Development of Two-Phase Dense Fluid Expander for Advanced Cryogenic Air Separation and Low-Grade Heat Recovery

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Project Objectives

- The first objective is to better understand the limitations associated with two-phase dense fluid expansion from aerodynamic, thermodynamic, and mechanical perspectives

- The second objective is to apply this knowledge to construct two prototype devices to further explore the basic properties of two-phase dense fluid expansion

Presentation Outline

- Background
- Prototypes
- Results
- Test Planning

Background

Background

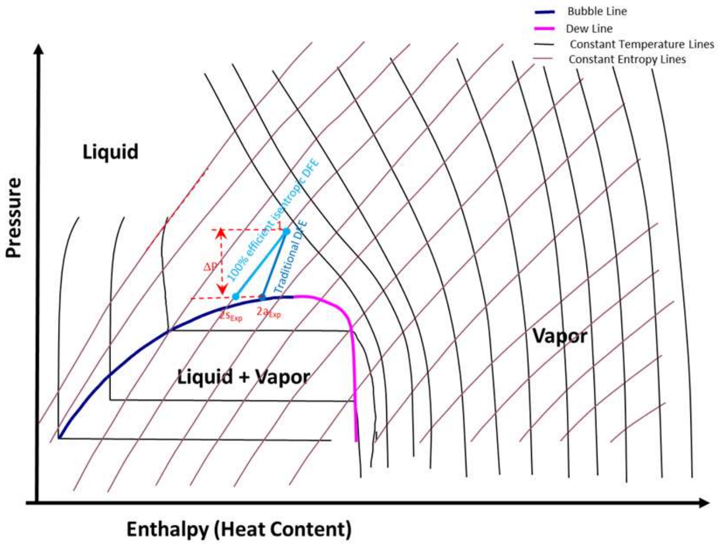
- Cryogenic air separation is the state of the art technology used to supply the vast amounts of oxygen required for coal gasification
- Power needed to drive the main air compressor (MAC) in a typical air separation unit (ASU) represents approximately 70-90% of ongoing operating cost for the entire ASU
- Usage of a dense fluid expander (DFE) within an ASU allows for more efficient plant operation, and therefore less power is required to produce an equivalent amount of oxygen product
- Typically 1HP refrigeration power created by the DFE equates to 5-6HP of electrical power savings

Background

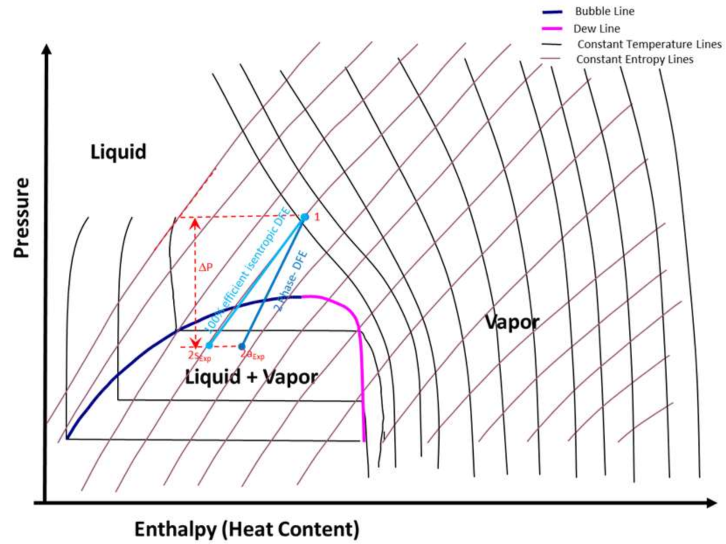
- State of the art cryogenic dense fluid expanders used in air separation are typically limited to single-phase flow (liquid in, liquid out)
- A single-phase DFE design with only liquid in the discharge typically experiences very little volume change upon expansion
- A two-phase DFE may experience volume increases of up to 10 times upon expansion
- The large volume difference between vapor and liquid poses challenges to designing equipment as it relates to machine efficiency, durability, erosion, stable operation, and other performance criteria

