# Integrated Ground Operations Demonstration Units

# Testing Plans and Status

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**Cryogenic propellant loading operations with their associated flight and ground systems are some of the most complex, critical activities in launch operations. Consequently, these systems and operations account for a sizeable portion of the life cycle costs of any launch program. NASA operations for handling cryogens in ground support equipment have not changed substantially in 50 years, despite advances in cryogenics, system health management and command and control technologies. This project was developed to mature, integrate and demonstrate advancement in the current state of the art in these areas using two distinct integrated ground operations demonstration units (GODU): GODU Integrated Refrigeration and Storage (IRAS) and GODU Autonomous Control.**

## Nomenclature

| | | |
|---|---|---|
| *ANSI* | = | American National Standards Institute |
| *ARC* | = | Ames Research Center |
| *ASME* | = | American Society of Mechanical Engineers |
| *CFM* | = | Cryogenic Fluid Management |
| *CTL* | = | Cryogenic Test Laboratory |
| *COTS* | = | Commercial Off the Shelf |
| *ETDP* | = | Exploration Technology Development Program |
| *FY* | = | Fiscal Year |
| *GODU* | = | Ground Operations Demonstration Unit |
| *gpm* | = | gallons per minute |
| *GRC* | = | Glenn Research Center |
| *He* | = | helium |
| *IRAS* | = | Integrated Refrigeration and Storage |
| *IRL* | = | Integrated Readiness Level |
| *ISRU* | = | In-situ Resource Utilization |
| *kgal* | = | kilogallons |
| *KSC* | = | Kennedy Space Center |
| *KPP* | = | Key Performance Parameter |
| *LH2* | = | liquid hydrogen |
| *LOX* | = | liquid oxygen |
| *JSC* | = | Johnson Space Center |
| *MSFC* | = | Marshall Space Flight Center |
| *NASA* | = | National Aeronautics and Space Administration |
| *NFPA* | = | National Fire Protection Association |
| *OCT* | = | Office of Chief Technologist |
| *PI* | = | Principal Investigator |
| $Q_R$ | = | Refrigerator Capacity |

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|---|---|---|
| $Q_{HL}$ | = | Heat Leak of System |
| *SSC* | = | Stennis Space Center |
| *TRL* | = | Technology Readiness Level |
| *ZBO* | = | Zero Boil-Off |

## I. Introduction

CRYOGENIC propellant loading operations with their associated flight and ground systems are some of the most complex, critical activities in launch operations. Consequently, these systems and operations account for a sizeable portion of the life cycle costs of any launch program. NASA operations for handling cryogens in ground support equipment have not changed substantially in 50 years, despite advances in cryogenics, system health management and command and control technologies. This project was developd to mature, integrate and demonstrate advancement in the current state of the art in these areas using two distinct ground operations demonstration units (GODU): GODU Integrated Refrigeration and Storage (IRAS) and GODU Autonomous Control.

The GODU IRAS and GODU Autonomous Control demonstration units will be used to raise the technology readiness levels (TRL) and integration readiness levels (IRL) of several key technology development areas from previous programs. The goal of the projects is to reduce operations life cycle costs of future programs at the agency's engine test and launch operations centers and serve as a demonstration of technologies for future exploration beyond low earth orbit. These units also serve excellent analog test environments for future extraterrestrial surface operations where communication time delays and the lack of a 'standing army of experts' will hamper a small crew's efforts to service their own spacecraft for a return trip home. Specifically these demonstrations will address two aspects of cryogenic operations utilizing two commodities, liquid hydrogen (GODU IRAS) and liquid oxygen (GODU Autonomous Control): 1) reducing the 'standing army' of highly skilled engineers associated with maintaining and operating ground system through the use of health management and autonomous control technologies utilizing the GODU Autonomous Control unit and 2) the reduction of the consumable costs associated with cryogenic propellant operations and demonstration of propellant handling operations (liquefaction, storage and distribution) utilizing the GODU IRAS unit. Combining the technology demonstrations from both these units provides an overall demonstration of technologies that are directly applicable to future space launch complexes. These units also provide excellent analog test environments for future exploration surface system operations on the Moon and Mars that utilize in-situ resource utilization (ISRU) systems to manufacture, store, and transfer propellants and other consumable commodities like Oxygen, Methane and Hydrogen in an environment where there is no 'standing army of cryogenic experts' to care and administer a complex set of hardware and processes and lengthy communication time delays hamper a small crew's ability to make timely and effective corrective action of anomalous conditions.

## II. Background

Advanced cryogenic systems are needed to minimize consumable losses (zero loss storage and helium conservation), enable higher performance launch vehicles (densified propellants) and enable lower program operations cost by reducing the need for large, highly skilled workforces at multiple locations (health management and autonomous control). On site liquefaction of cryogenic propellants opens up additional possibilities for future spaceports in the way propellants are procured. Instead of purchasing propellant at the plant and transporting the hazardous commodities hundreds of miles to the launch site (transportation costs are a significant percentage of propellant costs), on site liquefaction can enable local production of the propellant, significantly reducing operational constraints at busy spaceports. These advances make space access more reliable and affordable for all future launch activities. Low cost, reliable access to space is the necessary first step in any sustainable human exploration program and will benefit all exploration architectures. In addition, thermodynamic behavior, health management and autonomous control characterized and matured by these demonstration units will be directly applicable to future ISRU systems where propellant is produced, liquefied and utilized on extraterrestrial surfaces where minimum or no real-time crew oversight is available.

