MSU Mechanical Engineering Proposed PhD Research for:

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MSU Mechanical Engineering
Proposed PhD Research

The purpose of this briefing is to propose to MSU the research Mr. Woods would like to pursue for his PhD dissertation. At a high level, the result of this research can be summarized as:

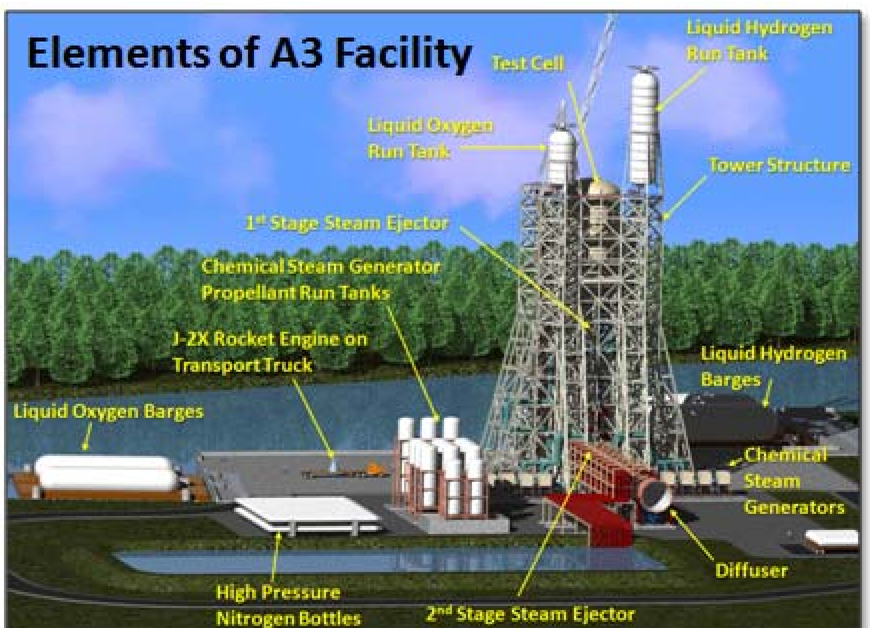
"Prediction of the service life of a rocket diffuser capture duct"

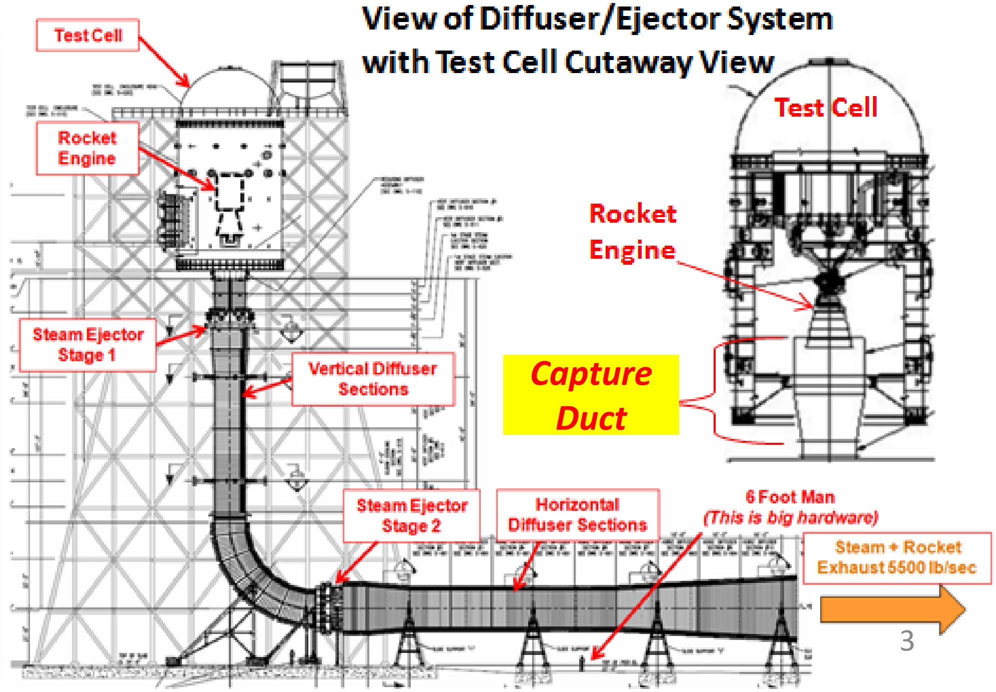
This capture duct is an actual piece of hardware installed at the A3 Test Stand which is now under construction at NASA's John C. Stennis Space Center. The remainder of this briefing will go into more detail about what this will involve and covers the following:

