube sat, for KSC testing, and for use in a vibration test to ensure adherence of the coating.



The reflectance spectrometer and two solar white samples.



Spray on coating on 7075 Al achieved 2.8% solar absorptivity!

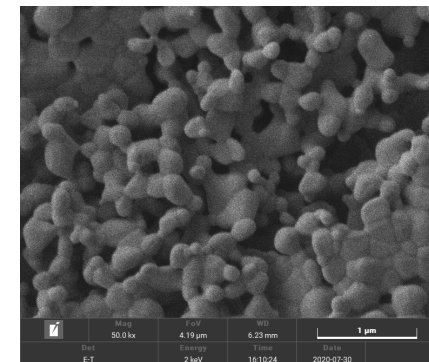
Accomplishments (cont.)



➤ Technical Accomplishments FY20

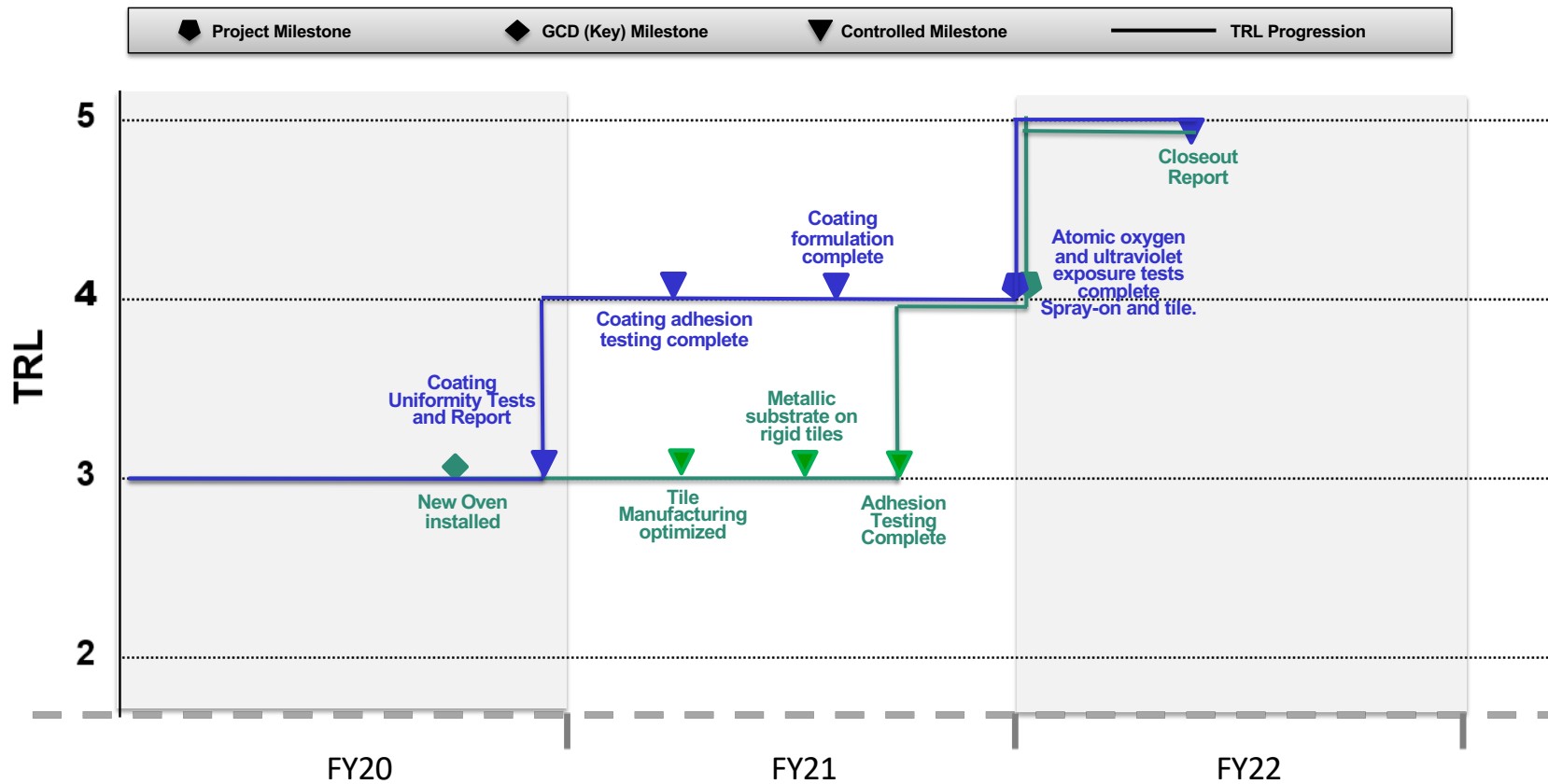
- Rigid Tile Development has proceeded with the receipt of a new oven (see photo) and better fabrication procedures. The new tiles are much stronger (see the SEM photo of a tile showing the welded particles) yet still exhibit good solar absorptivity (better than the NIST standard we compare against).
- Subcontracts with the KSC Thermal Protection System Facility were established in order to begin to migrate this technology to a manufacturing entity. COVID issues have affected this process.
- Atomic oxygen and ultraviolet exposure testing has been delayed due to the COVID shutdown at GRC.
- GRC is developing a deep space simulator but COVID issues have delayed final testing, delaying its use in testing the coatings.
- Submitted proposal to a US company in support of a Tipping Point, proposing Y2O3 spray-on coating for covering cryogenic tanks

