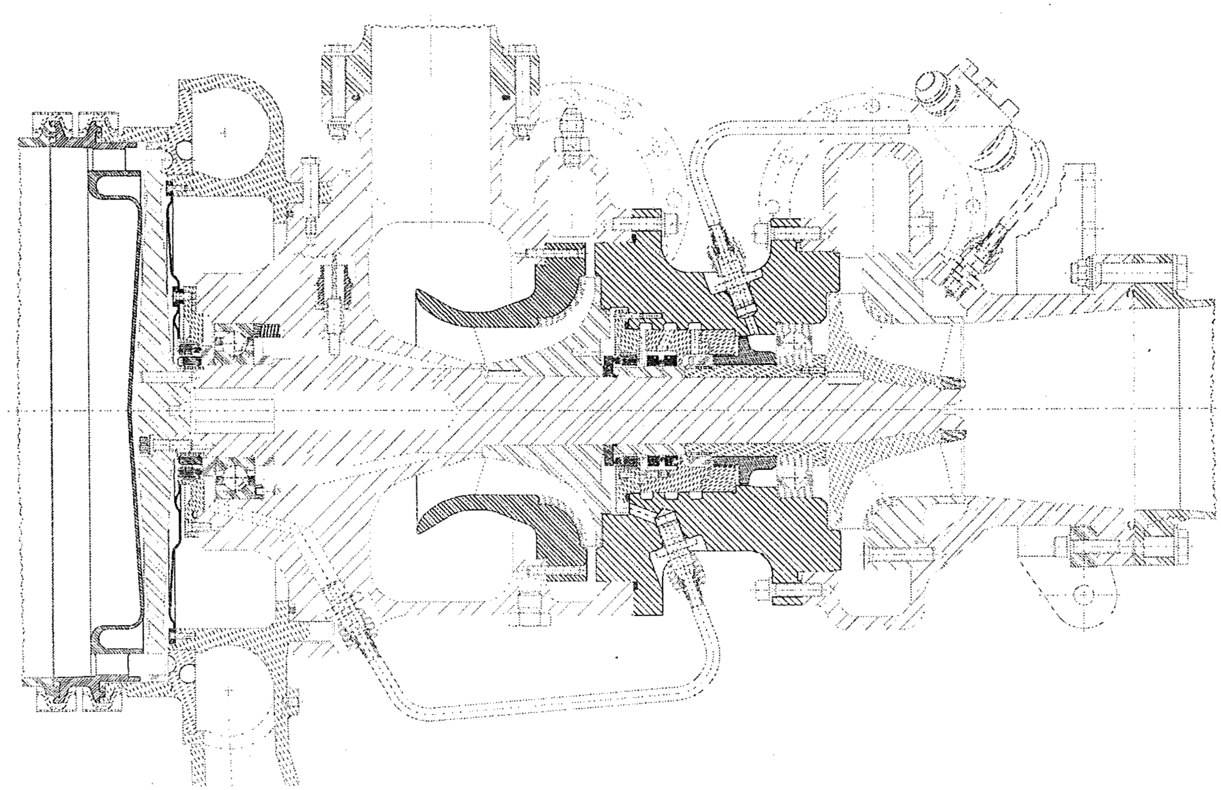
CONF PAPER/IN/34 524077 p23
2001 056 933

MC-1 LOX PUMP ROTATING CAVITATION

Issue and Investigation



MC-1 Lox Pump Rotating Cavitation

Background

Investigation History

Plan of Attack

System Level Approaches

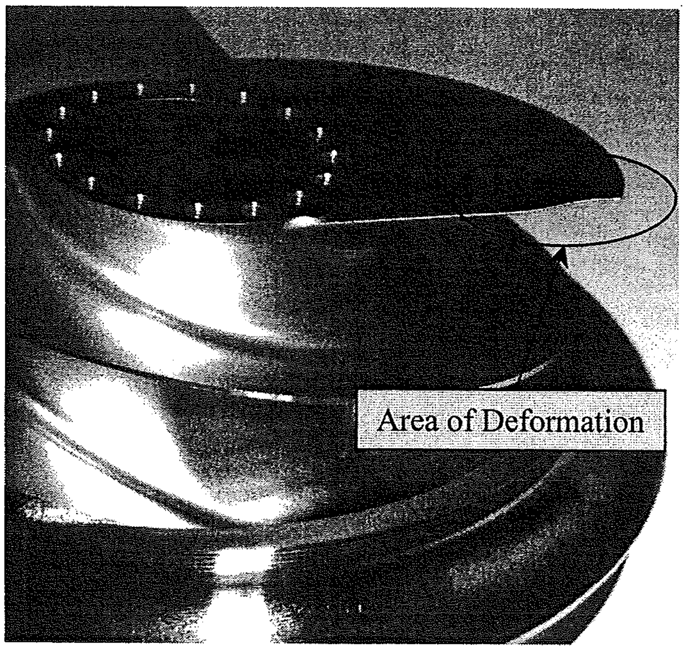
- Dynamic Modeling
- Tank Pressure Change

Turbopump Level Approaches

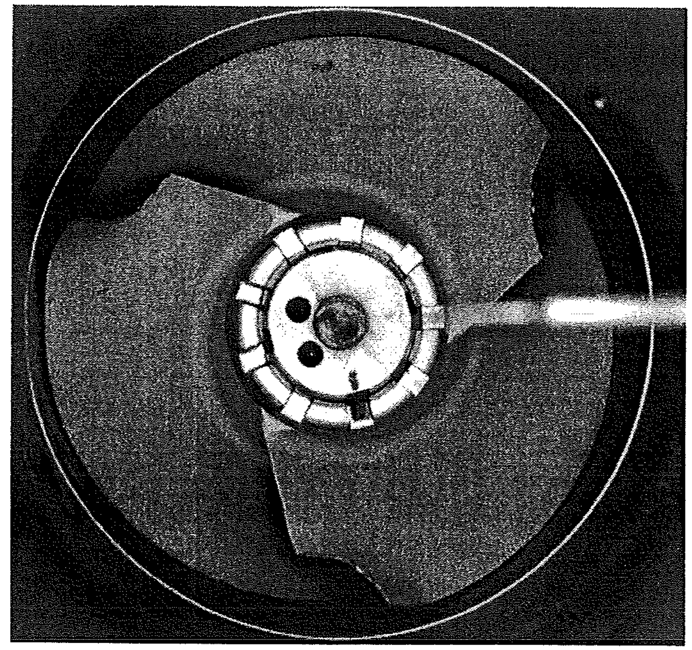
- Pump Inlet Housing Modifications
- Inducer / Impeller Redesign

Background

Leading edge tip deformation was noted on the LOX inducer from the component test unit at disassembly. The damage was in a location similar to a previous Fastrac water flow inducer failure.