- Overview of A3 Test Stand
  - A3 Altitude Test Stand basics
  - NASA NESC Structural Dynamics response analysis indicates Capture Duct as a concern
    - Possibly over-conservative assumptions made for capture duct loading and structural characteristics
- Three unique research challenges for predicting Capture Duct service life to be addressed
  - *Fluid Dynamics* – Source loading environment is impingement of rocket exhaust plume at altitude
  - *Fluid/Structural Dynamics* – Assessment of damping afforded by water in cooling water jacket
  - *Fatigue/Fracture Mechanics* – Crack growth from pre-existing notch and through a weld bead
- The proposed research includes both analytical and experimental components for each of the three challenges with analytical models being anchored by experiment
- **End result is combination of all aspects of research into Capture Duct life assessment through application of fluid and structural dynamics and fatigue/fracture mechanics models**

A3 Test Stand Overview

- A3 Test Stand has an open frame steel structure supporting a test cell, two propellant run tanks, a diffuser/steam ejector system, a signal conditioning building, and attached piping, valves, and miscellaneous systems & components
- Designed to test 300 klbf thrust LOX/LH2 rocket engines at simulated 100,000 ft altitude at engine start (0.16psia)
- Altitude conditions in test cell provided by diffuser/ejector system driven with ~5000lb/sec steam product from 27 chemical steam generators which burn LOX and isopropyl alcohol with water injection
- One concern during design phase not addressed by design contractor was structural dynamic response of the test stand under operating conditions – design philosophy was that static load cases (hurricane wind, static deflection requirements, etc.) would "trump" any dynamic loading
    - A3 Test Stand Chief Engineer requested NASA Engineering and Safety Center (NESC) perform an independent assessment of structural dynamic response under operational conditions and this assessment was completed
    - ***The only area of concern identified in the NESC assessment was the rocket diffuser capture duct***