The inside of the new oven, allowing higher sintering temperatures. A ceramic mold containing pressed powder is shown.



An SEM image of 1375 C sintered Y2O3 powder showing fusing, resulting in a strong, rigid, highly reflective material. The white bar is 1 micron long.

Cryo Thermal Coating Lifecycle Milestone/Maturity Schedule



Technical Assessment



Technical Elements	TRL				AD ²	
	Entry	Current ¹	Exit	TRL Verification	Entry	Current
1: Spray-on Coating (MRL)	3	3	5	K3->TRL 4, K4->TRL 5	7	7
2: Spray-on Coating (TRL)	3	3	5	K3->TRL 4, K4->TRL 5	7	7
3: Rigid Tile Coating (MRL)	3	3	5	C4->TRL 4, K4->TRL 5	7	7
3: Rigid Tile Coating (TRL)	3	3	5	C4->TRL 4, K4->TRL 5	7	7
¹ Date of last TA was May 12, 2020						

Cryo Thermal Coating: Key Performance Parameters (KPP) Status



Key Performance Parameters

Parameter	Units	State of the Art (SOA)	Threshold Value	Project Goal	Current Value To Date	Current Value: Technical Basis of Estimate	Expected Exit Value	Exit Value: Technical Basis of Estimate
KPP 1: Solar Absorption of Rigid Tiles	%	6 ⁽¹⁾	1	0.3	1.2	Substantiated ⁽²⁾	0.5	Estimated ⁽³⁾
KPP 2: Solar Absorption of Spray-on Coating	%	15 ⁽⁴⁾	6	3	2.8	Verified ⁽⁵⁾	3	Estimated ⁽⁶⁾

Notes: Examples

⁽¹⁾ Silvered Quartz

⁽²⁾ New rigid tiles have been fabricated, but COVID delays have prevented the upgrade of the deep space simulators (both at KSC and at GRC). 1.2% is the project entrance value based on a fabricated deep space simulator.