Background

Single-Phase DFE

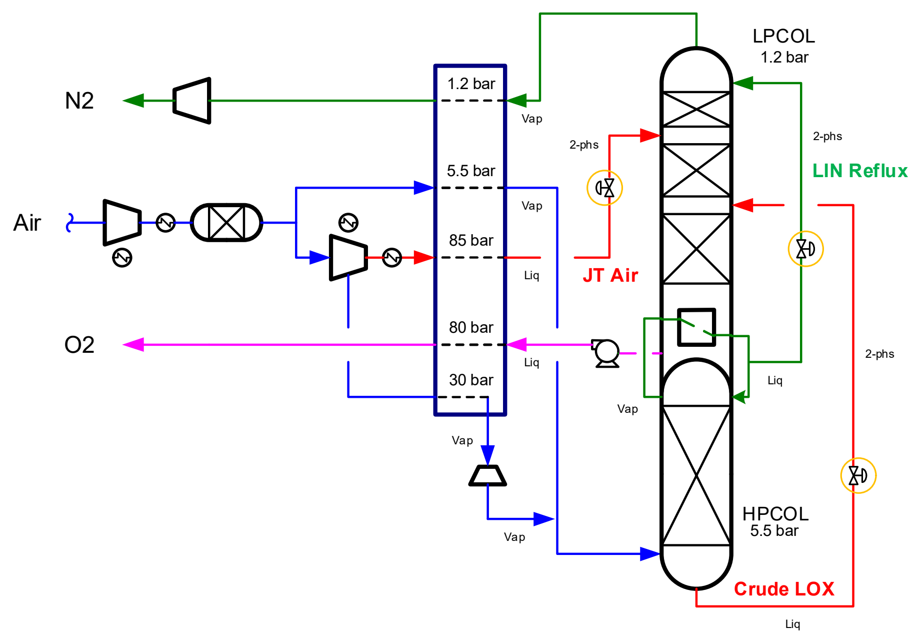


Two-Phase DFE



Opportunities for Additional DFEs in ASU Applications

Pumped-LOX Cycle



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Background

- Developing a successful two-phase dense fluid expander for cryogenic air separation will open doors for additional DFE applications and overall ASU plant efficiency improvement:
  1. Run traditional DFE applications two phase leading to more efficient plant operation. Current DFE's are back-pressured to keep discharge flow single phase.
     - Savings equal to ~0.3% of MAC electrical power = 130HP*
  2. Replacement of letdown valves with DFE's (3-6 valves per typical ASU)
     - Savings equal to ~1% of MAC electrical power = 450HP*
  3. Waste heat recovery cycles requiring two phase DFE's
     - Savings equal to ~5% of MAC electrical power = 2,250HP*

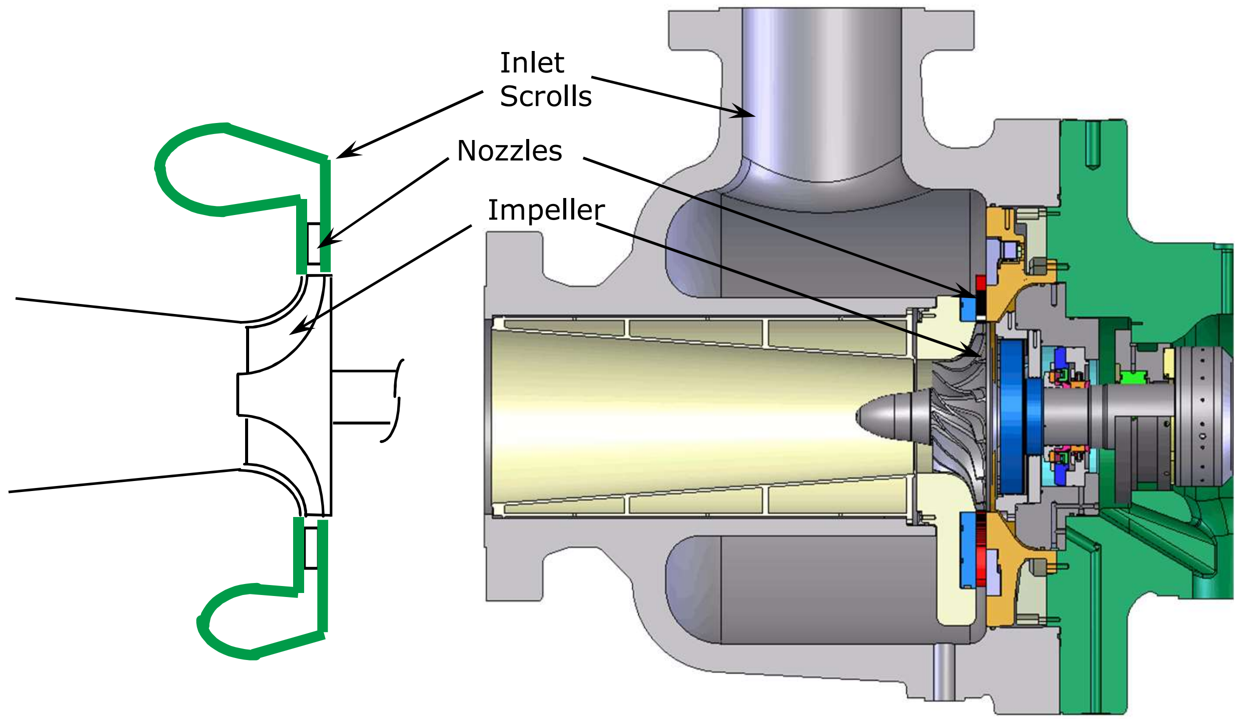
*varies based on plant size, numbers above reflect a 45,000HP MAC