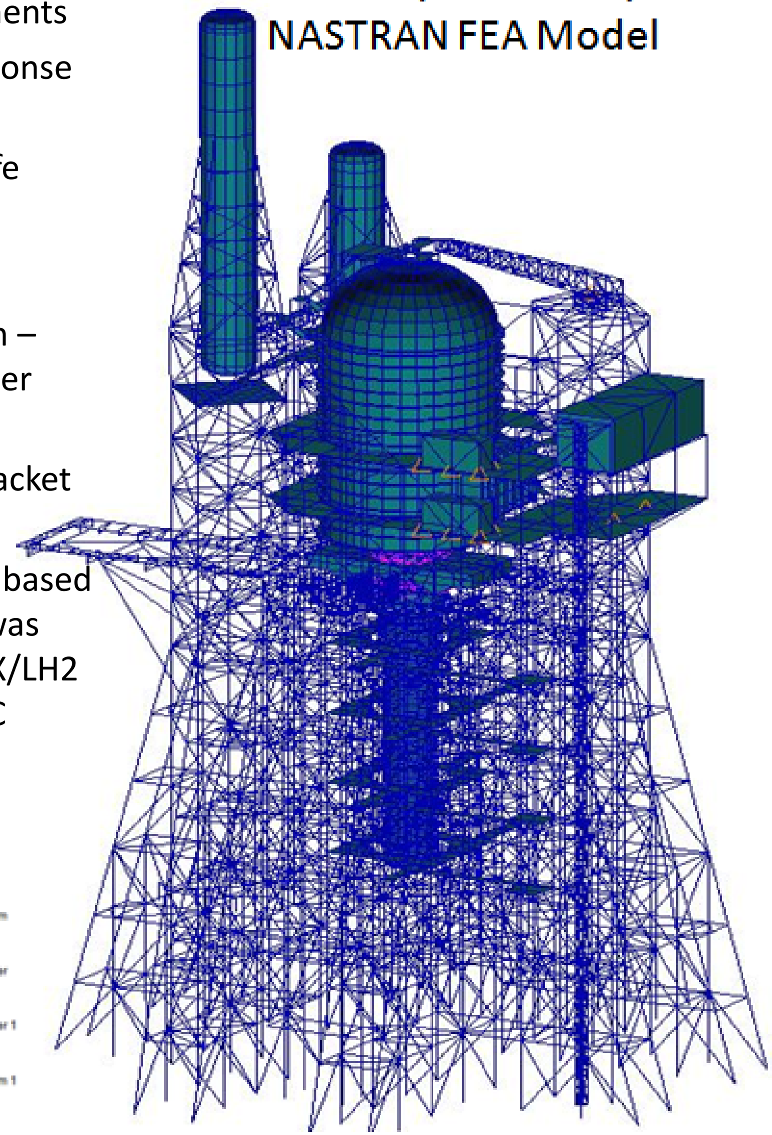




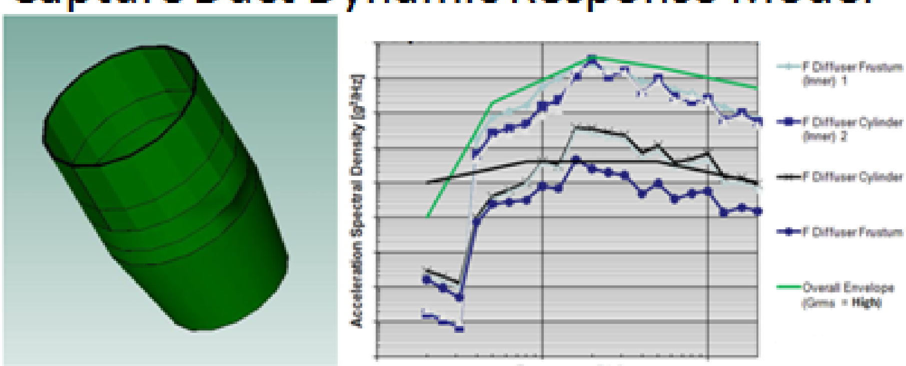
A3 Test Stand Capture Duct

- NESC dynamic response analysis consisted of combination of finite element and statistical energy analysis models of test stand components
- Capture Duct was modeled using statistical energy analysis and response predicted in terms of acceleration power spectral density
  - Predicted response was “high”, raising concern over service life
  - Life assessment not included, just dynamic response
- Capture Duct modeled with possibly over-conservative assumptions
  - Complex geometry smeared into shell element representation – actual geometry involves 2 pressure shells separated by a water jacket, stiffening ribs, and flexure joints
  - Across the board zeta damping ratio of 3% assumed – water jacket will likely afford modally dependent damping >>3%
  - Source loading environment from rocket plume impingement based on data from Orion capsule launch abort system testing and was possibly over-conservative (solids at 1 atm versus altitude LOX/LH2 engine at altitude) – because no applicable data existed, NESC approach was to be conservative and “hit it with a hammer”

Test Stand Dynamic Response NASTRAN FEA Model



Capture Duct Dynamic Response Model

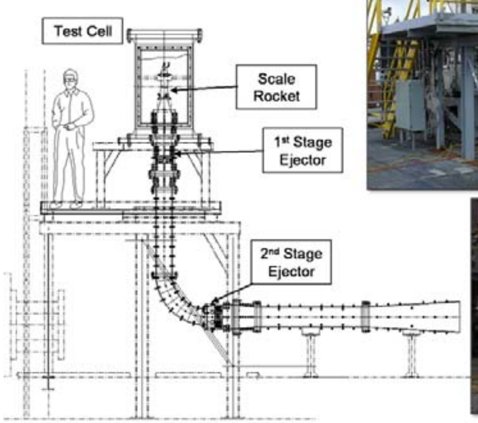


Three Research Challenges to be Addressed

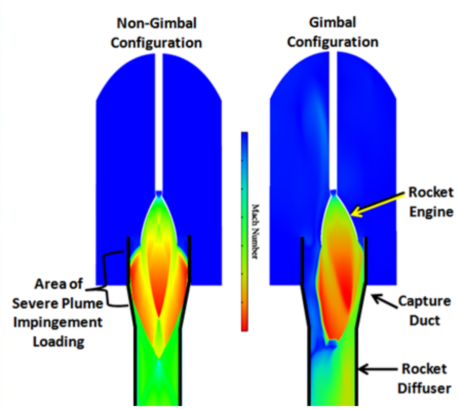
1) Fluid Dynamics – Capture Duct loading from rocket exhaust impingement at altitude (0.16 psia ambient), predicted to be most severe in gimbal position

- Need accurate representation of loading that captures pressure amplitude, spectral content, and spatial correlation and can be applied to a structural dynamics model
- Approach will be to develop numerical model of sub-scale geometry and anchor model results with experimental data then apply model methodology to full scale geometry
  - RANS, URANS, LES? – How much fidelity required? Can flow and/or turbulence parameters from a RANS simulation be used to derive statistical quantities needed for structural loading specification?
  - Scaling – need to ensure proper scaling from test scenario to full-scale
  - Testing planned as piggyback on sub-scale testing performed by A3 project at SSC, in addition testing is planned at MSFC cold gas facility
    - If the A3 project does not perform any further sub-scale testing at SSC, "plan b" will be to only test at MSFC's cold gas facility