Typically cryogenic propellant servicing systems and operations have been expensive from a consumables and labor standpoint, and this project will prove design and operational concepts that can substantially reduce these costs. This project will demonstrate advanced cryogenic hardware, health management and autonomous control systems and operations that will increase safety and reliability of launch operations and minimize losses of expensive commodities of hydrogen and helium. Advances in health management architecture and technology will enable the move from a manually intensive scheduled maintenance and reactive repair posture to a highly reliable, low manpower prognostic driven maintenance paradigm. These activities directly support the Office of Chief Technologist (OCT) technology roadmaps of TA-4 Telerobotics and Autonomous Systems, TA-7 Human Exploration Destination Systems and TA-13 Ground and Launch Systems Processing. Details on the test objectives and technical approach for each commodity follow below:

### A. GODU Autonomous Control (GODU LOX)

The primary objectives of the GODU Autonomous Control system are to:

- Demonstrate autonomous control of a sub-scale vehicle loading operation
- Demonstrate recognition of common system faults and anomalies and recover without human intervention
- Evaluate tools and techniques in real world application to advance health management and autonomous control technologies for future applications
- Demonstrate scalability and extensibility by replicating autonomous control of the 6,000 gallon LOX simulator system to the 33,000 gallon LH2 system
- Demonstrate helium conservation instrumentation and processes

Cryogenic propellant loading operations for the Shuttle program typically involved several large pockets of specialized engineers and managers from across the country (KSC, JSC, MSFC, Michoud and Rocketdyne) monitoring the propellant ground and flight systems during the critical final hours prior to launch. The hazardous nature, complexity, criticality, and vulnerability of the launch vehicle and associated ground servicing systems in conjunction with the lack of insight into system health combined to drive the size of this workforce on launch day. By demonstrating new health management and autonomous control techniques and technologies in the GODU Autonomous Control system, this project will show the potential for reducing man-power in future launch operations and provide critical concept validation of autonomous control of future surface systems that can minimize the need for real-time human oversight and intervention.

The GODU Autonomous Control system resides at the Cryogenic Test Laboratory (CTL) at KSC and consists of a small scale propellant loading system that mimics the cryogenic propellant servicing system at a typical launch pad including propellant storage tank (6kgal), pumping complex (0-400 gpm), control valve skids and vehicle simulator tank (500 gallon and 2 kgal). This system is being used to provide a testing environment for advanced cryogenic components, sensors, and health management technologies and the demonstration of a control system capable of recognizing and automatically correcting for simple system failures typical of heritage launch vehicle servicing systems. The system will allow the comparison, down select and maturation of the best ground health management and autonomous control concepts from ARC, SSC and KSC on typical cryogenic propellant servicing hardware.

Figure 2-1. The GODU Autonomous Control unit at the KSC Cryogenics Test Laboratory

Tools, technologies, and a health management capability and architecture will be developed and integrated into the GODU Autonomous Control unit to provide a robust approach to autonomous propellant loading operations. Control, fault detection, isolation, and recovery functions will be automated in the health management architecture to help improve system availability and ensure mission success with less specialized expert oversight. The health management capability will support integrated operations with traditional command, monitoring, and control functions; it will also support loading operations as a stand-alone, portable capability.

The automation of functions and processes within the architecture will provide repeatable, reliable, loading operations that need only minimal human oversight and intervention. Furthermore, the embedded system/process knowledge required for such automation will reduce the number of people and lower the skill levels required for the system's operation. The distribution/allocation of functions, processes, and system/component knowledge to the lowest appropriate levels within the architecture will provide fast, reliable operation, monitoring, and supervision functions.

This effort will produce viable concepts that will reduce the risk for maturing, demonstrating, and deploying autonomous ground systems and advanced ground systems capabilities for launch operations. It will also provide a robust, reliable, fault-tolerant architecture that will support the goals of lowering operations and maintenance costs and achieving rapid deployment, processing, and launch of vehicles and payloads with the minimum number of skilled personnel in the field. Furthermore, this approach will optimize information transfer (reducing the required data transfer bandwidth of traditional systems) and reduce the time required for data/process validation. Overall, the integration of system health management with the traditional command, monitoring, and control functions will improve system reliability while reducing human interaction in the operation, maintenance, and repair of the system.

Large-volume consumption of helium (He) remains in common practice for launch processing of vehicles that use LH2/LOX engines. Because He is a nonrenewable, finite resource, this unbridled use threatens its availability for use by future generations and adds significant consumables cost to any launch program over its operational life ($6M annually at KSC in the wanning years of the shuttle program). For prelaunch operations, sensing is required before introduction of both LH2 and LOX to verify that all the condensable gases have been removed from the propellant servicing feed lines. For post-launch operations, sensing is required for safing the LH2 system after launch or scrub turnaround to verify that the line has been inerted and that no hydrogen remains. Samples are extracted from a transfer line and sent to a lab for analysis, a time-consuming process that occurs during time-critical operations such as launch countdown or scrub operations. The current He purging philosophy is very conservative, using high flow rates and long flow times, to mitigate significant delays that could occur if the first samples taken for analysis fail the system purity requirements. The concept of operations for the He purge of LH2/LOX engine systems is expected to remain as is until technologies are developed for new launch propulsion systems.

In-situ sensing technologies (in partnership with GRC) will be demonstrated at SSC and KSC to provide real-time purity analysis of gases in the flow line and visibility into the system operation to enable shorter purge times and higher confidence in alternative purge methods. For a specific operation (the LH2 line purge), a savings of at least 30% over Space Shuttle practices is anticipated.

