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A Study on the Design of LOX Turbopump Inducers

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Introduction

The need of high thrust levels for future space transportation systems results in high chamber pressures in liquid rocket engines. The advantage of pump-fed over pressure-fed engines consists in the requirement of relatively low pump inlet pressure, and thus propellant tank pressure. The major part of the pressure required in the chamber is supplied by the pumps. Therefore, the use of turbopumps results in a decrease of system weight and an increase of performance as compared to pressurized-gas fed systems. Both dimensions and performance of the turbopump depend on the engine cycle and the requirements of the combustion chamber. Due to the high rotational speeds in the pump, the fluid pressure might drop below the vapor pressure resulting in cavitation. This flow phenomenon can lead to unstable operating conditions and pump failure. Rocket propellant fed turbopumps have inducers in order to avoid cavitation, improve the suction performance and reduce the propellant tank pressure and weight. The main task of the inducer is to provide a modest increase in pressure upstream of the main pump, typically a radial impeller, which in turns prevents cavitation and allows sufficiently reasonable operating conditions in the main pump.

First documents describing the design of inducers for liquid rocket engines came from the United States in the 1960s-70s [1, 2] where recommended ranges of relevant geometric parameters were given. Throughout the following decades, numerous studies have been conducted on the impact of geometric variations, such as the leading edge geometry, blade angle and sweep angle, on the performance. However, publications with design guidelines that embed and account for recent results of parametric studies and satisfy current requirements for liquid rocket engines are rare.

A design tool for inducers has been developed. In this paper, the design methodology, the design process as well as the blade design of the inducer for a LOX turbopump are discussed in detail. The design methodology is based on the NASA document NASA SP-8052 and standard literature, e.g. [3, 4]. However, the choice of several design parameters takes into account the results of more recent studies. The development of the design tool is embedded in the research project KonRAT [5] where a LOX turbopump for a LH_2/ LOX expander cycle engine is investigated.

1. Methods

The engine requirements and the resulting parameters, such as head rise, suction specific speed and available and required net positive suction head dictate the dimensions of the inducer. Moreover the preliminary design of the inducer is characterized by assumptions mainly based on [2]. The sizing of the inducer also strictly depends on the geometrical dimensions resulting from the preliminary design of the main radial stage. In the first loop of an iterative process it is assumed that the flow upstream of the impeller is swirl free. Thereby it is possible to calculate the main dimension of the impeller. From the second loop the assumption of a swirl free flow is corrected with data gained from the inducer design.

Presuming constant diameters at hub and shroud in the passage between inducer and impeller, [2], the main dimensions at impeller inlet dictate the dimension of the inducer at outlet. Choosing a cylindrical shape for the inducer shroud results in a constant inducer shroud diameter from inlet to outlet. Since the pump is driven from the rear, a hub-to-tip diameter ratio in the range of 0.2 and 0.4 has been chosen [2]. The head rise produced through the inducer is set to 10% of the head rise delivered by the whole pump [6, 7].

For the further blade design, velocities and velocity angles at different radii at inlet and outlet are required. The main geometrical dimensions and the expected performance of the inducer allow the analytical calculation of ideal velocities and flow angles. In order to reduce the complexity of the airfoil design, a flat plate helical inducer without camber has been chosen as a starting point for further parameter studies. The airfoil design is based on the analytical equations given in NASA SP-8052 as well as in Gülich [3]. However, the analytical approach is supported by the experience and new insights of recent studies on different parameters. A large number of studies about the influence of the blade leading edge on the inducer performance can be found. These studies concern both the leading edge geometry and the radial shape of the leading edge in terms of sweep back angle. In the preliminary design three flat plate inducers without camber and without blade sweep have been designed with different leading edge geometries. The performance of the inducers has been numerically investigated both three-dimensional and in a two-dimensional blade cascade in order to uncouple three-dimensional effects from those caused only by the leading edge geometry. First results of the two- and three-dimensional performance of the different geometries are presented and discussed.

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