Background

Application	**Machinery Device Selected**
Waste Heat Recovery from Main Air Compressor Intercooler	Centrifugal Expander
Crude Liquid Oxygen Letdown	Axial Impulse Turbine
Traditional Dense Fluid Expander in Two-Phase Operation	Centrifugal Expander

Centrifugal Expander

Expander Stage Layout



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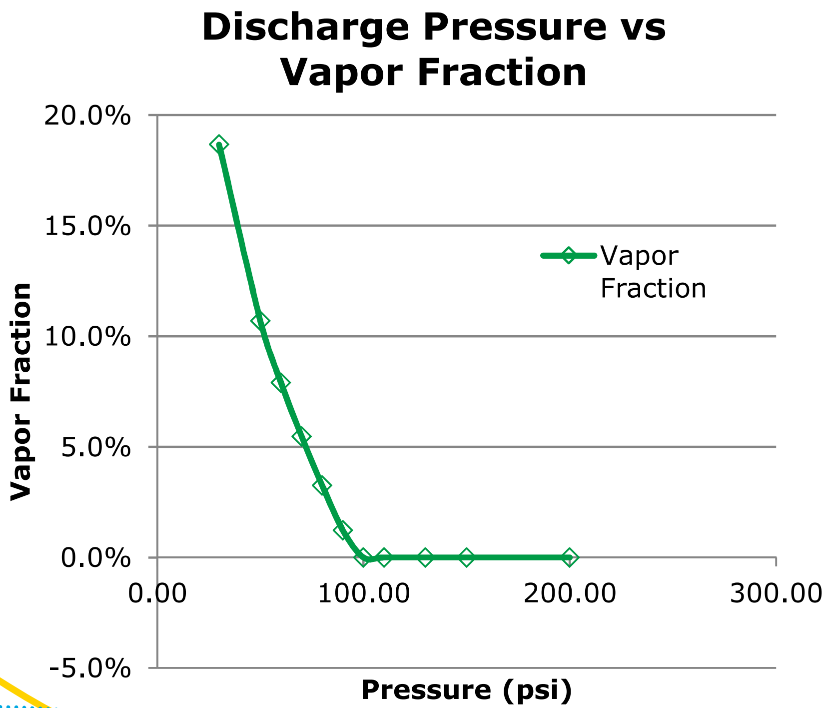
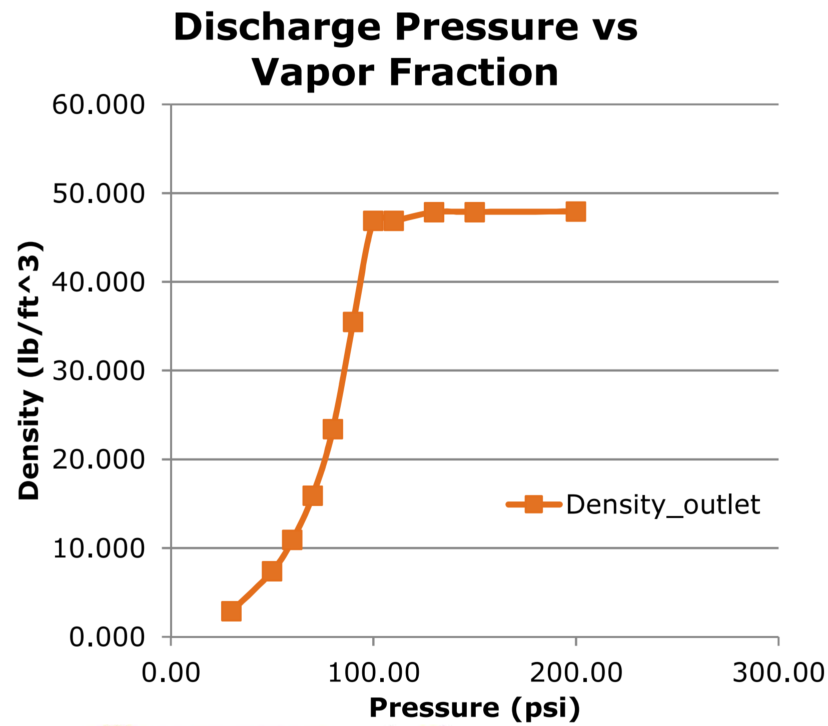
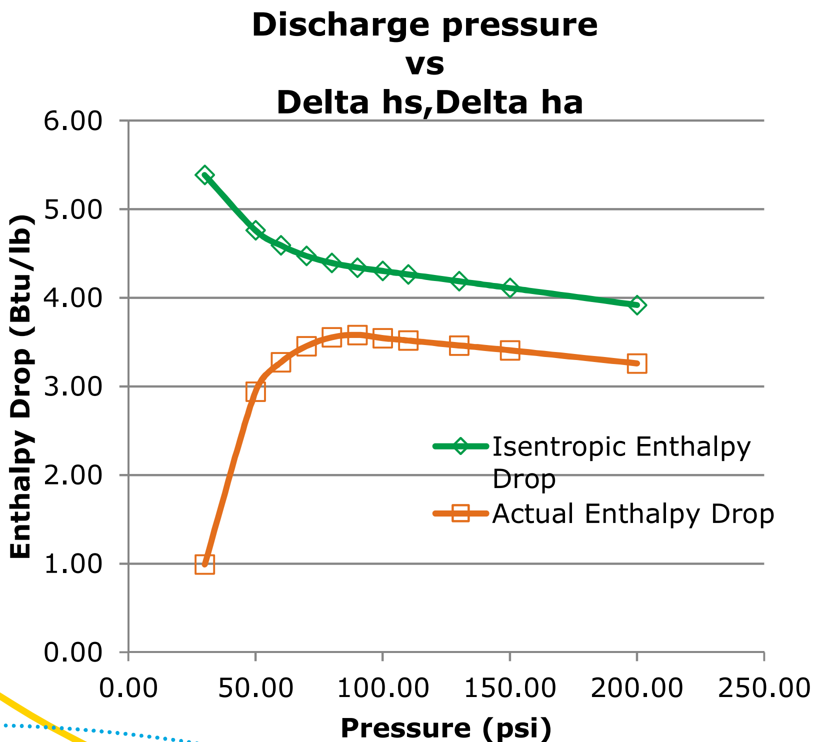
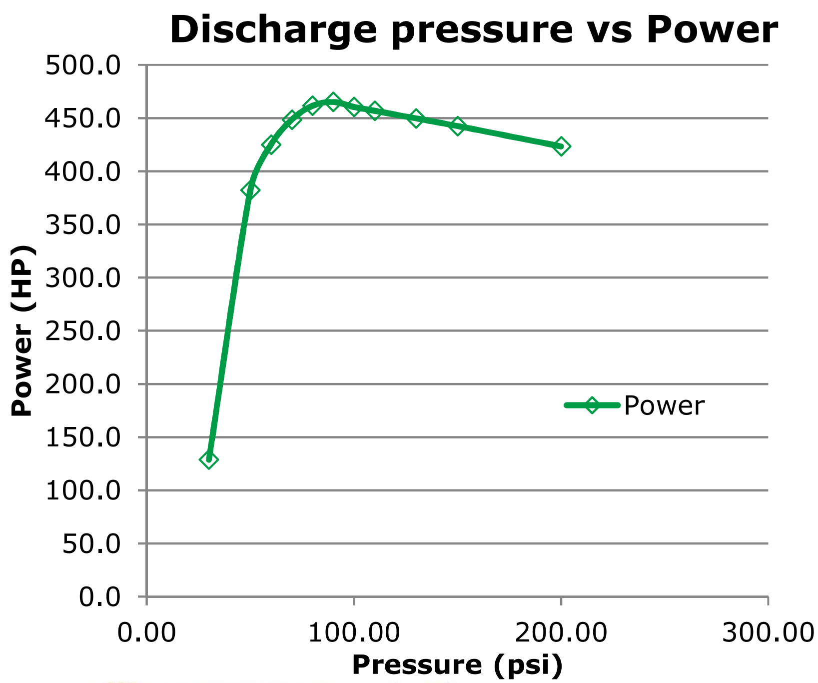
Analysis Summary