Alternatives to helium use, such as keeping lines continuously serviced, substituting helium with a gaseous nitrogen and hydrogen purge process and using advanced insulation systems to eliminate umbilical purge needs, have been proposed as high-priority technology needs. These approaches will be investigated in years 2 and 3 of this work effort at SSC and KSC, in which recommendations will be captured for future military and commercial launch programs. The ground operations demonstration units and the test infrastructure at SSC are perfect test beds for investigating, developing, and maturing these He conservation techniques. The long-term goal is to eliminate the need for He purging in ground systems.

### B. GODU Integrated Refrigeration and Storage (GODU LH2)

The Agency's two largest users of liquid hydrogen, KSC and SSC, lose approximately 50% of hydrogen purchased because of a continuous heat leak into storage and transportation vessels, transient chilldown of warm cryogenic equipment, liquid bleeds to maintain interface temperatures, ullage losses during venting processes, and other operational methods. The Shuttle Program's cost for cryogenic propellants for SSC and KSC was over $20M per year between 2006 and 2009. This number represents a mature program with minimal engine testing and a low annual flight rate. NASA needs to develop energy-efficient cryogenic ground systems to minimize propellant losses, minimize the size of new storage tanks, simplify test and launch operations, minimize helium consumption, and reduce the environmental impact of the space program.

Although NASA was one of the drivers of the development of large scale LH2 systems, commercial industry has since passed us by. The state of the art in cryogenic systems has advanced greatly in the past 50 years, especially in the field of cryogenic refrigeration. Hydrogen temperature refrigerators are available for a wide range of capacities and these refrigerators are critical to achieve active thermal control of the cryogens. Depending on the refrigerator capacity, this system can be used for zero boil off storage, in situ liquefaction, or propellant conditioning/densification. This Integrated Refrigeration and Storage concept allows liquid hydrogen to be stored in a quasi-equilibrium state. The simplest example of this is a zero boil off system (ZBO). The IRAS concept is novel in that it cools the liquid directly at the storage site and is designed to operate with refrigerator capacity to system heat leak ratio ($Q_R/Q_{HL}$) greater than 1. Continuous operation of the cryogenic refrigerator minimizes the overall refrigeration capacity required and increases reliability compared to systems designed to operate intermittently. Cooling the liquid directly allows for control of the bulk temperature of the fluid as opposed to pressure control of the ullage using vent and relief valves. This also enables easier depressurization of tank ullage pressure and bulk fluid conditioning for greater vehicle loading control. Conditioning operations can also serve as a store of refrigeration energy for load balancing. Higher $Q_R/Q_{HL}$ratios also allow for advanced operations, and future spaceport and test center architectural visions that culminate with a distributed production capability to individual pads for liquefaction and zero loss storage and transfer.

The ability to actively control the thermodynamic state of the hydrogen is a new concept, and there will be a learning curve associated with implementation. Currently the concept has been proven at the 180 liter scale using a COTS Gifford McMahon cryocooler in a partnership with the Florida Solar Energy Center. Storage and handling characteristics have been evaluated as the hydrogen volume increased from empty to 90% full via in situ liquefaction. Pressurization and depressurization cycles at various liquid levels were performed, and data was collected on thermal stratification. The system behaved as expected and testing at a more relevant scale in an operational environment is the next development step.

The overall goal of the GODU IRAS project is to demonstrate efficient LH2 operations on a relevant scale that can be projected to future Spaceport architectures. This goal will be demonstrated by completing three primary test objectives in the area of efficient and reliable integrated liquid hydrogen systems:

- Demonstrate zero loss storage and transfer of LH2 at a large scale.
- Demonstrate hydrogen densification in storage tank and loading of flight tank
- Demonstrate hydrogen liquefaction using close cycle helium refrigeration

Secondary project objectives include the creation of a semi-portable densified LH2 servicing capability from excess equipment. This servicing capability can be used at test stands, development centers, or launch sites, provide the opportunity for retention of critical skills at KSC, SSC, and GRC, and serve as a means of data generation for Launch Services Program cryogenic tank thermodynamic model validation. Demonstration of helium conservation operations will also occur. Modern component technology will be incorporated, so that even if future launch sites don't use IRAS concepts, they can use test data from these modern components to validate new concepts for the next generation ground systems.

The IGODU LH2 Project has derived the following Key Performance Parameters as shown in Table 2-1. These Key Performance Parameters (KPP's) identify those performance characteristics which are of most value to the potential end users. The IGODU LH2 Project KPP's are expressed in objective, quantifiable and measurable form and will define the performance parameters that are associated with project success criteria. The KPP's will be baselined and tracked by the associated PI for that objective. There is no separate full and minimum success criteria, if the performance target is not met then the project will not be considered successful. Since these KPP's are verified at the end of the test phase, they can only be evaluated at the end of the project life. To evaluate progress of the IGODU LH2 project during the development phase of the project, major milestones are tracked. Successful accomplishment of these major milestones will be the primary factor in project evaluation at the Continuation Review at the end of Year 1 and Year 2.