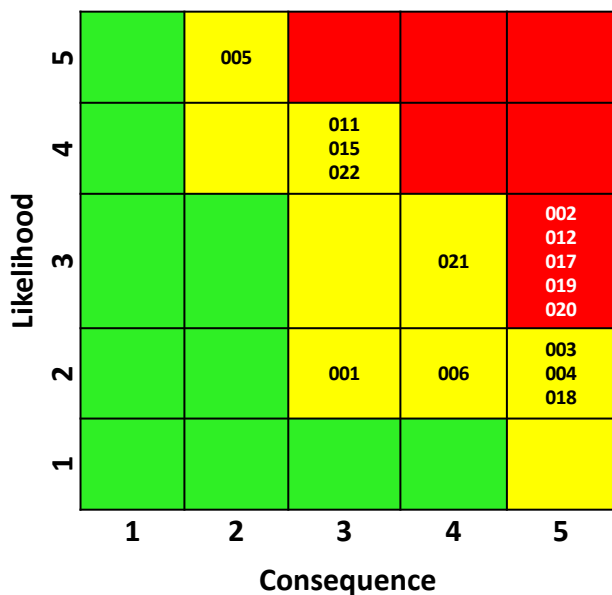
⁽³⁾ Measurements using a spectral reflectometer indicate the new tiles are superior to the earlier fabricated tiles so we expect to see this lower value upon testing in a deep space simulator. Also, we do not expect to see degradation due to UV or atomic oxygen exposure.

⁽⁴⁾ AZ-93, a commonly used high reflectivity paint used on spacecraft. A better paint exists (9%) but is expensive and not commonly used.

⁽⁵⁾ Test conducted on 08/04/2020 comparing the spray-on coating to a NIST traceable reflectance standard and using ASTM E903. Test Report "Y2O3 Based Spray-On Cryogenic Thermal Control Coating Study" contains further objective evidence. NOTE: This was a new sample that had not been exposed to any degrading environments.

⁽⁶⁾ We do not expect to see a significant drop in performance due to ultraviolet or atomic oxygen exposure. Exposure testing will occur in FY21.

Risk Summary



Legend	
	Decreasing LxC
	Increasing LxC
	Unchanged LxC
	New since last period

Risk ID	LxC	Trend	Risk Title	Approach
001	2x3		20W20K Cryocooler Software Documentation	Mitigate
002	3x5		Personnel Availability	Watch
003	2x5		150W90K Performance requirements under FFP contract	Watch
004	2x5		RGCT Zero- G Flight Availability	Watch
005	5x2		Coatings-Loss of Key Personnel	Mitigate
006	2x4		Coatings-Facility equipment availability	Watch
011	4x3		20W20K Incomplete Performance Mapping	Mitigate
012	3x5		20W20K Mechanical Failure	Watch
015	4x3		Operating Experience	Mitigate
017	3x5		Cryocooler Electronics Development	Watch
018	2x5		150W90K Heritage Design Issues from 20 K to 90 K RTB Cryocoolers	Watch
019	3x5		20W20K Rotor Coating Deficiency	Mitigate
020	3x5		RGCT-System Operation in Reduced Gravity	Mitigate
021	3x4		RGCT- Receiver Tank	Watch
022	4x3		RGCT-COVID-19 Impact to RGCT	Mitigate

Project Assessment Summary



Project Name	Performance				Comments
	C	S	T	P	
Mid Year					Cost, Schedule – RGCT: The current Integrated Master Schedule shows a date for flight hardware readiness to flight turnover (following ground testing) of the Tank to Tank Chilldown Rig that is 4-5 months behind the first scheduled flight aboard the ZeroG aircraft, affecting both schedule and cost.
Annual					The CFT Project Plan, now in approval cycle, has eliminated cost and schedule variances formerly existing for RGCT and 20W 20K Cryocooler

This assessment does not consider the impact that COVID-19 will have on schedule stretch out (and associated costs)

EPO Update



➤ Summary of Education and Public Outreach

Portfolio-Element	Lead Author	Secondary Authors	Title	Conference/ Date Location
RGCT	Alok Majumdar	A. LeClair, J. Hartwig, A. Martin, N. Rhys	Numerical Modeling of No Vent Filling of a Cryogenic Tank	55th AIAA/SAE/ASEE Propulsion & Energy Forum Exposition, 8/24-8/26/2020
Cryo Thermal Coating	Jarred Wilhite	Jason Wendell	Solar White Thermal Coating for Cryogenics Propulsion Systems	Thermal & Fluids Analysis Workshop (TFAWS) 2020, 8/18-8/20/2020

