Novel Diagnostic Techniques for Identification of Inducer Cavitation Dynamics

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Long Abstract

Introduction

The cavitation dynamics of a rocket engine turbopump inducer was characterized via high-response unsteady pressure and velocity measurements combined with front- and side-view optical imaging. The data was processed using Traveling Wave Energy (TWE) analysis to determine the temporal evolution of frequency, spatial shape, and direction of rotation of the natural oscillatory modes of the flow field during cavitation transients. The test inducer, dubbed the MIT inducer, is representative of a low-pressure liquid oxygen pump (LPOP) inducer of modern design. All experiments were conducted in the Aerospace Corporation's Cavitation Test Facility. The paper will also discuss a new approach to measuring fluctuating mass flow and velocity for potential use in forced response identification of the inducer transfer matrix relevant for POGO instability assessment.

Previous work on the mechanism responsible for rotating cavitation suggests that rotating cavitation is caused by coupling of the cavities on adjacent blades during alternate blade cavitation [1]. Due to the nearly tangential flow, the vortex lines from one of the non-cavitating blades wrap around the blade leading edge of the adjacent blade, which yields a drop in static pressure and cavity formation. The tip vortex interaction with the leading edge of the next blade leads to sheet cavity breakdown with periodic cavity growth and collapse. This creates the apparent super-synchronous rotation of the cavities. The measurements presented in this paper support these hypotheses.

1. Methods

The dynamics of alternate blade cavitation, rotating cavitation and cavitation surge were experimentally identified with a TWE analysis using a circumferential array of unsteady pressure transducers upstream of the impeller leading edge. The TWE methodology, previously used in detecting aero-engine compressor instabilities [2], was able to resolve frequency, spatial mode shapes, and rotation direction of cavitation instabilities and demonstrated several advantages over the standard spectral analysis and Hannover diagrams, which cannot discern spatial harmonic content and ambiguously define rotation direction of the cavities.

Furthermore, side-view and borescope imaging confirm the distinct cut-off/cut-on behavior for alternate blade cavitation and rotating cavitation. The TWE analysis was also adapted to the image data to interrogate frequency content and spatial mode shapes. The paper will demonstrate a new diagnostic tool for the characterization of cavitation instabilities.

Lastly, a fiber film probe was used to measure the unsteady velocity upstream of the test inducer during non-cavitating and cavitating operating conditions. In particular, the traverse measurements of axial and tangential velocity characterize the backflow region. The experiments also demonstrate the viability of fiber film probes for local unsteady velocity measurements during cavitation surge which could potentially be used in forced response system identification tests.

2. Results

The paper will provide details of TWE diagnostic results and demonstrate that the post-processed image and pressure data yield the same characteristics of the cavitation dynamics. A discussion of first-of-their kind fiber film probe measurements will also be provided. Figure 1 below illustrates the measured unsteady velocity fluctuations during cavitation surge. The fiber film probe was located on the duct centerline about one diameter upstream of the inducer leading edge. The cavitation number was set to 0.0292 for cavitation surge and the fiber film probe and optical measurements were acquired simultaneously. The two video stills at 4.4 and 12.3 rotor revolutions indicate flow reversal and forward flow during a cavitation surge cycle in concert with the troughs and peaks in measured flow coefficient. The paper will discuss the measurement setup and data processing in detail.

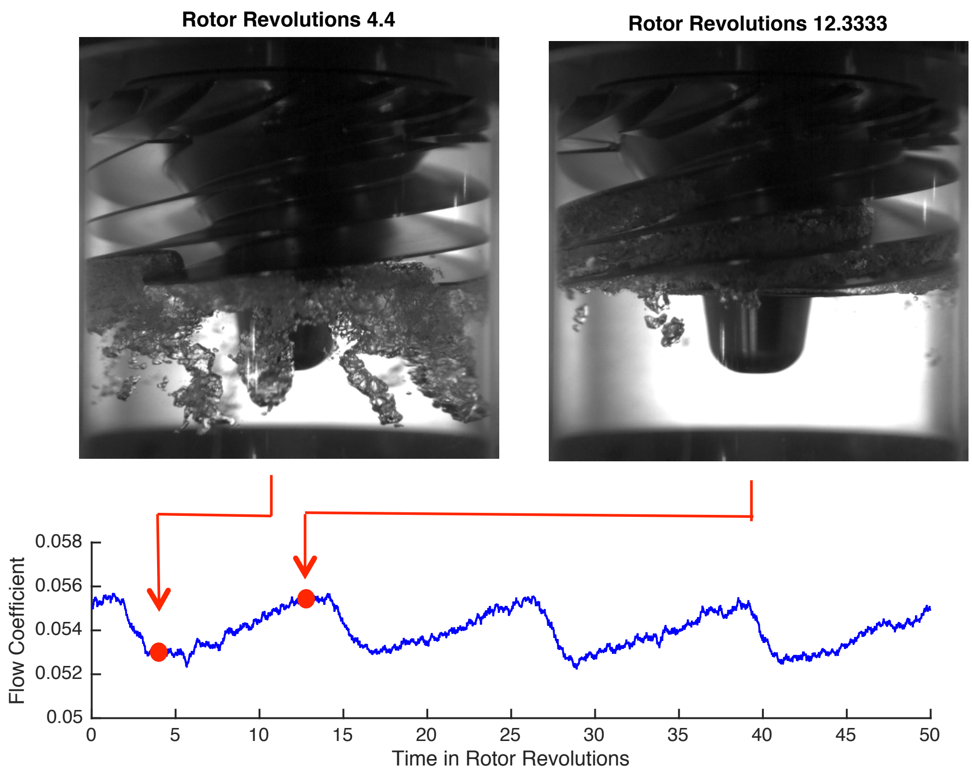

Figure 1. Measured unsteady velocity during cavitation surge.

References

[1] C. Lettieri and Z. Spakovszky. Origin of Rotating Cavitation in Four Bladed Turbopump Inducers. Submitted to AIAA Journal of Propulsion and Power.

[2] M. Tryfonidis, O. Etchevers, J. Paduano, A. Epstein, and G. Hendricks. Prestall Behavior of Several High-Speed Compressors. ASME. *J. Turbomach.* 1995;117(1).