| Objective | Operation | Current State of the Art | Full Success Criteria |
|---|---|---|---|
| **Zero Loss Storage and Transfer** | | | |
| Zero Boil Off Storage | Store LH2 in main storage tank | 0.5% to 0.75% per day boil off | 0% per day- No hydrogen venting in steady state storage operation |
| Zero Loss Tanker Offload | Transfer hydrogen from tanker to main storage tank | 10% loss of product | 0% loss - Offload 100% of tanker with no venting |
| Zero Loss Chill Down | Chill down transfer lines prior to operation | Varies by system mass, materials, fluid | 0% loss - Full recovery of all chill down vapor |
| Zero Loss Stop Flow | Leave transfer lines serviced between launch attempts | Lines drained and purged between launch attempts | 0% loss - No hydrogen vented for two days during simulated scrub turnaround |
| **Hydrogen Liquefaction** | | | |
| In Situ Liquefaction in IRAS tank | Allow for local liquefaction inside storage tank | Hydrogen liquefied in New Orleans and trucked to KSC | 50 gallons per day at 5% COP |
| Tank Pressure Control | Maintain positive pressure in tank during densification operations | Densification operations create subatmospheric pressure inside tank | 15 psia with bulk liquid temp near 16K |
| **Hydrogen Densification** | | | |
| Storage Tank Densification | Use refrigeration to control state of bulk fluid in tank | Past densification systems used large quantities of hydrogen consumed | Continuous densification inside closed storage tank with bulk fluid temperature near 16K |
| Flight Tank Densification | Load simulated flight tank with densified hydrogen | None | Simulated tank loading with bulk fluid temperature of 17.5 K |

Table 2-1: IGODU LH2 Project Key Performance Parameters

The GODU IRAS project is intended to increase the integrated readiness level (IRL) of an advanced LH2 system. There is no new technology development intended on the component level as part of GODU IRAS. Components such as cryocoolers, transfer lines, heat exchangers, and instrumentation that are used are at a high TRL, although in most cases these components will be used in new and innovative manners. Industry standard components are to be used, and industry specifications and standards (ASME, ANSI, NFPA) will be used in place of more traditional NASA Ground Support equipment specifications. The uniqueness of the effort is the integrated systems demonstration, how the standard components are integrated into a prototype system capable of reducing launch costs associated with the use of LH2. Past propellant densification efforts have been stalled partially due to additional complexity and cost of ground systems; this approach is more simple and reliable and does not depend on extensive technology development.

The preliminary design and development of the GODU IRAS system are leveraged off efforts originally started in the ETDP CFM program. A similar project was planned to start in FY10 before funding was cut in Feb 2010. However, there was substantial effort expended in the preliminary design before the project termination, and a preliminary design was completed. Figure 2-2 shows an engineering rendering of this system.

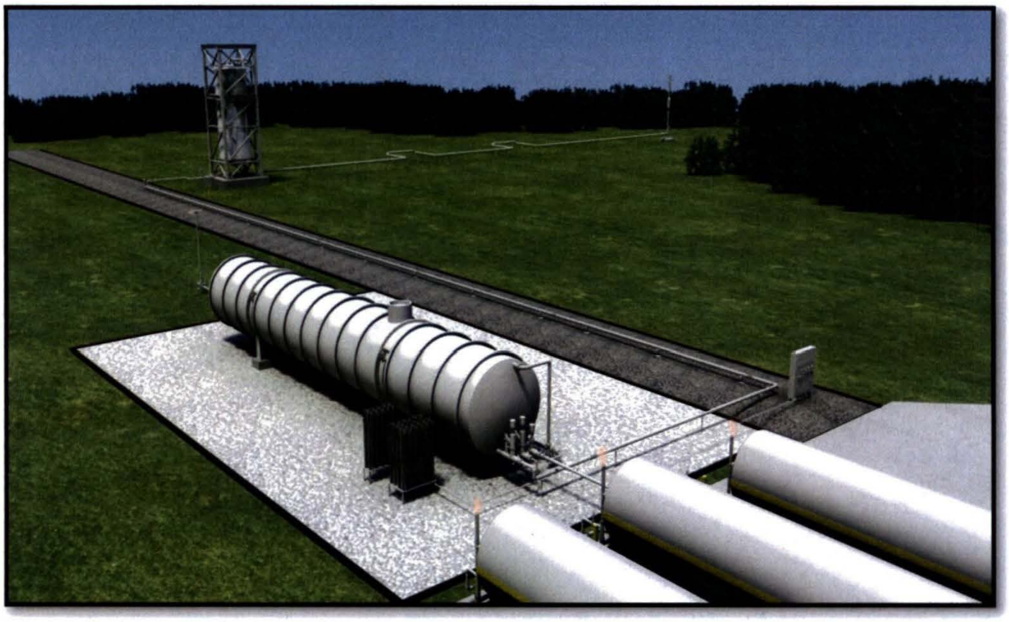

Figure 2-2. Preliminary Design Drawing of System at the Designated Test Site Completed for ETDP in FY10. Rendering shows ground storage tank and supply tankers, cryogenic lines, simulated flight tank, vent and flare stacks, vaporizers, and pneumatic panels

Due to limited procurement funds available, the GODU IRAS system is reusing spare and excess equipment wherever possible. There currently is a supply of high value cryogenic components at KSC that can be used. Figure 2-3 shows some of these components and their heritage.