Component Test K-Monel Inducer



Water Flow Aluminum Inducer

A team was formed to investigate the anomaly.

MC-1 Lox Pump Rotating Cavitation

Background

Investigation History

Plan of Attack

System Level Approaches

- Dynamic Modeling
- Tank Pressure Change

Turbopump Level Approaches

- Pump Inlet Housing Modifications
- Inducer / Impeller Redesign

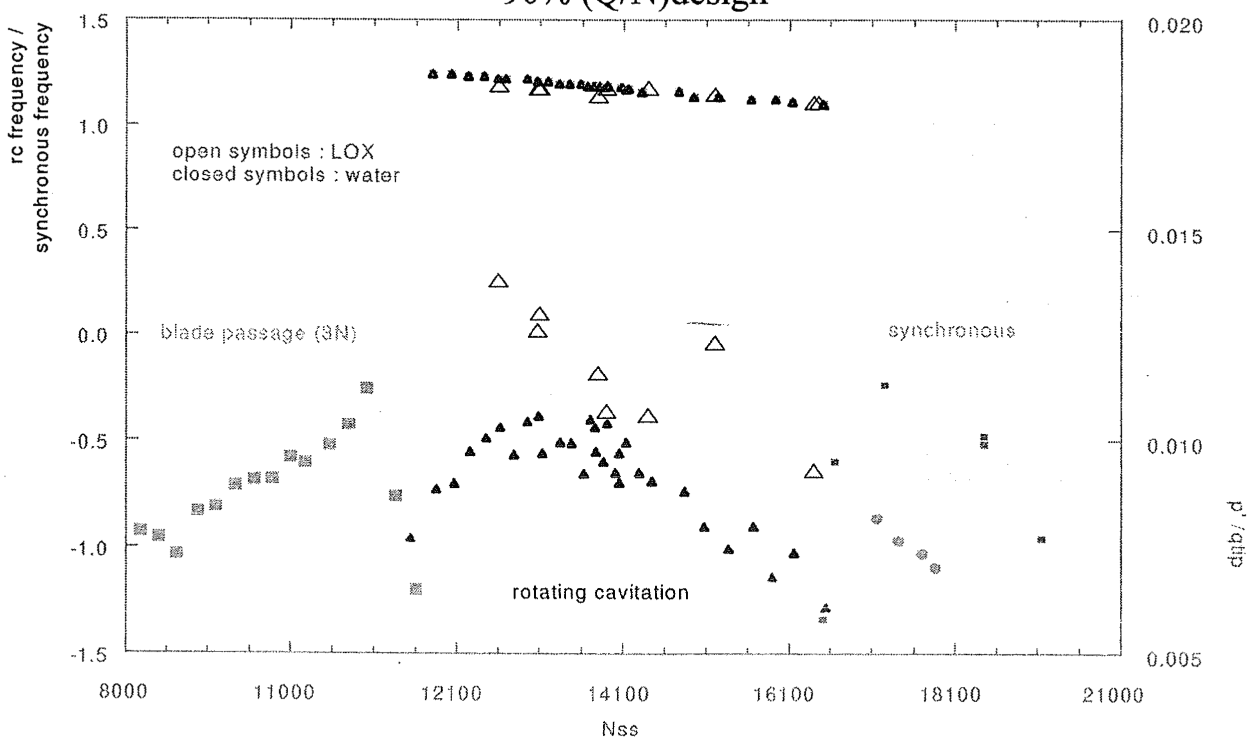
Investigation History

Marshall Space Flight Center

The team initially determined that the blade loading mechanism is most likely related to an anomalous ≈1.2N vibration which was seen in all turbopump testing (water flow, component, and engine) and which exists over a specific range of Nss.

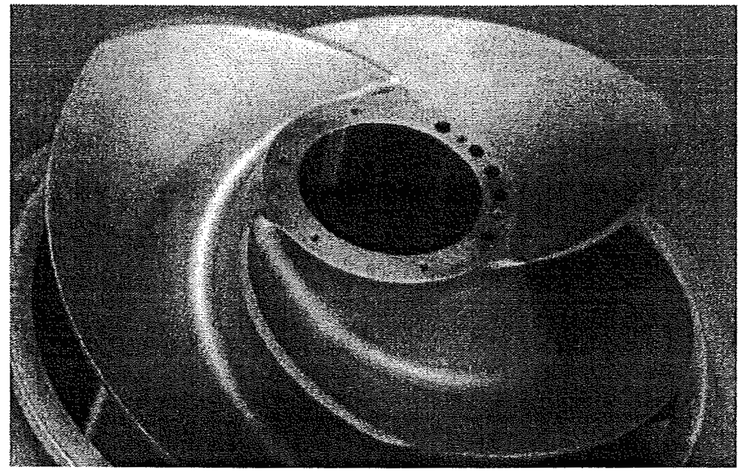
- The vibration is due to rotating cavitation and is influenced by flow coefficient and Nss. The resulting dynamic loading is similar to water hammer.
- As Nss increases, the ≈1.2N vibration first transitions to synchronous then to a cavitation regime having a reduced amplitude random vibration.

Fastrac Water Flow Baseline LOX Inducer Unsteady Performance in LOX and Water at ≈90% (Q/N)design



Investigation History

An existing water flow rig inducer/impeller was modified by wire EDM to sweep back the blade leading edges. Testing of the cutback inducer showed the rotating cavitation was reduced but not eliminated.



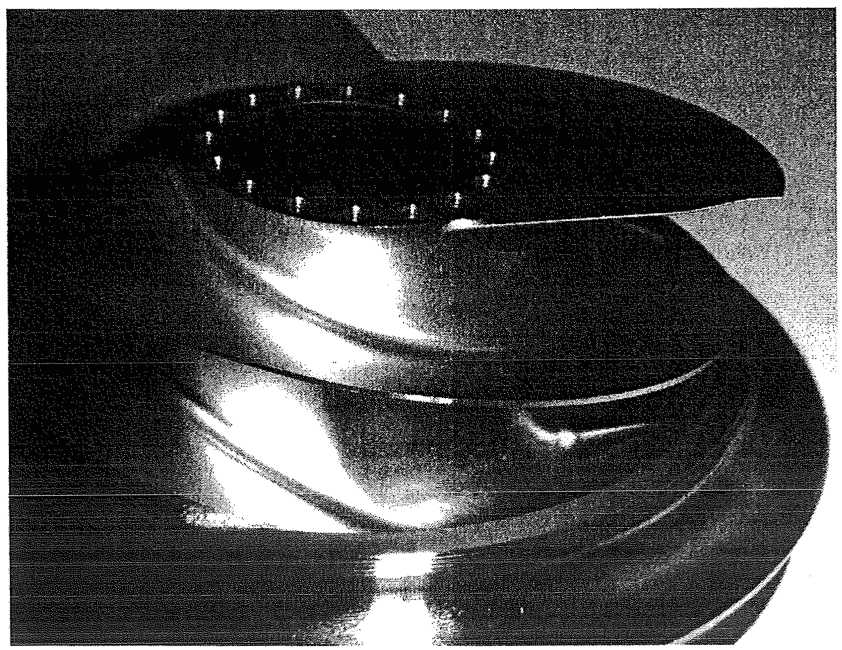
A tracking method was developed to limit the engine test time to less than that seen on the damaged component test inducer.

