Modification of a LH_2 Tank for Integrated Refrigeration and Storage

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INTRODUCTION

- **Integrated Refrigeration and Storage (IRAS) Concept**
  - Interface a refrigerator to a storage tank via an internal heat exchanger
- **Benefits**
  - Reduced commodity losses (i.e. no venting).
    - During the Space Shuttle program NASA lost 50% of the hydrogen purchased.
  - Control the state of the fluid via system heat removal to achieve:
    - Zero Boil-Off (ZBO)
    - Liquefaction
    - Densification (sub-cooling)
    - Zero-Loss Tanker Off-loads
- **Requires Unique Hardware & Equipment**
  - No large COTS IRAS tanks exist for LH_2.
  - Must operate over a wide range of pressure and temperature conditions.

GODU-LH2 Project

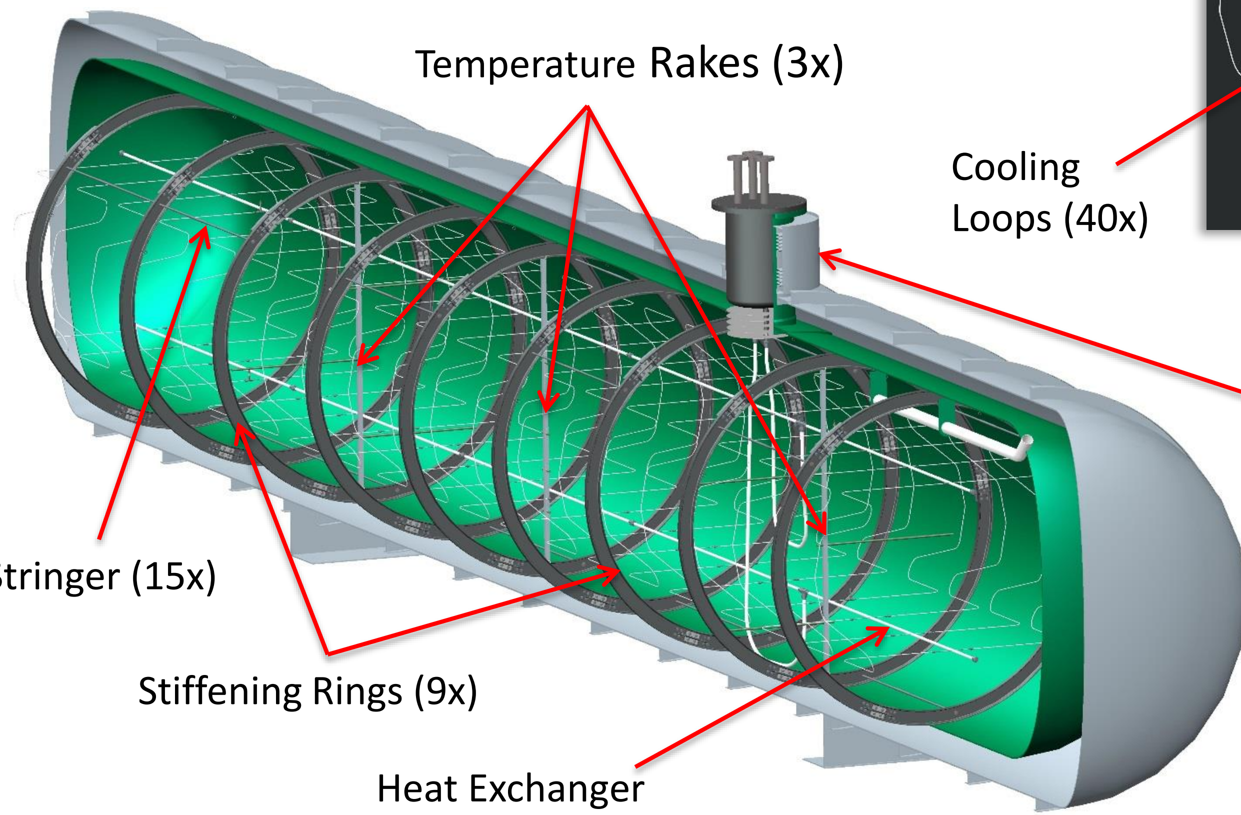
- **Ground Operations Demonstration Unit for Liquid Hydrogen (GODU-LH2) Project**
  - Transform an existing 125,000 Liter horizontal dewar into an IRAS tank to test next generation storage and transfer methods for liquid hydrogen.