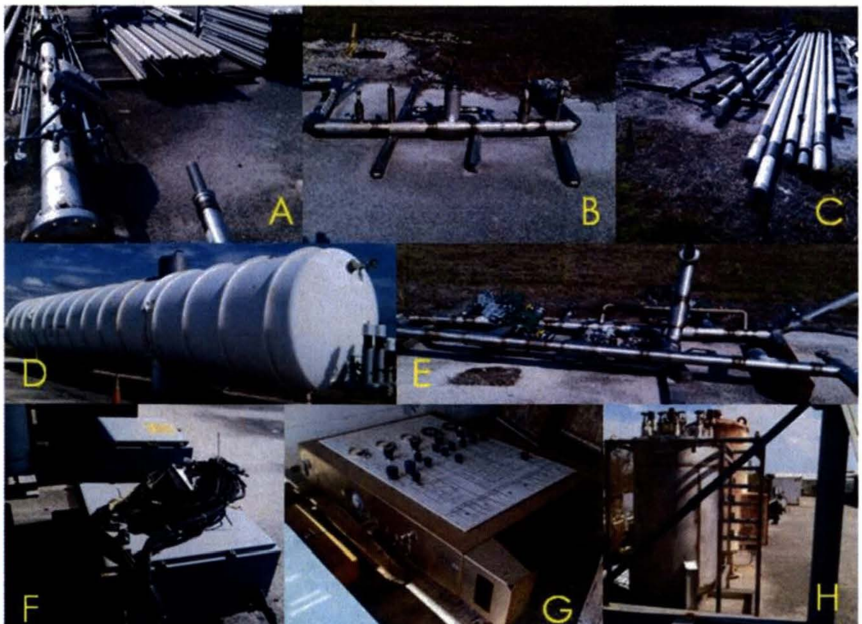


Figure 2-3. Existing Cryogenic Process Equipment Targeted for Use for this Program
Shown are: (A) flare stack and vaporizers from the X-33 launch site, (B) test tank control skid from X-33, (C) 200 feet of 2×4 vacuum jacket pipe including tanker fill ports from X-33, (D) 33,000-gallon LH2 tank from the USAF Titan pad (LC-40), (E) test tank control skid from the 2nd Gen RLV program, (F) Allen Bradley PLC and DAQ from the SBIR program, G) pneumatic panel from LC-20, and (H) test tank from the SBIR program

## III. Project Status

### A. GODU LOX

*FY12 1st Quarter (October 2011 – December 2011)*

Taking advantage of previous programs test apparatus, The GODU LOX system was completed in early 2012 with the addition of a 500 gallon composite cryogenic tank provided by the Air Force Research Laboratory. This addition completed an end to end, small scale representation of a typical LOX propellant loading system. The GODU LOX team began by first baselining the current system configuration at the Cryogenics Test Lab (CTL). Skid walkdowns were conducted beginning in mid-October, as well as a complete review of the previously used loading procedures. Skid components were calibrated in preparation for system activation. A GODU LOX skid component dry run was conducted on December 12. During the checkout, a skid relief valve was removed and calibrated in preparation for system chilldown. A high failure rate of linear variable differential transformers (LVDTs) was also found during the checkout; this led to a delay in initial Liquid Nitrogen (LN2) flow through the skid. Slight corrosion in the LVDTs was found and the components were removed and sent to the materials lab for analysis. Meanwhile, the Air Force Research Lab (AFRL) 500 gallon composite tank was transferred to the KSC CTL, on November 28th, for evaluation and instrumentation installation. Concrete slab analysis of the foundation at the CTL where the tank would be located was in work. This analysis was also looking at future tank placement.

Figure 3-1: GODU LOX Component Checkout

*FY12 2nd Quarter (January 2012 – March 2012)*

During the beginning of the second quarter the team was working on correcting the issues found in early December during the dry system run. The LVDTs were replaced, walkdowns continued, and the team performed the first cold flow of LN2 through the skid on January 24th, dumping the LN2 on to the drain trench. The system thermal performance was low and work on a custom insulation system design began. The chilldown sequencing of the ground system was also in work. The autonomous control team members were identified and the cryogenic Test Bed Control Systems Upgrade 30% Design Review was also completed. The KSC safety review panel presentation package for approval of the AFRL composite tank hydrostat test was approved in late February. The safety board approval recertified the tank for GODU LOX use. The tank was inspected by composite tank experts and determined to be unacceptable for long term use. The resin was non- UV stabilized and the pedigree of tank was in question. The limited pedigree of the experimental composite tank and the close proximity of the test apparatus to the Cryogenics Test Laboratory building precluded safely pressurizing the tank to mimic the full launch countdown simulation. The project was to switch out to a 2000 gallon metal tank in late summer. Continuing with the board approved plan, the AFRL tank was hydrostat tested on March 16th, pressurizing to 4 times the operating pressure. Strain & baseline data was collected using a developmental tank health monitoring technique (PZT sensors).