# of Students	Education Level	School Name
1	MS, 1 st year	Ohio State University
1	MS, 1 st year	Case Western Reserve University

➤ Upcoming Significant Media Coverage

➤ None

Summary



➤ Accomplishments for the Year

- Held Concept Design Reviews for Alternative 150W/90K Cryocoolers (November), and submitted a white paper on discussing status of 150W/90K cryocooler development (January)
- Modified and flight qualified a test rig to obtain low-g line chilldown data for RGCT (February)
- Successfully completed System Requirements Review for RGCT Tank Chilldown flight rig (March)
- Successfully completed 150W/ 90K Cryocooler Initial Design Review (June)
- New journal bearings and rotors for the 20W 20K Cryocooler were manufactured, then subsequently inspected at both Creare and MSFC, with good comparison, leading to approval to rebuild Compressors (July)
- Completed systematic study of High Reflection Y2O3-Based Spray on Coating. Three different formulations were applied to aluminum, steel, silver, and multilayer insulation, achieving project goal of 3% solar absorptivity (July)
- Rigid Tile development has proceeded with the receipt of a new oven and better fabrication procedures, yielding stronger tiles that still exhibit good solar absorptivity (July)

➤ Plans Forward <FY21>

- Hold RGCT Tank Chilldown Concept Validation Review (October)
- Activate Deep Space Simulator (Cryogenic Thermal Coating) at GRC (October, but dependent upon timely RTOW)
- Conduct RGCT Line Chilldown flight testing (November)
- Assemble and test the 20 W/ 20K RTB Cryocooler compressors and conduct Gate Review (February)
- Optimize tile manufacturing (March)
- Complete 150W/ 90K cryocooler brassboard acceptance testing -recuperator, turbo-alternator, and previously built compressor (April)
- Solar White Coating formulation complete (June)
- Complete Atomic oxygen and ultraviolet exposure tests on Spray-on coating and rigid tile (August)



Primary GCD Interfaces

GCD Program Manager
Drew Hope (LaRC)

GCD Program Element Manager
Matt Melis (GRC)

WBS 1.0 Cryo Fluid Technologies
Project Manager – Michael Doherty
Lead Technologist – Wesley Johnson
MSFC Lead – Jonathan Stephens
KSC Lead – Robert Youngquist
CDM Lead – Tracy Leonard
SMA Lead – Sean Beckman
Scheduler – Alan Sikon
Resource Analyst – Marcus Tarver

WBS 4.1
High Cap 90K Cryocooler

WBS 4.1.1
Alternative Concepts
PI – Wesley Johnson

WBS 4.1.1.1
Lockheed Martin
COR – Wes Johnson

WBS 4.1.1.2
Northrup Grumman
COR – Wes Johnson

WBS 4.1.2
Create
PI – Jonathan Stephens

WBS 4.2
Reduced Gravity Cryo Transfer
PI – Jason Hartwig

WBS 4.2.1
Line Chilldown Analysis,
Gr. & Flt. Testing (U of F)
COR – Jason Hartwig

WBS 4.2.2
Tank PL Design & Test
PLE – Eric Carlberg

WBS 4.2.3
Model. & Data Analysis
Jason Hartwig

WBS 4.3
20W 20K Cryocooler
PI – Ben Nugent

WBS 4.3.1
Cryocooler Development
and Acceptance Testing

WBS 4.3.2
Cryocooler
Characterization Testing

WBS 4.4
Cryo Thermal Coating
PI – Robert Youngquist

WBS 4.4.1
Materials Development
Angela Krenn

WBS 4.4.2
Deep Space Solar
Simulator Testing
Lead - Jason Wendell

EPO Summary Chart



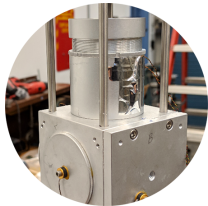
➤ Conferences attended (virtual attendance)