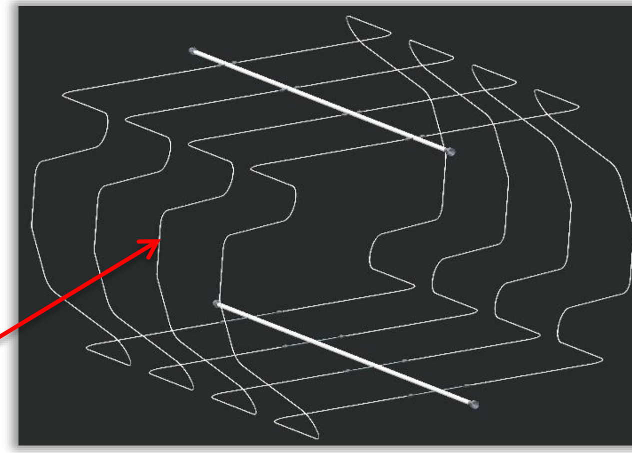
<u>Tank Info</u>

- LH_2 storage vessel built in 1991 by MVE.
- Used by Titan program until 2005.
- Vacuum-jacketed (26 cm annular space).
- Inner tank diameter = 2.9 m, length = 21.8 m
- Inner tank material is SA240 304L stainless steel.
- Original ASME ratings: 0 to 655 kPa (gauge) (95 psig), and 20 K to 311 K

IRAS Tank Modifications

- **Three major internal IRAS modifications were made to the tank**
    1. Structural stiffening rings & stringers
    2. Balanced flow, broad-area heat exchanger
    3. Temperature instrumentation rakes





Heat Exchanger Section

All components, tools, personnel, etc. had to fit through the 58 cm diameter man-way.

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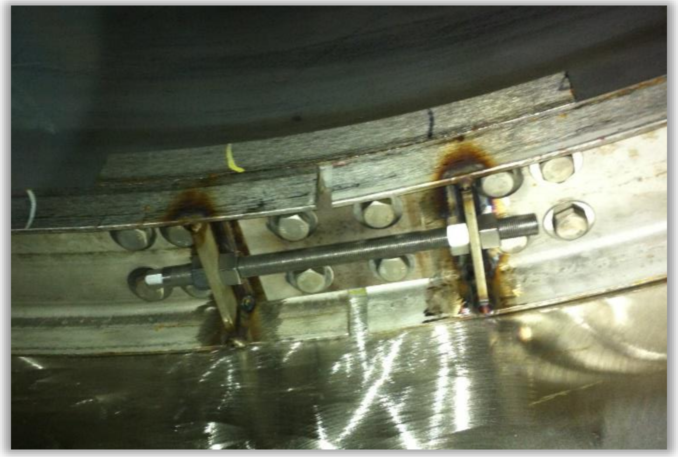
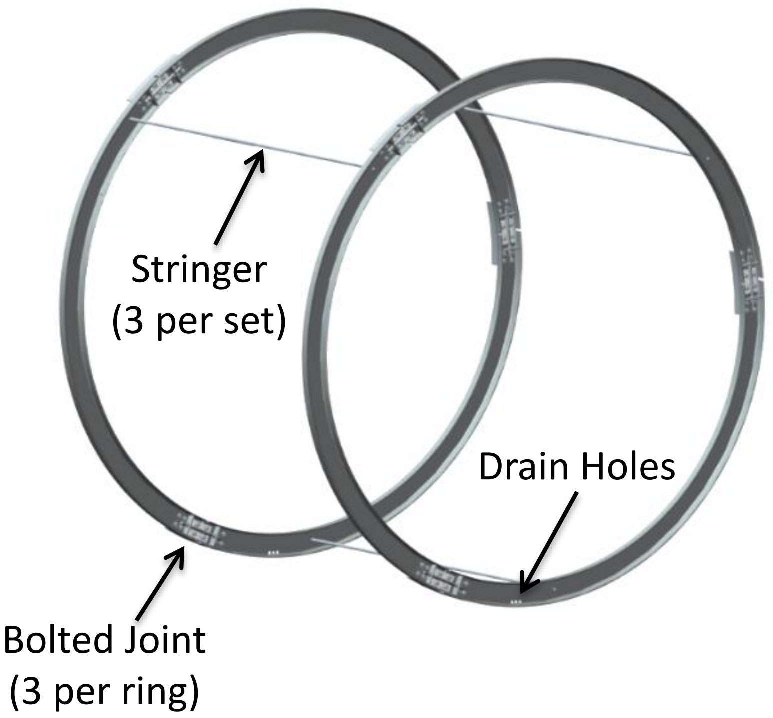
Design & Installation of Structural Modifications