Analysis Summary





Centrifugal DFE Testing

- Perform full scale testing on an asset located in the US (LaSalle, IL)
- Upgrade instrumentation at site to able to accurately quantify performance of unit

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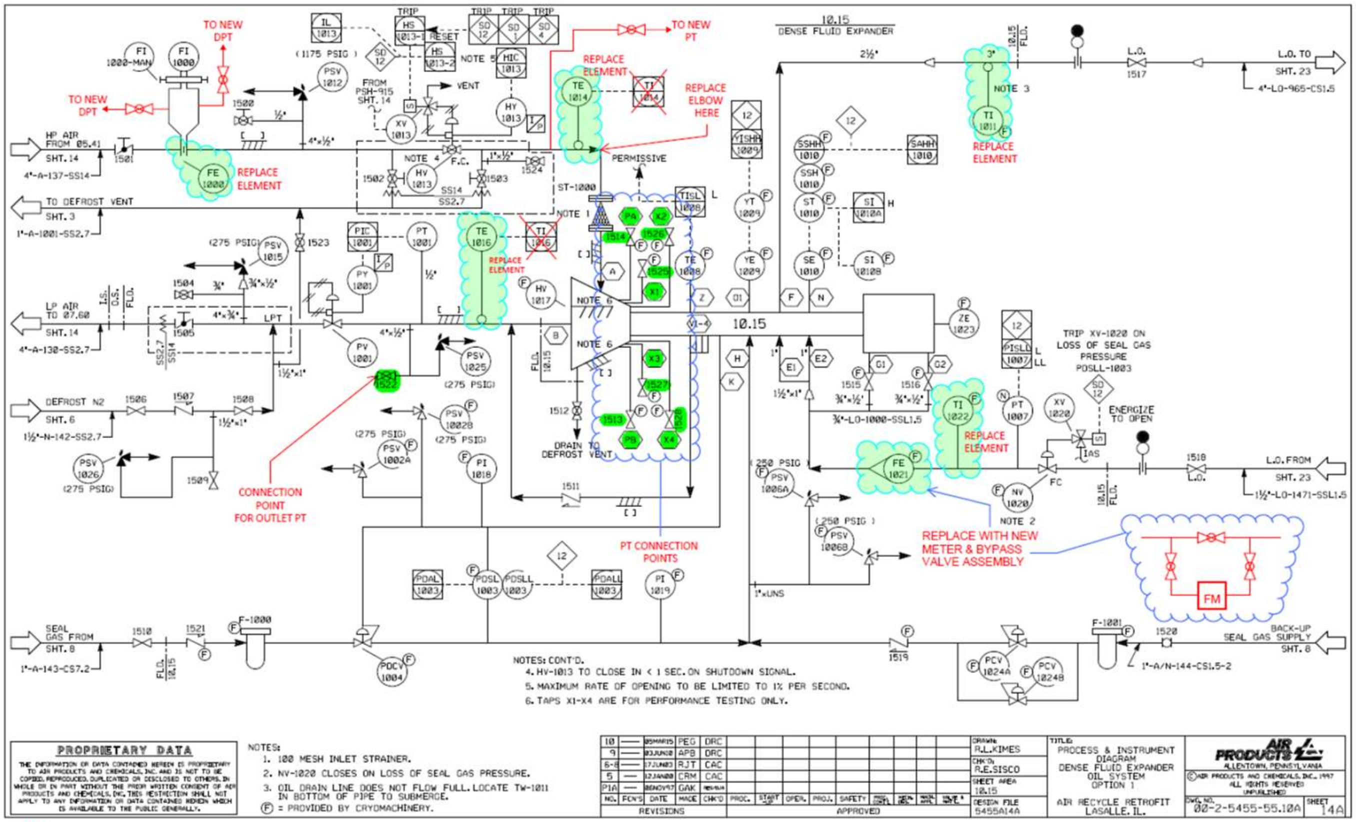
Instrumentation



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Instrumentation - Process

- Process Inlet Flow Meter (FE-1000)
  - 4"-600#, 316SS, Bore 2.6772", thickness .125"
- Process Inlet Elbow
  - Replace existing spool with new spool that has additional pressure taps.
- Process Inlet and outlet temperature elements (TE-1014 & TE-1016)
  - 4-wire dual element RTD at inlet and one 4-wire RTD at outlet.
- Process Pressure Measurements: Connect 1/8" SS sensing lines to the following ports:
  - DFE downstream pressure via V-1522
  - Port X1 (DFE eye) via V-1525
  - Port X2 (DFE contour) via V-1526
  - Port X3 (DFE impeller tip) via V-1527
  - Port X4 (DFE Zero Clearance ring) via V-1528
  - Port PA (DFE case inlet flange) via V-1514
  - Port PB (DFE case outlet flange) via V-1513
  - Port U1 or U2 on new inlet elbow (upstream of thermocouple).