- According to the tracking method, an inducer inadvertently tested in the Nss regime having rotating cavitation on PTA should have been damaged but disassembly results did not reveal any anomalies.
- With further analysis, it was determined that the blade loading mechanism was not solely due to the local turbopump instability but also involved feed system interaction.

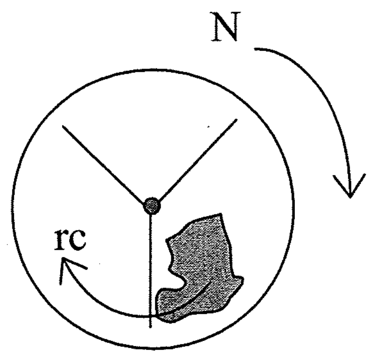
Investigation History

It was determined that the Fastrac LOX turbopump inducer blade deformations resulted from the transient hydraulic loading generated by a rotating cavitation induced system instability.

- LOX pump dynamic parameters combined with those of the facilities provided highly unstable flow modes within critical frequency bands open to excitation by the inducer rotating cavitation.
- The resulting transient pressure and flow oscillations generated "water hammer" loads large enough to deform inducer leading edges.



Investigation History

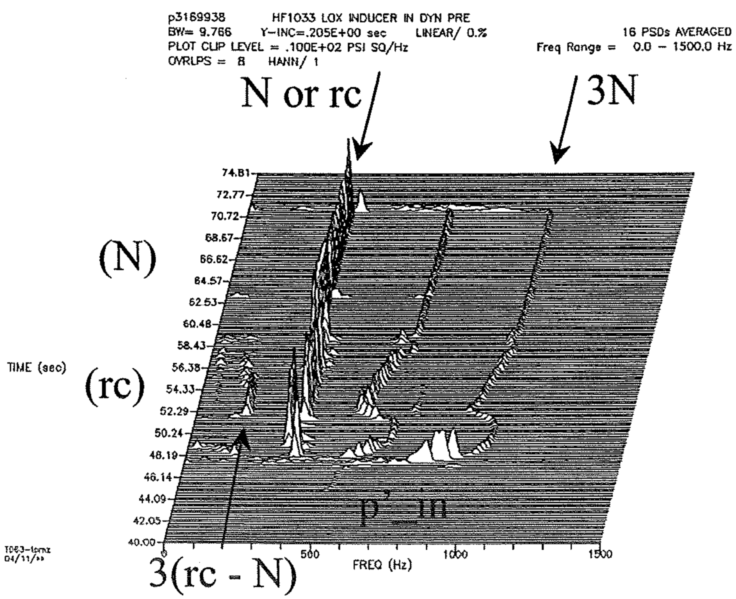


rc: passing rate of cavitation cell relative to housing

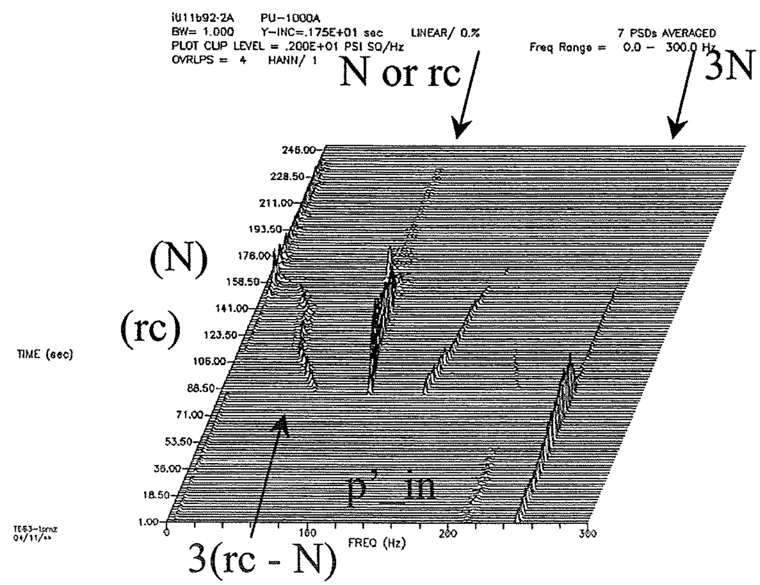
(rc - N): cell passing rate relative to blade

3(rc - N): cell to blade passing rate in rotating frame (channel blockage rate)