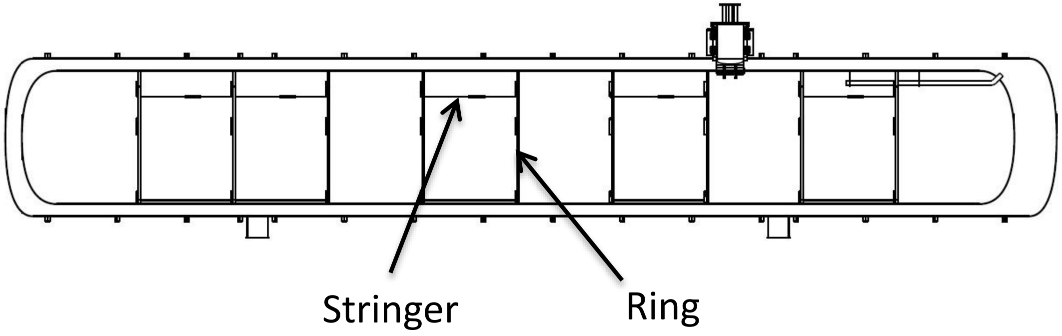
- **Internal stiffening rings were required by the ASME Boiler & Pressure Vessel Code (BPVC) in case annulus vacuum was lost while at sub-atmospheric tank pressures.**
  - LH_2 densified to 15 K → tank pressure ≈ **13.8 kPa (2 psia)**.
  - Calculated minimum tank pressure at 15 K, w/o stiffening rings ≈ **87 kPa (12.6 psia)**.
- **BPVC was used to determine stiffener section and quantity**
  - 9 total rings, made from C5x6.7 C-channel, 304L stainless steel
- **Custom designed rings were divided up into 3 segments to fit through the man-way port, then bolted together to form a continuous ring.**



Design & Installation of Structural Modifications

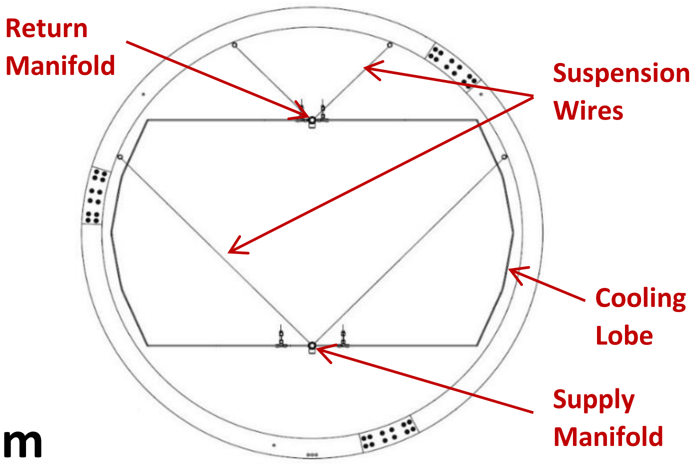
- **Longitudinal stringers were required to prevent out-of-plane movement of the rings if they became loose.**
  - Only sets of rings were tied together, not all nine.
  - Custom-built stringers are telescoping to allow for thermal contraction.





Heat Exchanger Design & Installation

- **Detailed HX design presented at 2013 CEC in Anchorage, AK**
  - J.E. Fesmire, T.M. Tomsik, et. al., "Integrated Heat Exchanger Design for a Cryogenic Storage Tank, *Advances in Cryogenic Engineering AIP Conf. Proc*. Vol. 1573, pp 1365-1372 (2013).
- **"Whale Skeleton" construction to provide maximum heat transfer area, flexibility, and modularity.**
  - 25 mm OD supply and return manifolds + forty 6.4 mm OD cooling lobes (≈300 m total).
  - Tubing connected using **Swagelok VCR-type fittings** with silver plated gaskets.
  - **Flow balanced system** using precision orifice plates.
  - Suspended from stiffening rings via stainless steel wire (≈123 kg total weight).
  - Employs 4 **custom in-line GHe flow temperature sensors**, silicon diode type.