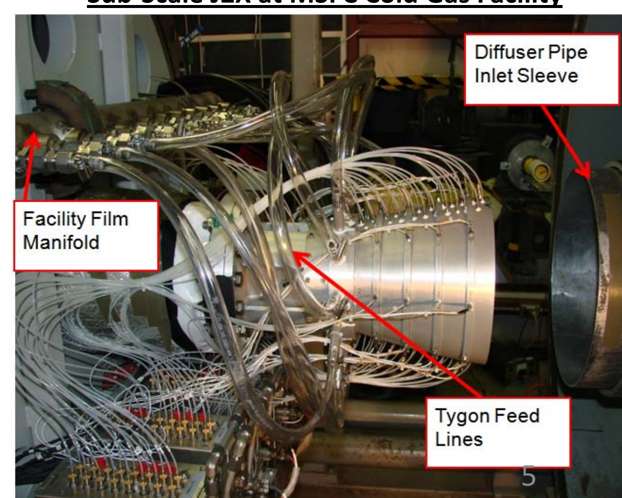
Sub-Scale A3 Facility *(1/17th scale)*
At SSC



Mach Number plots from CFD Analysis of Simulated Altitude Rocket Engine Test



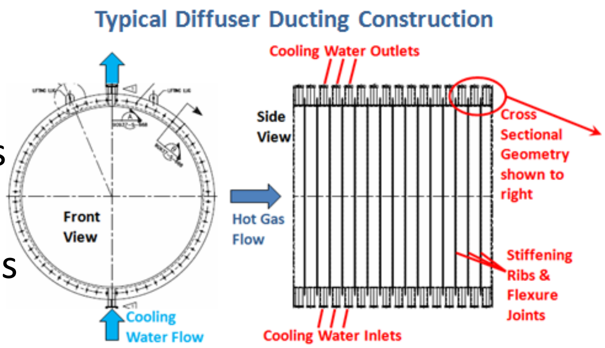
Sub-Scale J2X at MSFC Cold Gas Facility

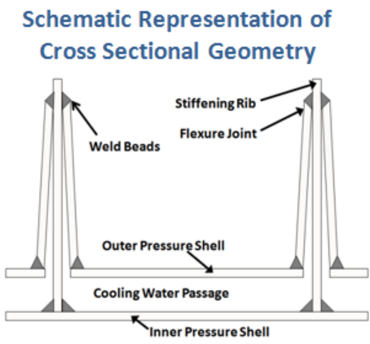


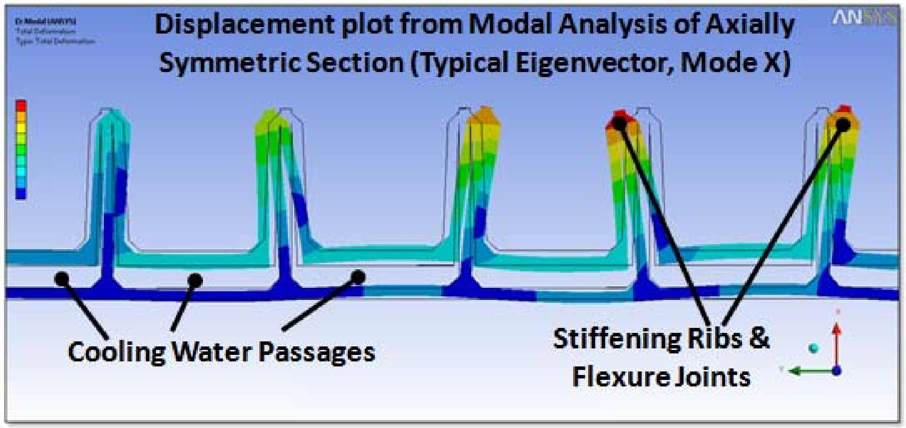
Three Research Challenges to be Addressed

2) Fluid/Structural Dynamics – Assessment of damping afforded by cooling water jacket

- It is hypothesized the cooling water jacket will provide modally dependent damping which will be well above the 3% zeta damping assumed in the NESC analysis - this must be assessed
  - Illustration of diffuser construction including circumferential water jacket shown at top right
  - As structure deflects in response to dynamic loading, water passage dimensions change, thus forcing water movement and dissipating energy
  - An eigenvector plot from a modal analysis of this geometry is shown at bottom right
  - The amount of forced water movement will vary between the modes depending on the dimensional changes associated with each eigenvector, thus allowing the damping to be modeled with modal damping coefficients
  - The analytical/experimental approach will be to design and fabricate a sub-scale or similar geometry and measure damping coefficients through vibration testing, then develop an analytical model (CFD/FSI, Basic Principles, etc?) anchored by experimental data that accurately predicts damping coefficients and apply to actual geometry to predict damping coefficients for capture duct structural dynamics model