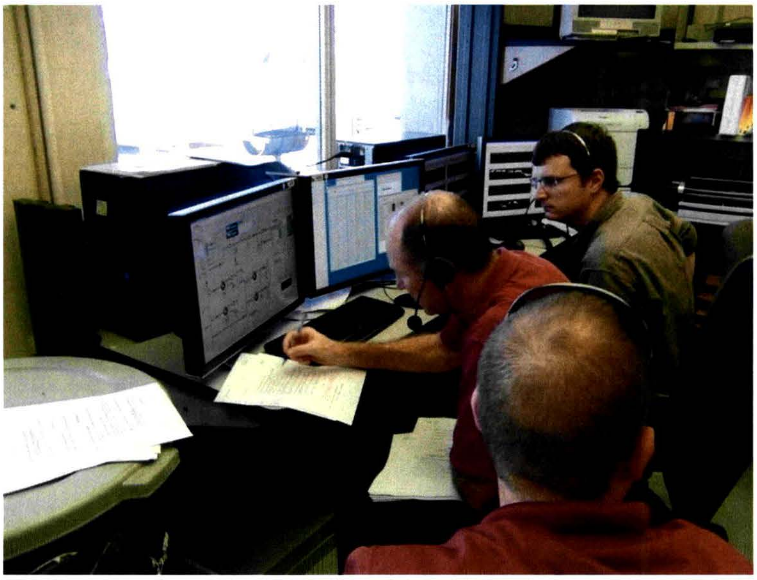

Figure 3-2: GODU LOX team conducting cold flow test

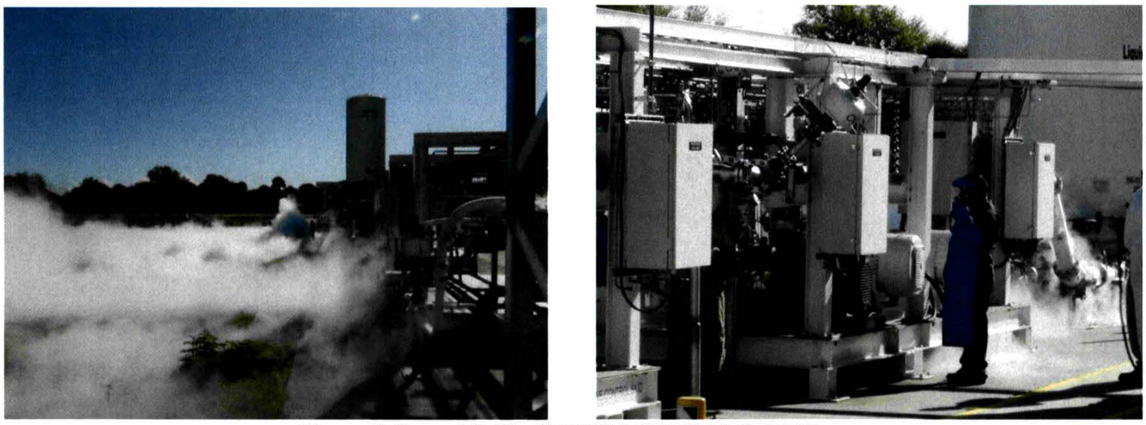

Figure 3-3a and 3-3b: GODU LOX Skid Cold Flow

*FY12 3$^{rd}$ Quarter (April 2012 – June 2012)*

The third quarter began with the completion of the 3rd cold flow of the LOX skid. Skills development of several civil servant engineers working on the LOX project continued with accomplishments such as three cold flows performed with progressive OJT (working with equipment by shadowing then performing test conductor and console operator roles). Hardware and instrumentation procurement for composite tank integration to skid was completed and installation and checkout was in work. The team prepared for May manual loading of the composite tank. Per the previous cold flow tests findings on the system thermal performance, the team installed insulation on both the chilldown line of LOX skid and the lower section of composite tank. The single wall transfer system was insulated with a combination of Aspen Aerogel blanket insulation and Reflectix insulation barrier to control the thermodynamic state of the liquid nitrogen utilized for the test. This combination of materials is holding up very well to the Florida environment and will continued to be studied throughout the project to understand it's long term applicability for inexpensive, durable cryogenic insulation in a field application. On May 16$^{th}$ the first pressure fed loading of the AFRL composite tank was successfully performend. Civil servant skills development and responsibility of running the tests continued and the third flow was run, on May 24$^{th}$, through the control room by civil servant operators and test conductor. LOX skid and AFRL composite tank manual flow optimization remained during each flow. By the end of the quarter, the team had completed the GODU LO2 Manual Loading Milestone successfully with 11 manual loadings in total. These loading attempts were performed with a pressure transfer similar to that used in the Atlas V program and helped characterize the systems' thermal performance. In preparation for the late Summer tank replacement, the team also began the design of structure and flow configuration of the

2000 gallon stainless steel tank. This tank will be used after the National Instruments control system to Allan Bradley control switchover.

Figure 3-4: GODU LOX Insulated AFRL composite tank and chill down line.

*FY12 4th Quarter (July 2012 – September2012)*

The command and control upgrade continues and will be ready for verification in late August. Meanwhile, major procurements have been submitted including: cryo tracker and engine cut-off sensors, KC fittings, control valves, magnetic inductive sensors, and cryogenic pump sized to better reflect a shuttle loading timeline this fall. KSC systems engineering preliminary design and requirements review for the 2000 gallon Stainless Steel tank, that will replace the AFRL composite tank, was approved on August 2nd. This new configuration will enable a fully sequenced loading demonstration and a terminal countdown tank pressurization demonstration similar to the shuttle programs loading process in FY13. The team is working on the final design review products such as refining the drawings and the models. The KSC systems engineering final design and requirements review for tank foundation was approved on August 6th. The team can now proceed with concrete procurement and vendor fundation pour. The KSC systems engineering design review products for the simulated propellants loading system (SPLS) are currently being written by the team. Products include concept of operations, requirements plan, drawings, funding plan, schedule, systems engineering management plan, risk matrix, and complete systems.