Portfolio-Element	Lead Author	Secondary Authors	Title	Conference/ Date Location
RGCT	Alok Majumdar	A. LeClair, J. Hartwig, A. Martin, N. Rhys	Numerical Modeling of No Vent Filling of a Cryogenic Tank	55th AIAA/SAE/ASEE Propulsion & Energy Forum Exposition, 8/24-8/26/2020
Cryo Thermal Coating	Jarred Wilhite	Jason Wendell	Solar White Thermal Coating for Cryogenics Propulsion Systems	Thermal & Fluids Analysis Workshop (TFAWS) 2020, 8/18-8/20/2020

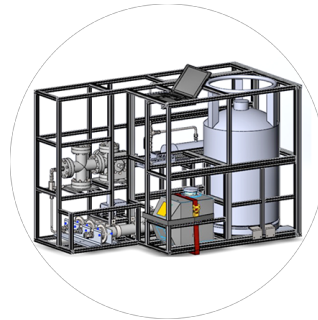
➤ Academic involvement

# of Students	Education Level	School Name
1	MS, 1 st year	Ohio State University
1	MS, 1 st year	Case Western Reserve University

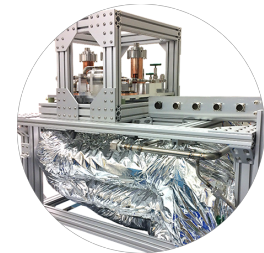
Cryo Fluid Technologies



GRC Deep Space Solar Simulator



UF Transfer Line Chilldown Test (Existing Hardware)



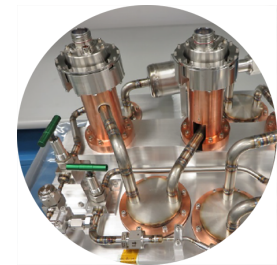
20W 20K Cryocooler in Clean Room



20W 20K Cryocooler Recuperator



Cryo Thermal Coating Sample



20W 20K Cryocooler Compressors

GCD Project Performance Evaluation Criteria



	Technical/Performance
Green	Project is demonstrably making progress on the Learning Trajectory (e.g. milestones met, knowledge advanced) or advancing TRL. Project is on track to meet L1 requirements.
Yellow	Project is making progress on the Learning Trajectory or advancing TRL with issues. Project is on track to meet L1 requirements but issues exist that may threaten achievement.
Red	Project has ceased to make progress on the Learning Trajectory or advance TRL. Project is unable to meet one or more L1 requirements.
	Cost
Green	Project can meet its commitments with its planned/allocated budget.
Yellow	Project cannot meet its commitments within its planned/allocated budget but will not be requesting additional budget from Program. Mitigation plans have been developed.
Red	Project cannot meet its commitments within its planned/allocated budget and will be requesting additional budget from Program.
	Schedule
Green	Project can meet its commitments within its planned/allocated schedule baseline for critical milestones.
Yellow	Project cannot meet its commitments within its planned/allocated schedule baseline but mitigation plans have been developed to pull it back in.
Red	Project cannot meet its commitments within its planned/allocated schedule baseline.
	Programmatic (Institutional, Internal/External Dependencies **)
Green	Relevance of technology to stakeholders and/or technology infusion path is maintained. Mission sponsor still actively interested. No issues exist with workforce, test facilities, etc.
Yellow	Relevance of technology to stakeholders and/or technology infusion path are threatened. Mission sponsor backing off. Issues exist with workforce, test facilities, etc. but plans to mitigate are available.
Red	Relevance of technology to stakeholders and/or technology infusion path are not projected to be met, or has lost relevance to stakeholders. Mission sponsor cancelled interest. Issues pertaining to workforce, test facilities, etc. are preventing progress along the Learning Trajectory.