LOX



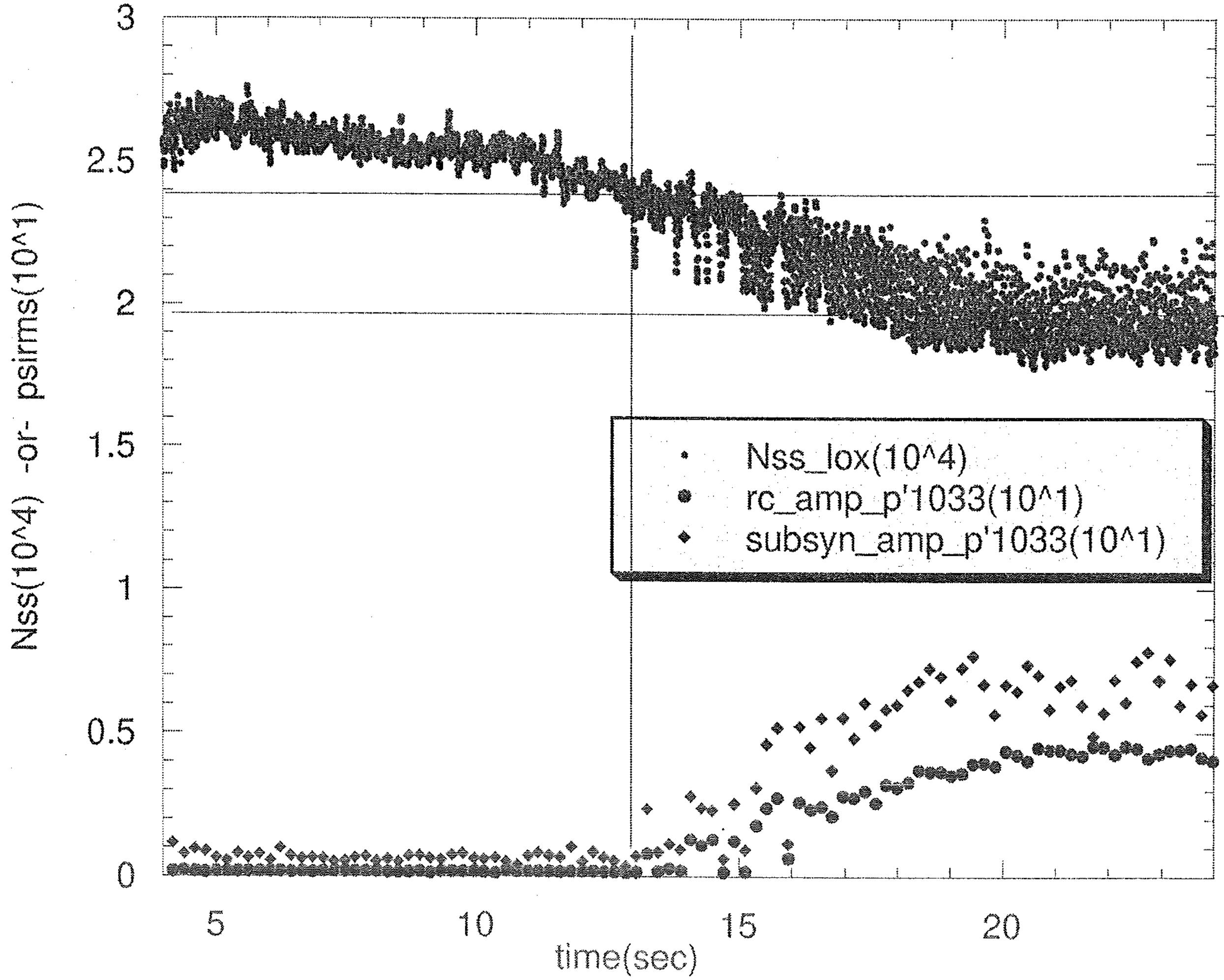
WATER



Investigation History

Pressure was increased during an engine test to examine the rotating cavitation inception point. An Nss range of 19500 to 26000 was traversed.

The rotating cavitation began to decrease in amplitude at ≈22000 Nss and was gone by ≈24000 Nss.



MC-1 Lox Pump Rotating Cavitation

Background

Investigation History

Plan of Attack

System Level Approaches

- Dynamic Modeling
- Tank Pressure Change

Turbopump Level Approaches

- Pump Inlet Housing Modifications
- Inducer / Impeller Redesign

Plan of Attack

The problem is being attacked at both the system and turbopump levels.

- At the system level:
  - Develop facility dynamic models for water flow, component and engine test facilities, and the X-34 vehicle. Anchor the models to test data and make a stability assessment.
  - Investigate lowering the LOX tank pressure to increase margin to operation in the rotating cavitation regime.
- At the turbopump level:
  - Modify the pump inlet to provide a diversion path for the vapor.
    - Decide on the appropriate inlet geometry for testing.
    - Test concepts at the water flow facility and possibly at the component level.
  - Initiate redesign of inducer for more cavitation margin.
    - Determine appropriate geometry for cavitation margin.
    - Design, analyze, and fabricate a model for water flow test.

MC-1 Lox Pump Rotating Cavitation

Background

Investigation History

Plan of Attack

System Level Approaches

- Dynamic Modeling
- Tank Pressure Change

Turbopump Level Approaches

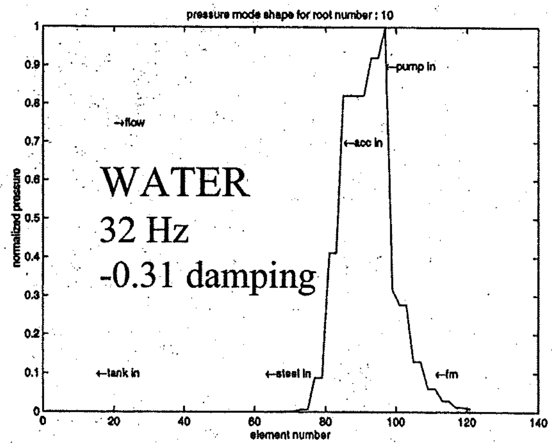
- Pump Inlet Housing Modifications
- Inducer / Impeller Redesign

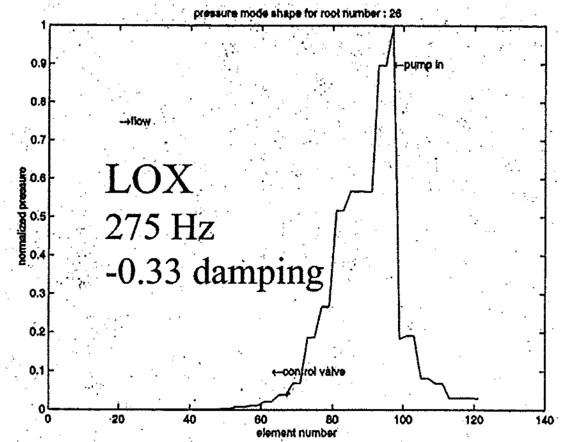
System Level Approach: Dynamic Modeling

The model pump dynamic characteristics were anchored to water flow and component level test results (where blade deformations occurred).

The stability assessment attempts to define the mechanism that damaged blades and to see if similar unstable behavior will exist on the X34 vehicle.

- Both the water flow and component test facility models show the most unstable system modes have similar mode shapes (both unsteady pressure and flow) which have the highest response at the inducer inlet.





- Vehicle model runs for 20,000 to 30,000 Nss were completed at various tank levels. The highly unstable inducer-localized mode predicted in the water flow and component test facility models is not exhibited in the vehicle model. The current design should be acceptable for use with X34.