## B. GODU LH2

*FY12 1st Quarter (October 2011 – December 2011)*

The GODU LH2 kickoff meeting and team formulation began at the start of FY12. Much of the preliminary design was done by the ETDP effort and constrained by available hardware and the GODU LH2 Preliminary Design Review was held November 15-17, 2011. Team members presented status of their respective engineering subsystems during the three-day review. The Systems Requirements Document was nearly finalized and the Process and Instrumentation Diagram (P&ID) was developed as well. A concept of operations was started based on the P&ID. One of the critical early design projects was the cold helium heat exchanger sizing, which was needed to develop the specification for the refrigeration system. Thermal and fluids analysis was performed using Sinda Fluint to optimize the design to distribute the cooling along the IRAS tank. Designs for the Command and Control System, Instrumentation, transfer and vent systems, and test site support systems were reviewed. In December, the KSC Engineering Directorate approved an alternate location for the GODU LH2 test site. Although 3 more months were needed to finally get full KSC approval, this allowed the project to focus on one site. Actions from the Preliminary Design Review were completed, to include updating the Systems Requirements Document, P&ID and Integrated Schedule. In addition, a Hazards Analysis team was formed to evaluate hazards associated with the GODU LH2 project. Work began on refurbishing the 33,000 gallon LH2 storage tank, the vacuum jacketed lines and the pneumatic panel. Vacuum readings on the MVE tank and PHPK VJ lines (after almost 10 years) were encouraging, with only one major leak found.

*FY12 2nd Quarter (January 2012 – March 2012)*

Two of the major procurements for GODU LH2 were initiated at the start of the new year: the refrigeration system and the new vacuum jacket lines. Only two interface spools were needed for the VJ procurement and PHPK was selected based on them being the original line manufacturer. The selected company for the refrigerator procurement was Sierra Lobo, using a Linde LR 1620 refrigerator that produces 850W at 20K with LN2 precooling. Design concepts for the IRAS tank heat exchanger and the instrumentation were presented to the engineering team, and detailed design began after engineering approval. Vacuum jacketed line refurbishment continued, as did corrosion repair and recertification of the 33,000 gallon LH2 storage tank. The detailed design of the IRAS tank manway plug and internal modifications began. The GODU LH2 site plan was approved by KSC Master Planning, and the Facility Management Board approved the turnover of the M7-0912 clamshell building (to function as an operations support building) at the test site to GODU LH2 with unrestricted use starting in September 2012.

*FY12 3rd Quarter (April 2012 – June 2012)*

In the third quarter of FY12, the GODU LH2 team was hard at work preparing for the Phase 1 80% Design Review scheduled for mid-July. The vacuum jacketed line precision cleaing was completed, and cold shock, pneumostat and leak check operations began on the 8 refurbished lines. Additional procurements were sent out, including the chiller, hydrogen isolation and relief valves, and actuators. The GODU LH2 groundbreaking ceremony and clean-up day was held on June 25, 2012 at the test site. The refrigerator critical design review was held at Sierra Lobo and with no major issues identified, the fabrication of the refrigerator was initiated. Corrosion repair of the 33,000 gallon LH2 storage tank was nearly completed and the design of the concrete tank foundation design began. Refurbishment of the GN2 pneumatic panel was completed after functional tests verified components operation at desired pressure.

Figure 3-5: GODU LH2 Engineers During the Ceremonial Groundbreaking on 6/25/12

*FY12 4th Quarter (July 2012 – September2012)*

The Phase 1 80% GODU LH2 Design Review was held July 9-13 at the Kennedy Space Center. Team members presented status of their respective engineering subsystems during the five-day review. Multiple actions were assigned during the review and are currently in work by the team, with a completion date of 9/1/12. Successful conclusion of the review is pending the resolution of two design issues: PVS shop buy in of an internal stiffening ring design to mitigate subatmospheric operations, and final design of the IRAS tank vent/relief system. A topographical site survey and utility survey were performed on the test site, and a dig permit was approved for the installation of the IRAS tank foundation. The corrosion repair of the IRAS tank was completed, and tank move to the test site is anticipated for mid-September. The final version of the GODU LH2 site plan showing the updated layout of the test site was submitted to KSC Master Planning and is out for review. All necessary pneumatic panels and storage bottles were identified and secured from excess from the HMF, LC-39, and OPF transition and retirement. Additional GODU LH2 procurements were submitted including: the vacuum pump, IRAS heat exchanger, instrumentation, operations support trailer, and facility power.

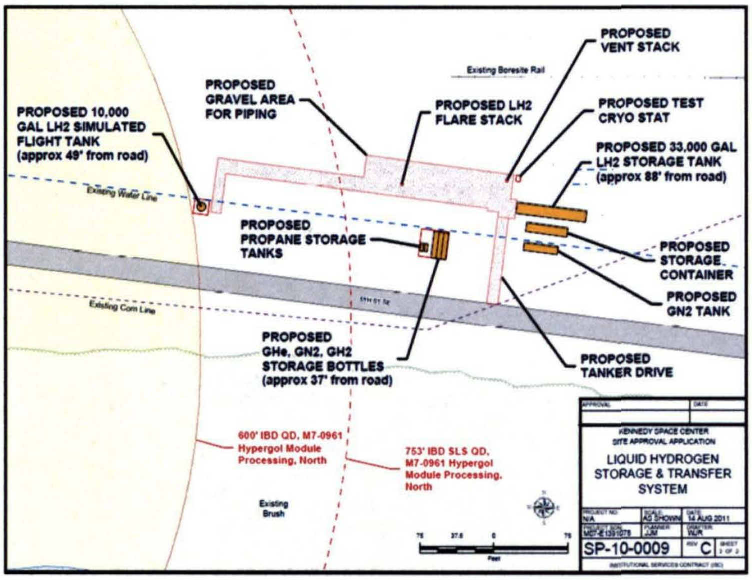


Figure 3-6: GODU LH2 Test Site Layout

## IV. Conclusion

NASA's Advanced Exploration Systems program is investing in a wide variety of technologies to help enable future exploration missions and architectures. The IGODU project is a three year effort (FY12-14) developing and maturing technologies and techniques to lower life cycle costs of all future launch operations and providing analog test capability for any future exploration architecture relying on ISRU activity for extended surface stays. The first year of the IGODU project has been successful in activating and operating the liquid oxygen simulated vehicle loading system and completed the design process for building the liquid hydrogen integrated refrigeration and storage demonstrator which will begin construction in FY2013. Both demonstration units will be utilized to explore emerging technologies, advanced hardware and software options for future system architectures and prove health management and autonomous control techniques to help make cryogenic propellant servicing operations safer, more routine, and require a smaller group of experts than launch programs of the past.