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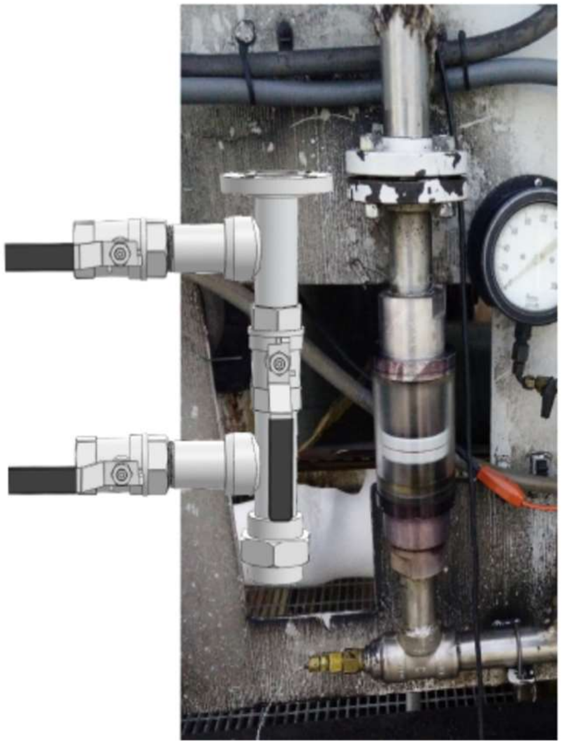
Instrumentation – Oil

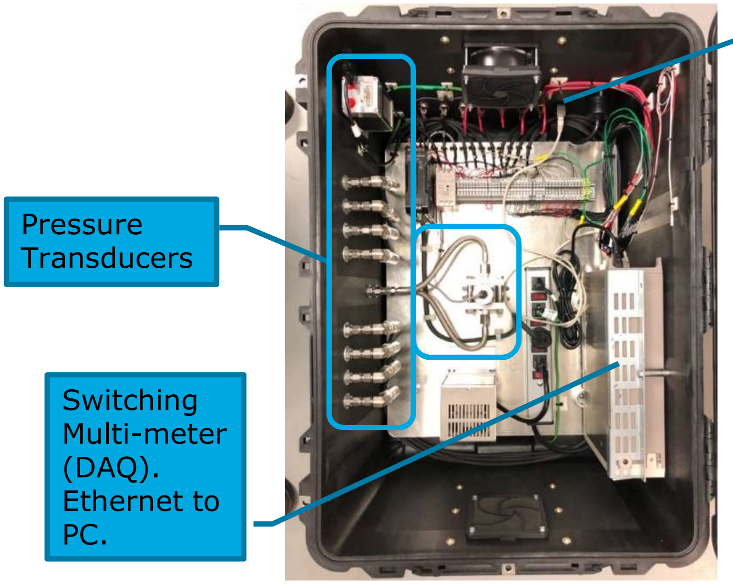
- Lube Oil Supply (TI-1022) & Lube Oil Drain (TI-1011): Replace existing elements (unused and both in thermowells) with a 4-wire RTD.

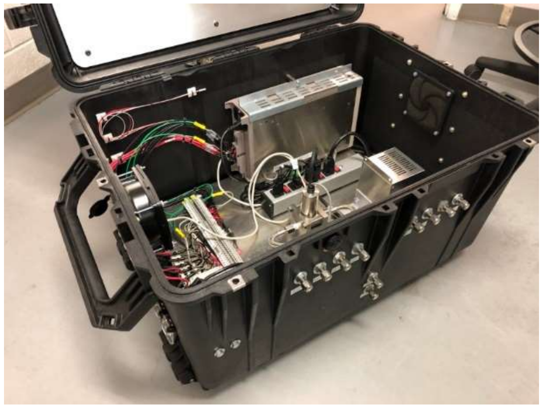
- Lube Oil Flow Meter (FE-1021)

- Replace existing variable area meter with a new turbine-type meter. New meter to be plumbed external to existing panel and connected via hoses in order to achieve the required straight upstream and downstream lengths.