MC-1 Lox Pump Rotating Cavitation

Background

Investigation History

Plan of Attack

System Level Approaches

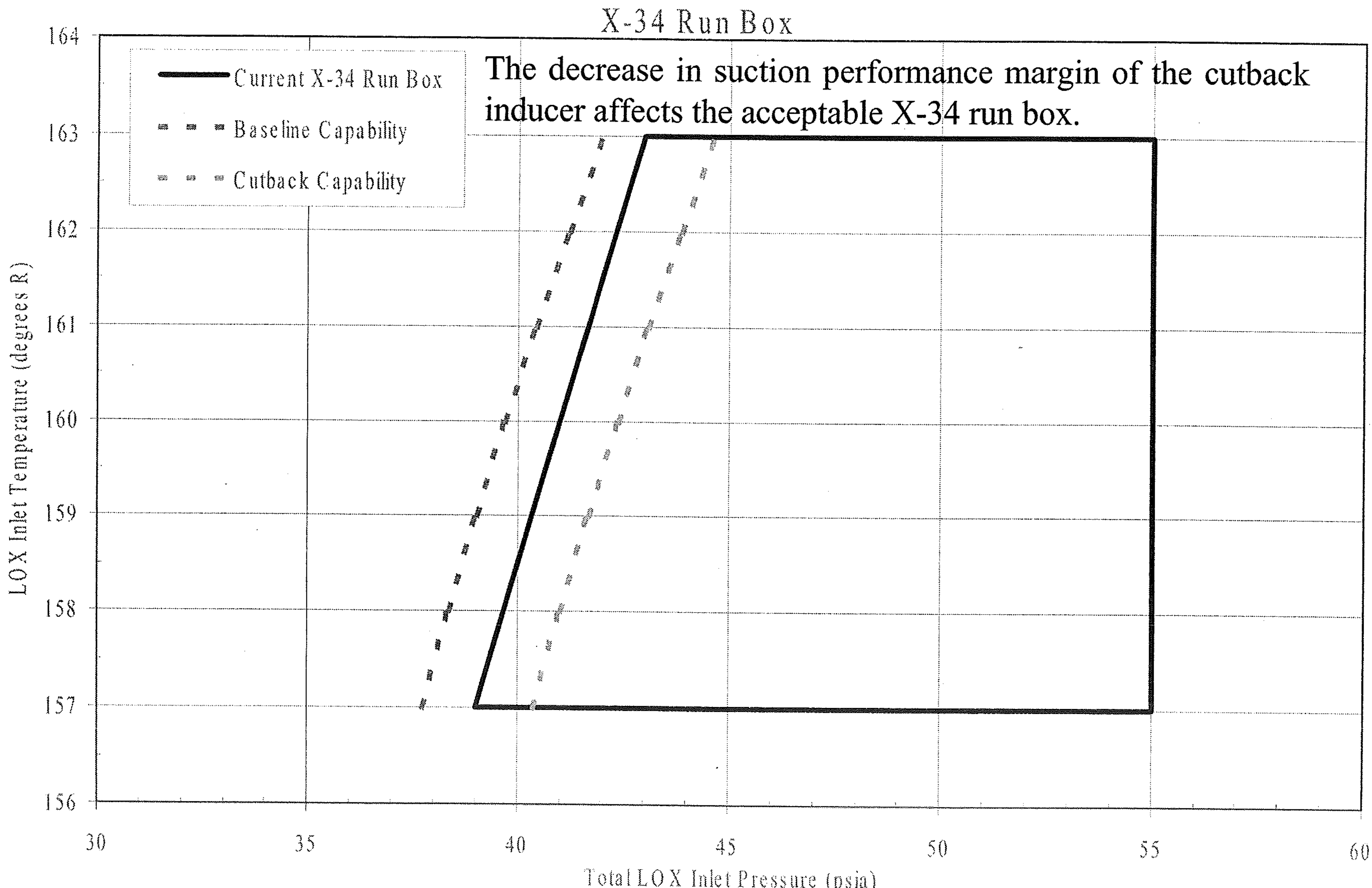
- Dynamic Modeling
- Tank Pressure Change

Turbopump Level Approaches

- Pump Inlet Housing Modifications
- Inducer / Impeller Redesign

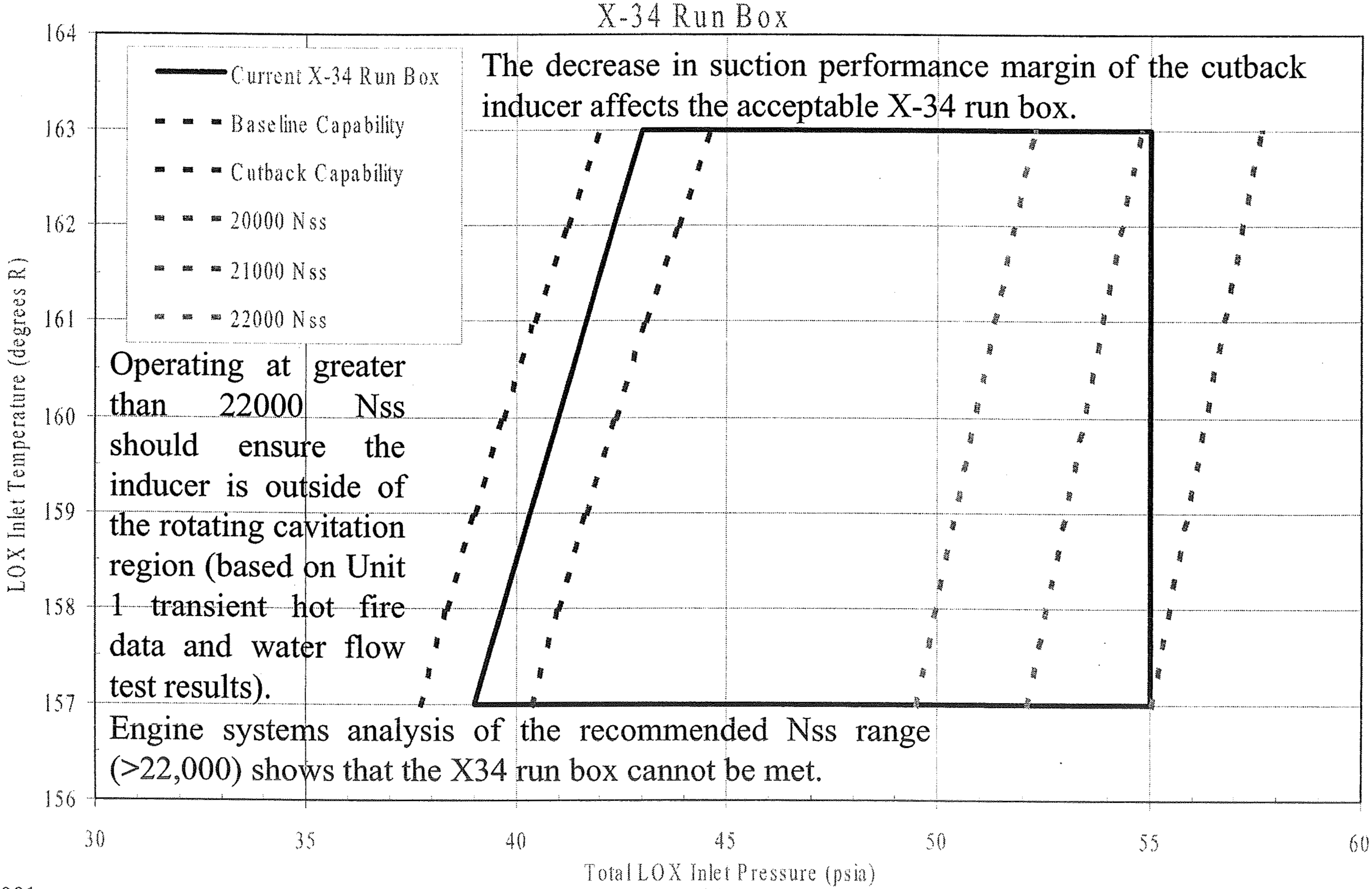
System Level Approach: Tank Pressure Change

LOX pump X-34 ICD requirements are set by Nss limitations and maximum tank pressure.