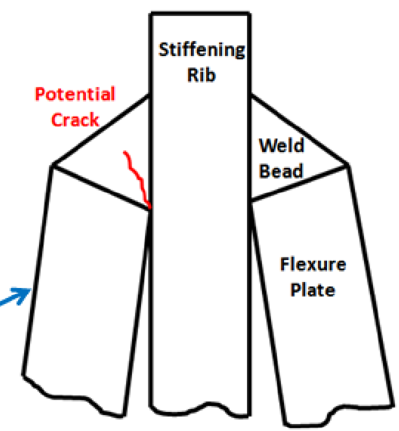


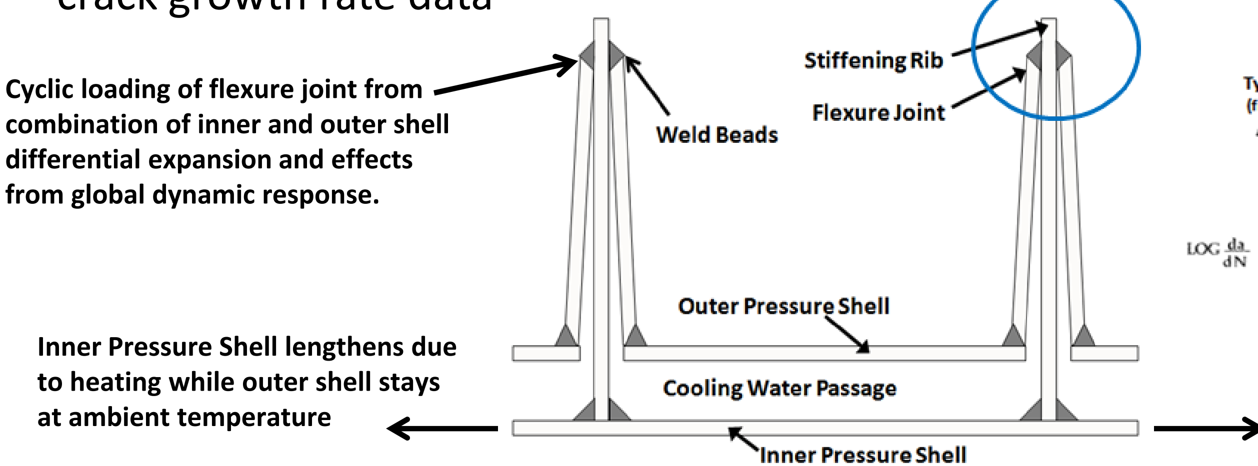


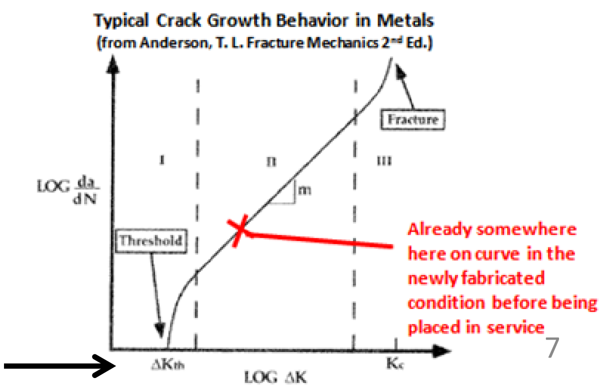
Three Research Challenges to be Addressed

3) Fatigue/Fracture Mechanics – Crack growth from pre-existing notch and through weld bead

- One of the potential Capture Duct failure modes is crack growth from a pre-existing notch, or “Engineered Crack”, and through a weld bead at the flexure joint
  - Since this crack has in effect already initiated, typical ASME life assessment is not applicable and ${}^{da}/_{dN} = f(\Delta K, R)$ or other Fracture Mechanics assessment is more appropriate
  - Very limited data exists on crack growth rate parameters, particularly through a heat affected zone and/or weld bead
  - Experimental approach will be to to obtain relevant data to be used in a Fracture Mechanics life assessment of Capture Duct
    - Fabricate test specimens with similar geometry and identical materials and processes as capture duct flexure joint
    - Develop and execute test program to obtain appropriate crack growth rate data







Final Result

The end result is combination of all aspects of research into Capture Duct life assessment

- All efforts and work leading to this result documented in a PhD Dissertation
  - Further documentation through publication of some work in journal articles and some in internal NASA documents
- Flow Chart for proposed work shown below, subject to realignment as work progresses