Data Acquisition system





Axial Impulse DFE

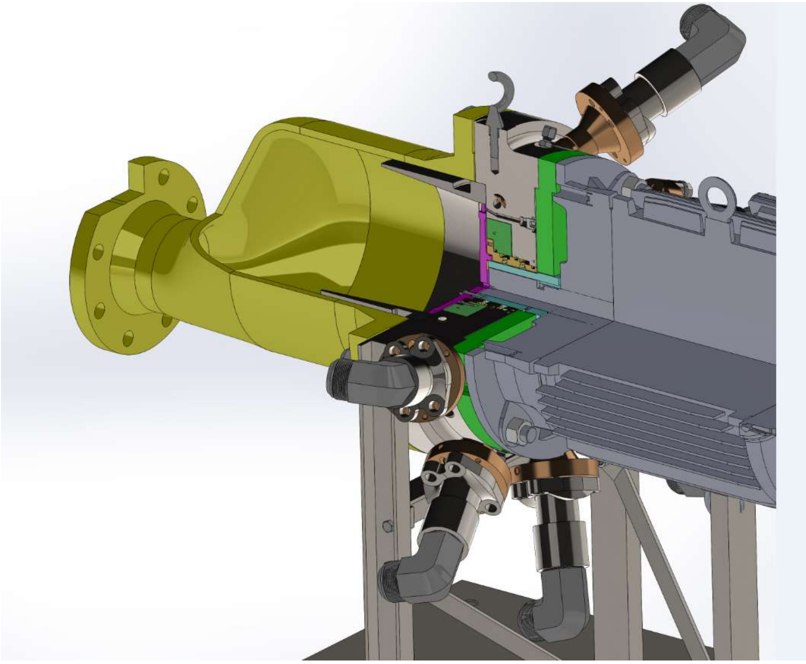
Axial Impulse DFE

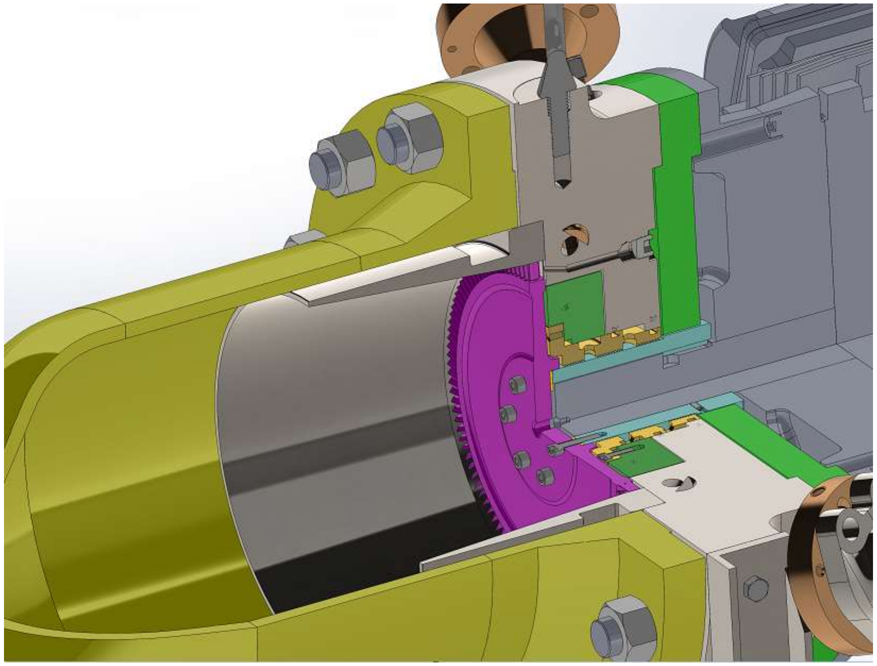
An Axial Impulse design has been selected for the crude LOX letdown conditions, other applications such as LIN to storage may also benefit.