System Level Approach: Tank Pressure Change

LOX pump X-34 ICD requirements are set by Nss limitations and maximum tank pressure.



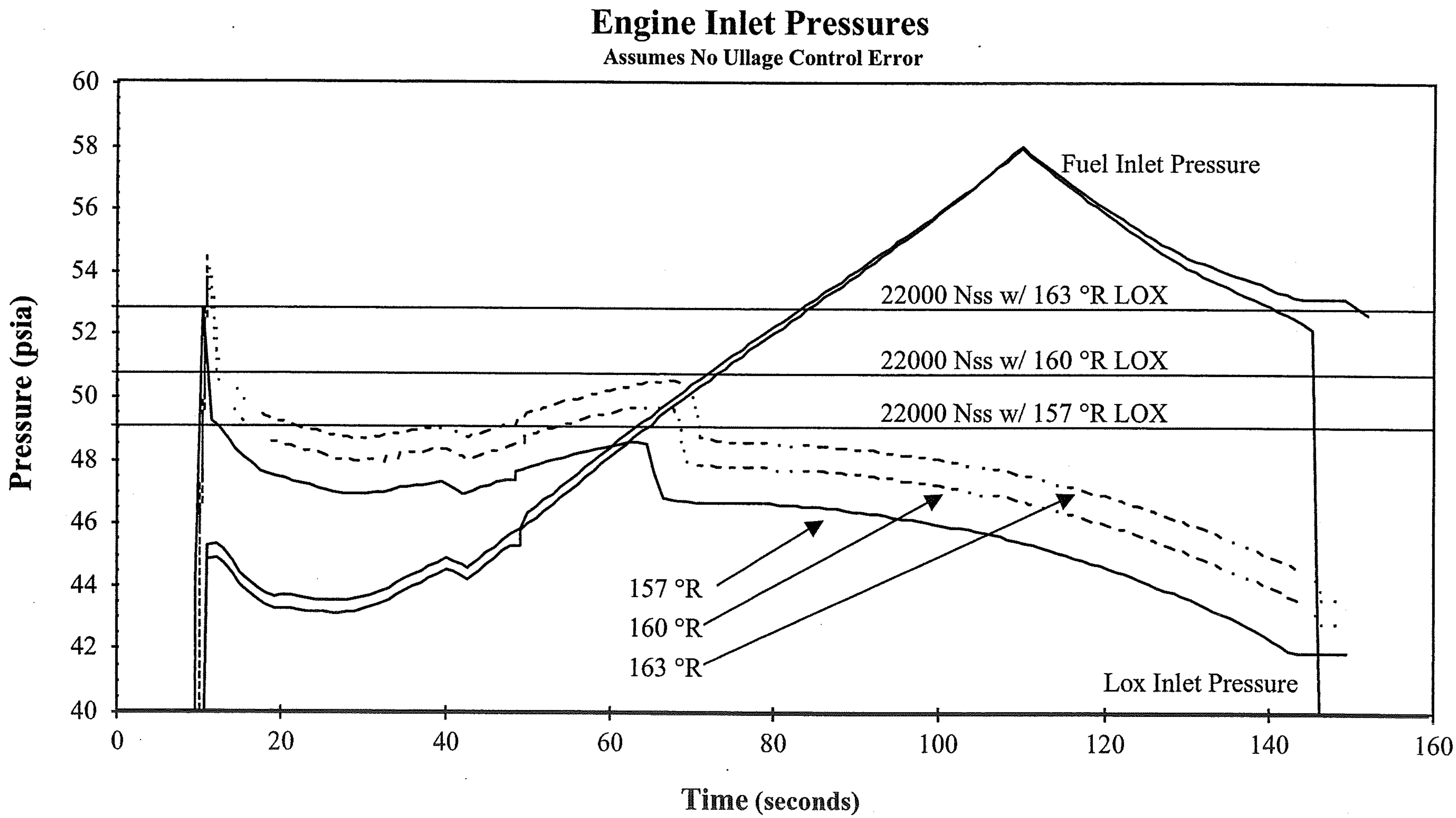
The decrease in suction performance margin of the cutback inducer affects the acceptable X-34 run box.

Operating at greater than 22000 Nss should ensure the inducer is outside of the rotating cavitation region (based on Unit 1 transient hot fire data and water flow test results).

Engine systems analysis of the recommended Nss range (>22,000) shows that the X34 run box cannot be met.

System Level Approach: Tank Pressure Change

Evaluation of the current planned trajectory indicates most of the flight occurs in the higher Nss region further substantiating the decision to remain with the current design.