## Acknowledgments


The authors thank the Advanced Exploration Program at NASA HQ for their financial support and the Engineering Directorate at KSC for their management support for the GODU LH2 project.

[6]Volpe, R., "Techniques for Collision Prevention, Impact Stability, and Force Control by Space Manipulators," *Teleoperation and Robotics in Space*, edited by S. B. Skaar and C. F. Ruoff, Progress in Astronautics and Aeronautics, AIAA, Washington, DC, 1994, pp. 175-212.

Publisher, place, and date of publication are required for all books. No state or country is required for major cities: New York, London, Moscow, etc. A differentiation must always be made between Cambridge, MA, and Cambridge, England, UK. Note that series titles are in roman type.

*Proceedings*

[7]Thompson, C. M., "Spacecraft Thermal Control, Design, and Operation," *AIAA Guidance, Navigation, and Control Conference*, CP849, Vol. 1, AIAA, Washington, DC, 1989, pp. 103-115

[8]Chi, Y., (ed.), *Fluid Mechanics Proceedings*, SP-255, NASA, 1993.

[9]Morris, J. D. "Convective Heat Transfer in Radially Rotating Ducts," *Proceedings of the Annual Heat Transfer Conference*, edited by B. Corbell, Vol. 1, Inst. Of Mechanical Engineering, New York, 1992, pp. 227-234.

At a minimum, proceedings must have the same information as other book references: paper (chapter) and volume title, name and location of publisher, editor (if applicable), and pages or chapters cited. Do not include paper numbers in proceedings references, and delete the conference location so that it is not confused with the publisher's location (which is mandatory, except for government agencies). Frequently, CP or SP numbers (Conference Proceedings or Symposium Proceedings numbers) are also given. These elements are not necessary, but when provided, their places should be as shown in the preceding examples.

*Reports, Theses, and Individual Papers*

[10]Chapman, G. T., and Tobak, M., "Nonlinear Problems in Flight Dynamics," NASA TM-85940, 1984.

[11]Steger, J. L., Jr., Nietubicz, C. J., and Heavey, J. E., "A General Curvilinear Grid Generation Program for Projectile Configurations," U.S. Army Ballistic Research Lab., Rept. ARBRL-MR03142, Aberdeen Proving Ground, MD, Oct. 1981.

[12]Tseng, K., "Nonlinear Green's Function Method for Transonic Potential Flow," Ph.D. Dissertation, Aeronautics and Astronautics Dept., Boston Univ., Cambridge, MA, 1983.

Government agency reports do not require locations. For reports such as NASA TM-85940, neither insert nor delete dashes; leave them as provided by the author. Place of publication *should* be given, although it is not mandatory, for military and company reports. Always include a city and state for universities. Papers need only the name of the sponsor; neither the sponsor's location nor the conference name and location are required. *Do not confuse proceedings references with conference papers.*

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CD-ROM publications and regularly issued, dated electronic journals are permitted as references. Archived data sets also may be referenced as long as the material is openly accessible and the repository is committed to archiving the data indefinitely. References to electronic data available only from personal Web sites or commercial, academic, or government ones where there is no commitment to archiving the data are not permitted (see Private Communications and Web sites).

[13]Richard, J. C., and Fralick, G. C., "Use of Drag Probe in Supersonic Flow," *AIAA Meeting Papers on Disc* [CD-ROM], Vol. 1, No. 2, AIAA, Reston, VA, 1996.

[14]Atkins, C. P., and Scantelbury, J. D., "The Activity Coefficient of Sodium Chloride in a Simulated Pore Solution Environment," *Journal of Corrosion Science and Engineering* [online journal], Vol. 1, No. 1, Paper 2, URL: http://www.cp/umist.ac.uk/JCSE/vol1/vol1.html [cited 13 April 1998].

[15]Vickers, A., "10-110 mm/hr Hypodermic Gravity Design A," *Rainfall Simulation Database* [online database], URL: http://www.geog.le.ac.uk/bgrg/lab.htm [cited 15 March 1998].

Always include the citation date for online references. Break Web site addresses after punctuation, and do not hyphenate at line breaks.

*Computer Software*

[16]TAPP, Thermochemical and Physical Properties, Software Package, Ver. 1.0, E. S. Microware, Hamilton, OH, 1992.

Include a version number and the company name and location of software packages.

*Patents*

Patents appear infrequently. Be sure to include the patent number and date.

[17]Scherrer, R., Overholster, D., and Watson, K., Lockheed Corp., Burbank, CA, U.S. Patent Application for a "Vehicle," Docket No. P-01-1532, filed 11 Feb. 1979.

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References to private communications and personal Web site addresses are generally not permitted. Private communications can be defined as privately held unpublished letters or notes or conversations between an author and one or more individuals. They *may* be cited as references in some case studies, but only with permission of the AIAA staff. Depending on the circumstances, private communications and Web site addresses may be incorporated into the main text of a manuscript or may appear in footnotes.

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