Axial Impulse design is attractive from various aspects

- High tolerance to 2 phase mixtures both at inlet and discharge
- Slower rotor speeds – improved reliability, lower cost (manufactured and installed)
- Simple and inexpensive to manufacture relative to radial inflow designs
- Low cost installation
  (no lubrication system, limited monitoring/controls)
- Significant turndown achievable with impulse design through partial admission
- Ability to use off the shelf induction motor as basis for the unit for our application
- Potential stepping stone for multistage and axial reaction turbine stages for other applications

Axial Impulse DFE

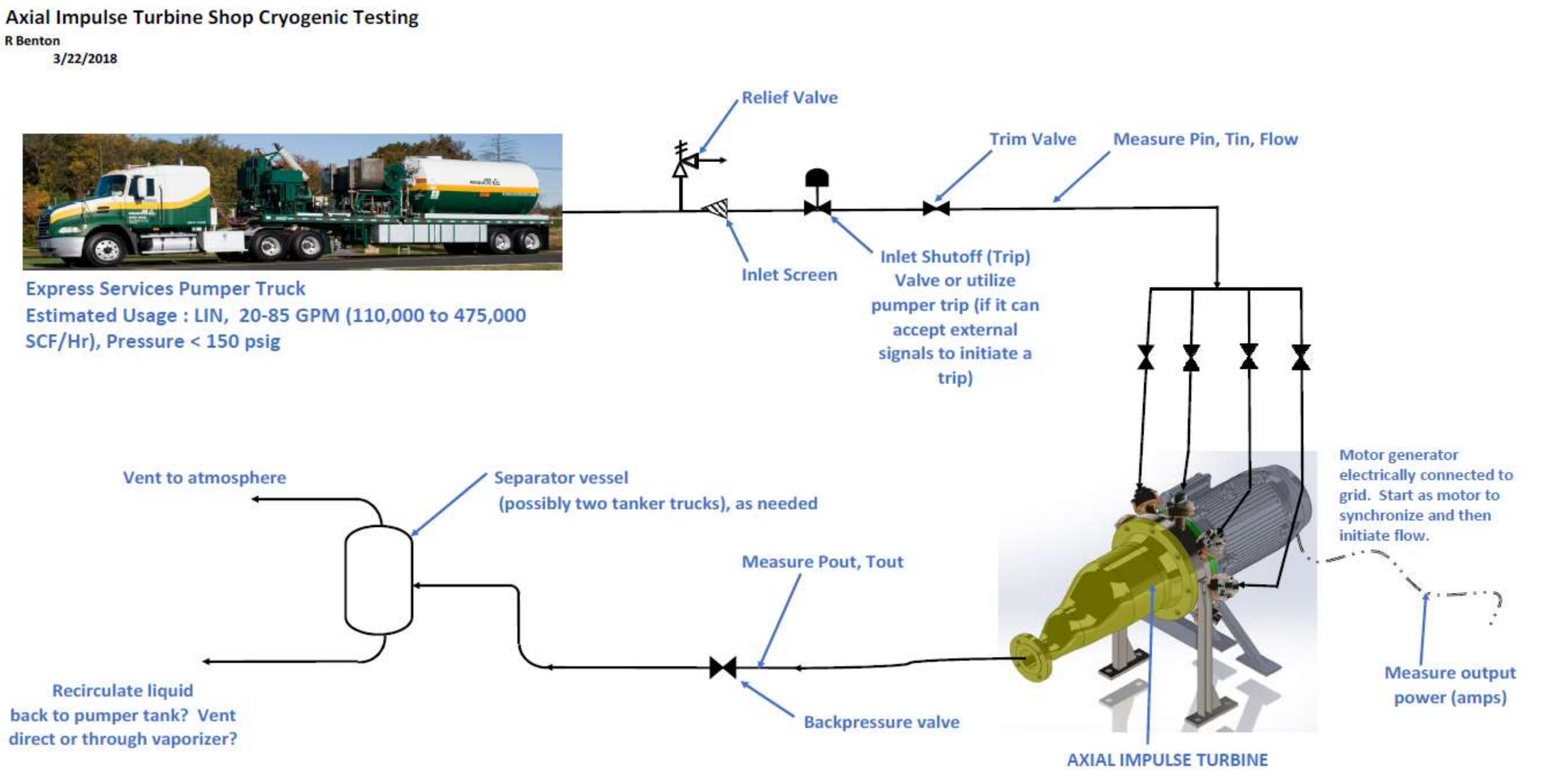




Axial Impulse DFE

- Layout and Detailed Design Completed
  - All machine components detailed and manufactured
- Fabrication
  - All major components in-house
- Assembly
  - Assembly procedure and drawing in progress
  - Machine assembly planned for April/May 2018

Cryogenic Test Diagram



Plan for Remainder of FY18

- Complete initial testing of existing LaSalle DFE in two phase flow in April timeframe, exact timing based on plant outage
- Complete detailed design of new LaSalle DFE aero stage
- Fabricate, install, and test new aero stage at LaSalle
- Assembly, Shop Testing of Axial Impulse Turbine

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Acknowledgement

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