MC-1 Lox Pump Rotating Cavitation

Background

Investigation History

Plan of Attack

System Level Approaches

- Dynamic Modeling
- Tank Pressure Change

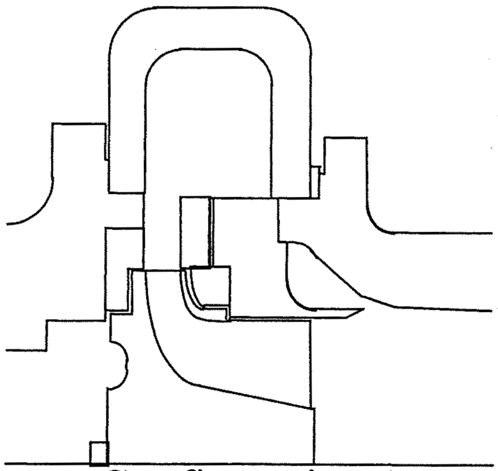
Turbopump Level Approaches

- Pump Inlet Housing Modifications
- Inducer / Impeller Redesign

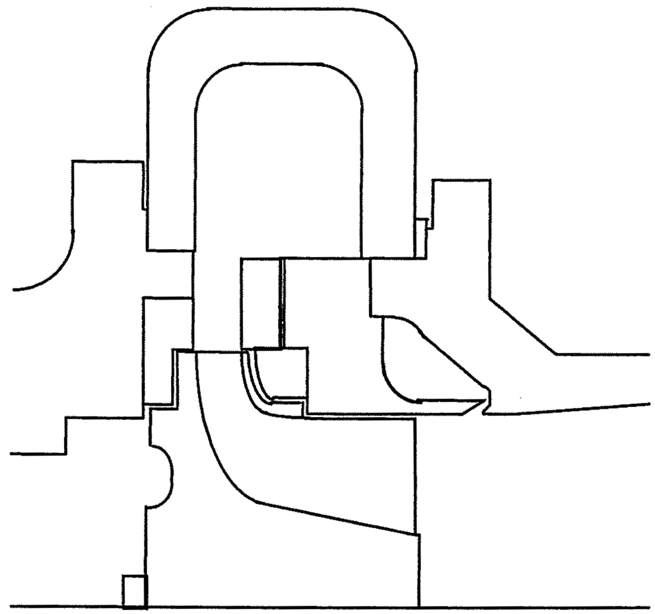
TPA Level Approach: Inlet Housing Modifications

Marshall Space Flight Center

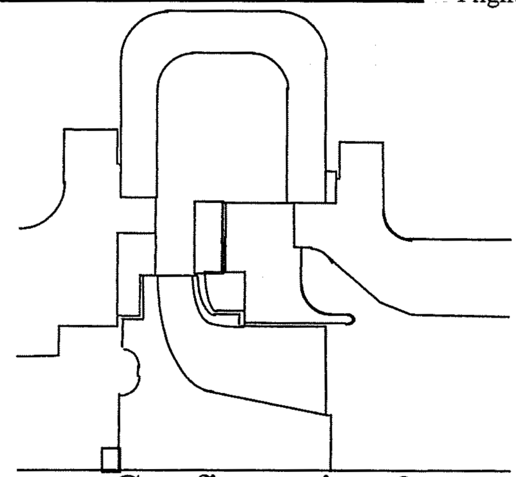
Two shroud designs and two housing designs were water flow tested in four combinations.



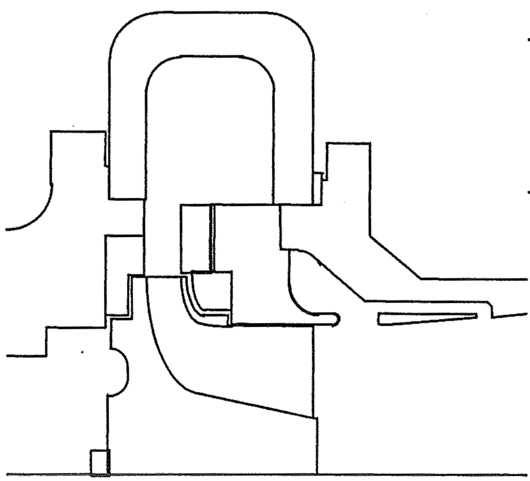
Configuration 1
Opened inlet
Baseline shroud



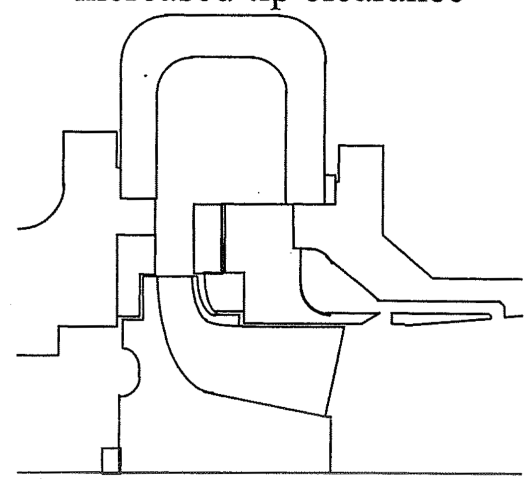
Baseline Geometry



Configuration 2
Opened inlet
Shroud w/ cut-back lip, increased tip clearance



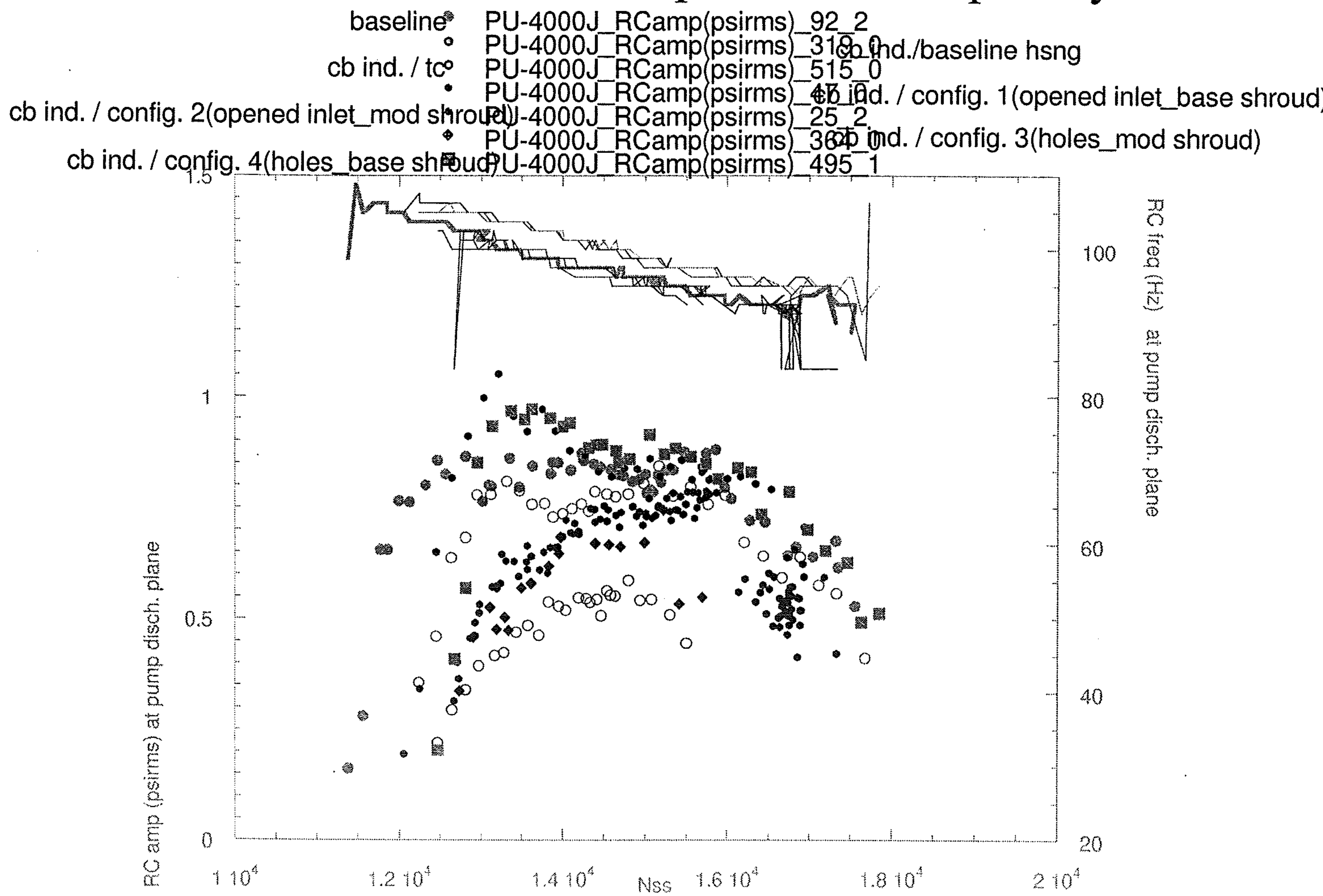
Configuration 3
Axial holes in inlet
Shroud w/ cut-back lip, increased tip clearance



