Dynamics of the Blade Channel of an Inducer under Cavitation-Induced Instabilities

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ISROMAC
Long Abstract

Introduction

Liquid-fed rocket engines still play a crucial role in primary space propulsion systems. In these applications propellant feed turbopumps are one of the most important components, whose design and operation are critical for the success of the mission. Modern turbopumps are high power density, dynamically stable machines capable of meeting the extremely demanding suction, pumping and reliability requirements of modern Space Transportation Systems.

The attainment of such high power/weight ratios is invariably obtained by running the impeller at the maximum allowable speed and lower shaft torque. Operation under cavitating conditions with lighter – but also more flexible – shafts is therefore tolerated, exposing rocket propellant feed turbopumps to the onset of dangerous cavitation-induced fluid dynamic and rotordynamic instabilities that can be easily responsible for catastrophic failures of the machine.

Cavitation represents the major source of degradation of their suction performance, efficiency, reliability, power density and useful life (Stripling and Acosta 1962). More importantly for space applications, cavitation can provide the necessary flow excitation and compliance for triggering dangerous fluid mechanic and/or rotordynamic instabilities of the turbopump (Sack and Nottage 1965, Natanzon et al. 1974, Brennen and Acosta 1973, Brennen and Acosta 1976, Ng and Brennen 1978, Braisted 1979, d'Auria et al. 1995, d'Agostino et al. 1998, d'Agostino and Venturini-Autieri 2002, d'Agostino and Venturini-Autieri 2003), or even, through the coupling with thrust generation and the structural response, of the entire space vehicle (POGO auto-oscillations, Rubin 1966).

The present paper illustrates the results of an experimental campaign performed at SITAEL S.p.A. in the CPRTF (Cavitating Pump Rotordynamic Test Facility) which is used to carry out tests on turbomachines under thermal and fluid dynamic similarity by using water as working fluid and changing its cavitating behavior by regulating the liquid temperature. Tests have been performed in order to characterize the dynamics of the blade channel of a three-bladed inducer, named RAPDUD, under typical flow regimes characterized by flow instabilities in both non-cavitating and cavitating conditions.

1. Methods

The Cavitating Pump Rotordynamic Test Facility is a versatile and easily instrumentable facility operating in water at temperatures up to 90 °C (Pace et al., 2012). The facility is intended as a flexible apparatus that can readily be adapted to conduct experimental investigations on virtually any kind of fluid dynamic phenomena relevant to high performance turbopumps in a wide variety of alternative configurations (impeller with axial, radial or mixed flow, with or without an inducer). The CPRTF has been especially designed for the analysis of unsteady flow phenomena and rotordynamic impeller forces in scaled cavitation tests under fluid dynamic and thermal cavitation similarity conditions.

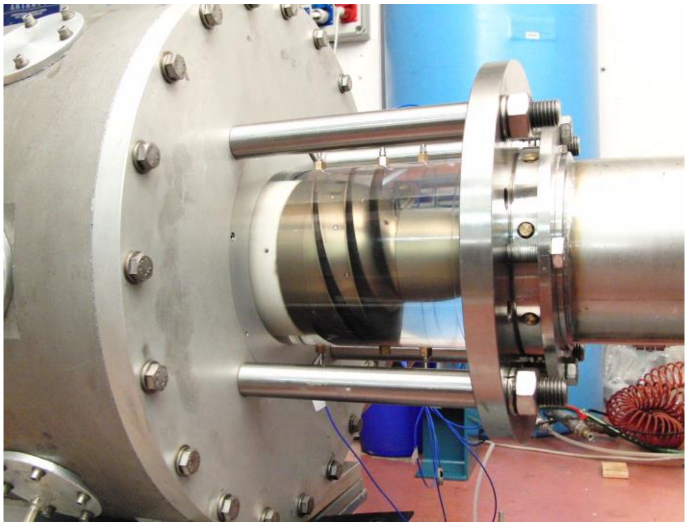

Figure 1. Test Section of the Cavitating Pump Rotordynamic Test Facility at SITAEL S.p.A.

The facility has been instrumented in order to characterize the pumping and suction performance of the RAPDUD inducer, as well as to characterize the flow instabilities in the flow through the pump. In particular, pressure transducers have been placed on the inlet section, made of Plexiglas, which allows for optical access to the inducer flow. Eight piezoelectric pressure transducers have been flush mounted on the Plexiglas at several axial and at azimuthal positions (Figure 1). At each axial station up to five transducers can be mounted with a given angular spacing, in order to cross-correlate their signals for amplitude, phase and coherence analyses. Cross-correlation of two pressure signals from different locations allows for determining the axial or azimuthal nature of each instability and, in the second case, the number of rotating cells involved.

In the present experimental campaign, pressure transducers have been flush mounted also on the inducer hub (Figure). The effects of the typical cavitation-induced instabilities, already detected in the statoric frame, have been characterized in the rotating frame along the blade channel. A special focus has been devoted to the characterization of the most dangerous cavitation-induced instabilities such as the rotating cavitation and the cavitation surge detected both at low frequencies (classical low order instabilities) and at high frequencies (high order instabilities). The experimental data will be compared to a suitable developed analytical model of the transfer matrix of the blade channel.

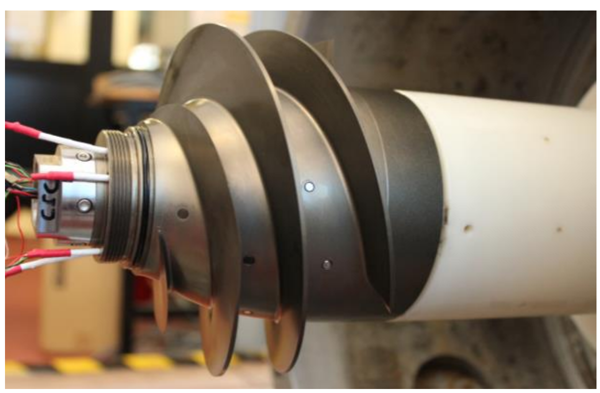

Figure 2. The RAPDUD inducer equipped with pressure taps along the blade channels.

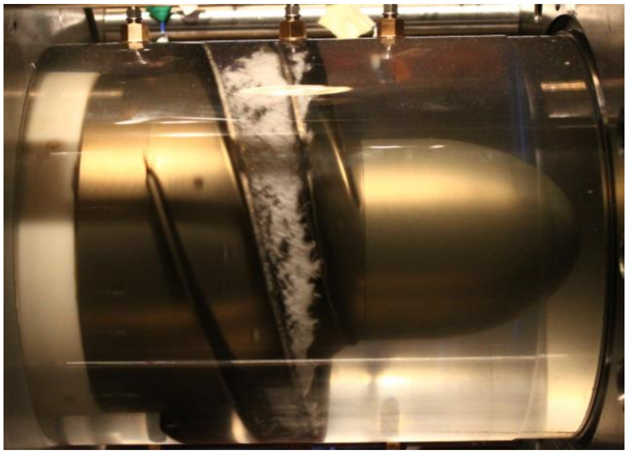

Figure 2. A picture of the RAPDUD inducer under cavitating conditions.

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