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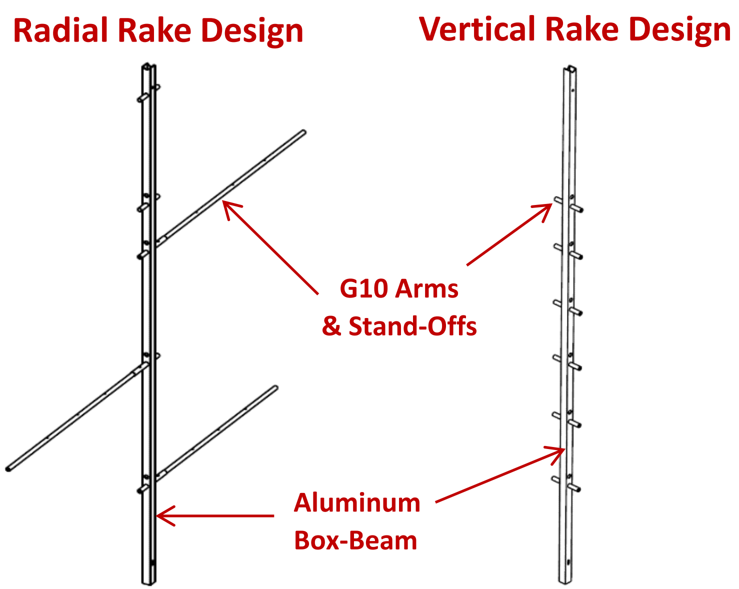
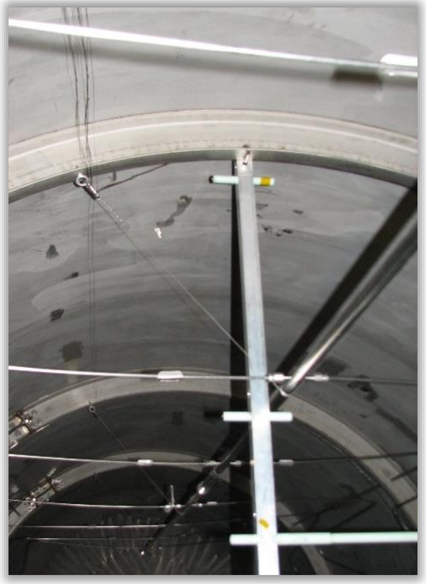
Temperature Rake Design & Installation

- **Three rakes installed to measure temperature distribution inside the tank.**
  - Total of 20 silicon diode sensors.
  - Two rake designs: 1x vertical-only data, 2x vertical + radial data.
  - Aluminum box-beam center support with G10 arms and stand-off's for sensor isolation.
  - Modular: foldable system lowered through man-way and deployed inside.
  - Attached to the stiffening rings via J-hooks.
  - Wire bundles suspended by carabineer clamps used to support the HX (farthest rake is 9 m from the connector interface).





Man-Way Feedthrough Design & Installation

- **New man-way plug assembly was designed and fabricated at Stennis Space Center in Mississippi.**
- **Features include:**
  - Four, 24-wire Conax brand instrumentation feedthroughs.
  - Three bayonet-style fluid feedthroughs.
  - Volume filled with 3M brand type K1 glass bubbles and evacuated.
  - Five polished aluminum radiation shields to further reduce heat-leak.

Unique Challenges & Lessons Learned

- Structural mods are extremely **labor intensive** to perform on an existing vessel.
- Unfavorable **working conditions** inside the tank → unbearably hot in the Summer, noise was amplified, trip hazards.
- Maintaining **tank cleanliness** is an issue → water condensation on the inner tank wall, difficult to clean.
- **More instrumentation** would be preferable → camera, tank wall temperatures, etc.
- **Recertification** is a significant challenge → 2 year effort; extensive analysis, inspection and testing, could not recertify to the lower temperature due to impact test requirements.

Conclusion

- **Modification of an existing VJ LH_2 tank for IRAS operations was fully successful.**
  - Tank was subjected to a positive and negative pressure test, and LN2 cold-shock for ASME recertification (officially granted in October 2014).
  - Heat exchanger underwent overpressure and decay tests, and has been performing as designed since March 2015.
  - Data from all silicon diode temperature sensors inside the tank are intact, and working properly down to 20 K.
  - Data from the custom in-line GHe temperature sensors also working properly.

- **Future Plans**
  - Testing different modes of operations at various fill levels.
  - Research investigations of bulk fluid dynamics and heat leak.
  - Various testing of densified LH_2 dynamics.