Configuration 4
Axial holes in inlet
Baseline shroud

TPA Level Approach: Inlet Housing Modifications

The steady state performance is not significantly different in any of the configurations, though suction performance results show a decrease in suction capability for all configurations when compared with the baseline. Configuration 3 has the lowest suction performance capability.



MC-1 Lox Pump Rotating Cavitation

Background

Investigation History

Plan of Attack

System Level Approaches

- Dynamic Modeling
- Tank Pressure Change

Turbopump Level Approaches

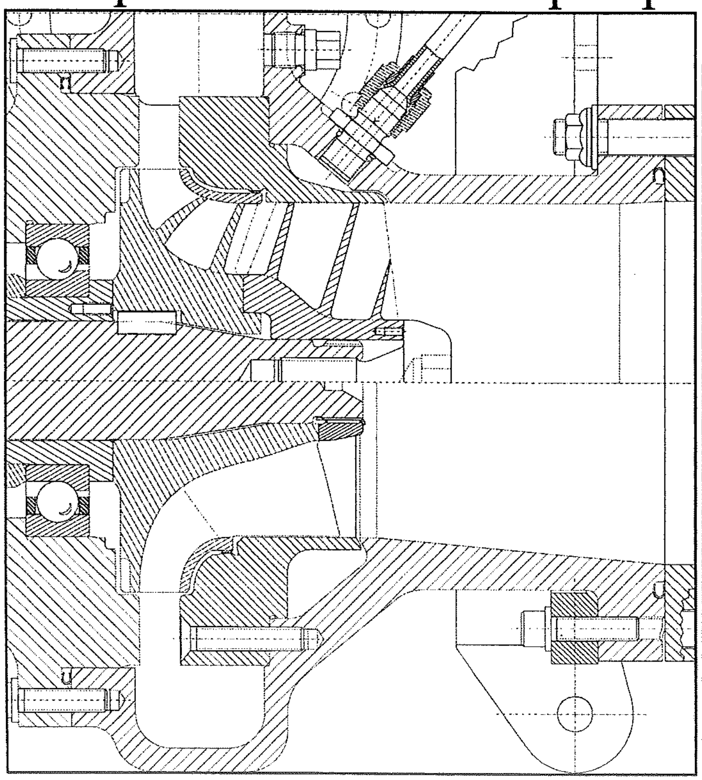
- Pump Inlet Housing Modifications
- Inducer / Impeller Redesign

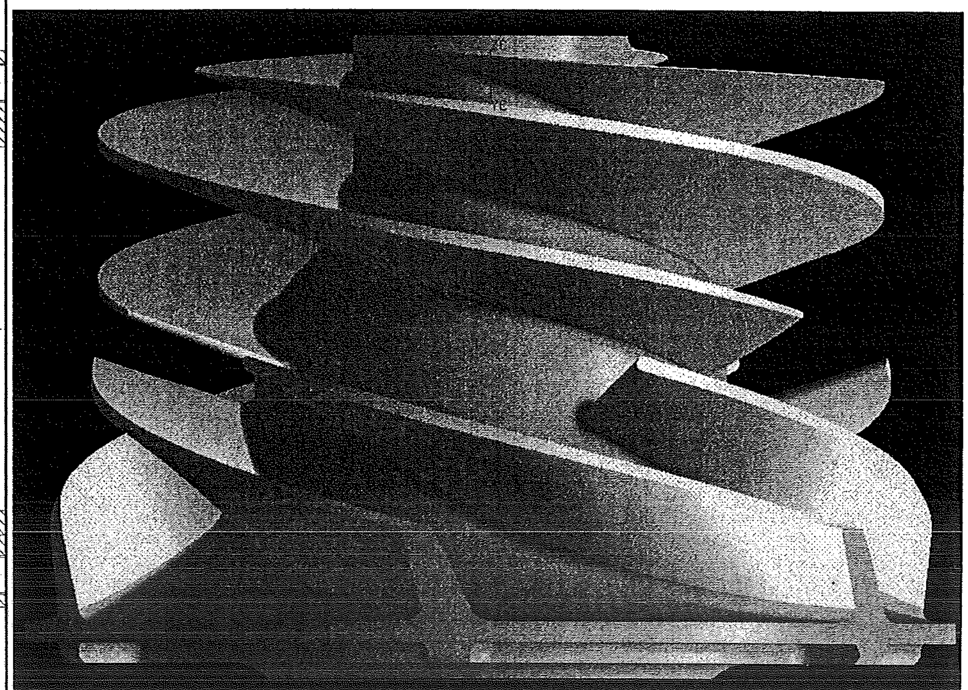
TPA Level Approach: Inducer/Impeller Redesign

A redesign of the inducer/impeller has been initiated with the goals of eliminating unsteady pressure oscillations and increasing suction performance.

Hardware is being procured for water flow evaluation of the design.

The changes in shape and pressure distribution of the new inducer significantly impact axial thrust calculations which must be resolved before incorporation into a turbopump.





Plan of Action: Conclusion

Several courses of action were considered in order to prevent operation in the regime in which the rotating cavitation induces a system instability. Both system level approaches and turbopump level approaches were investigated.

System level dynamic modeling indicates that the highly unstable inducer-localized mode predicted in the water flow and component test facility models is not exhibited in the X34 vehicle model. Therefore, remaining with the current design inducer/impeller should not pose a problem for X34.

If the turbopump is implemented in another vehicle or test facility, the choice of solution to the rotating cavitation induced system instability must be revisited.