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Modeling of a hydraulic arresting gear using fluid–structure interaction and isogeometric analysis

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ABSTRACT

Fluid–structure interaction (FSI) analysis of a full-scale hydraulic arresting gear used to retard the forward motion of an aircraft landing on an aircraft-carrier deck is performed. The simulations make use of the recently developed core and special-purpose FSI techniques for other problem classes, specialized to the present application. A recently proposed interactive geometry modeling and parametric design platform for isogeometric analysis (IGA) is directly employed to create the arresting gear model, and illustrates a natural application of IGA to this problem class. The fluid mechanics and FSI simulation results are reported in terms of the arresting-gear rotor loads and blade structural deformation and vibration. Excellent agreement is achieved with the experimental results for the arresting gear design simulated in this work.

1. Introduction

Military aircraft, during landing on the deck of an aircraft carrier, eject a “hook” that engages a wire connected to a tape drum. The resultant tape-drum angular momentum is transferred to the rotor inside a hydraulic energy absorber (or a hydraulic arresting gear). The rotor, which is a steel structure several feet in diameter, accelerates rapidly, reaching speeds of 800 rpm. The rotor acceleration is then arrested by the drag forces coming from the surrounding water inside the arresting gear. This, in turn, puts the wire in tension and rapidly slows the aircraft forward motion. The rotor speed and blade topology, geometry, and structural design play a critical role in the performance of the device, both in its function to arrest the motion of landing aircraft, as well as in its ability to withstand the internal hydrodynamic loads and perform multiple consecutive aircraft arrests without failure. As a result, accurate prediction of rotor loads and the structure response to these loads is important, requiring advanced modeling and simulation, which we undertake in this work.

Experimental study of the hydraulic arresting gear presents many challenges, which mainly arise due to the large spatial scales and high rotor speeds involved in the device operation. The fact that the device is completely enclosed complicates the situation further. However, the hydraulic arresting gear lends itself nicely to analysis using computational fluid–structure interaction (FSI). Computational FSI has matured significantly over the last decade and many core and special purpose techniques were developed in this arena, which can be used to address the various challenges involved in the arresting-gear problem (see, e.g., [1–37] and references therein for a sampling of FSI methods developed in recent years.)

In addition to FSI, the present application lends itself nicely to Isogeometric Analysis (IGA) [38,39], which is a relative newcomer to the field of computational mechanics. The use of IGA enables relatively simple construction of the arresting gear geometric and structural design, its complete surface and volume parameterization, and analysis using the same underlying geometric representation in terms of Non-Uniform Rational B-Splines (NURBS) [40] or T-splines [41,42].

The paper is outlined as follows. In Section 2, we describe the geometry of the Virginia Tech (VT) arresting gear design [43], which belongs to the Model 64 [44] energy absorber system. We describe a novel technique for IGA analysis-suitable geometry construction of the arresting gear design. We make use of a recently proposed interactive geometry modeling and parametric design platform [45], which is based on the Rhino 3D CAD software [46] with an embedded visual programming tool Grasshopper [47]. Rhino 3D gives the user access to complex geometry modeling functionality with objects such as NURBS and T-splines, while Grasshopper is employed for the generative algorithm approach to

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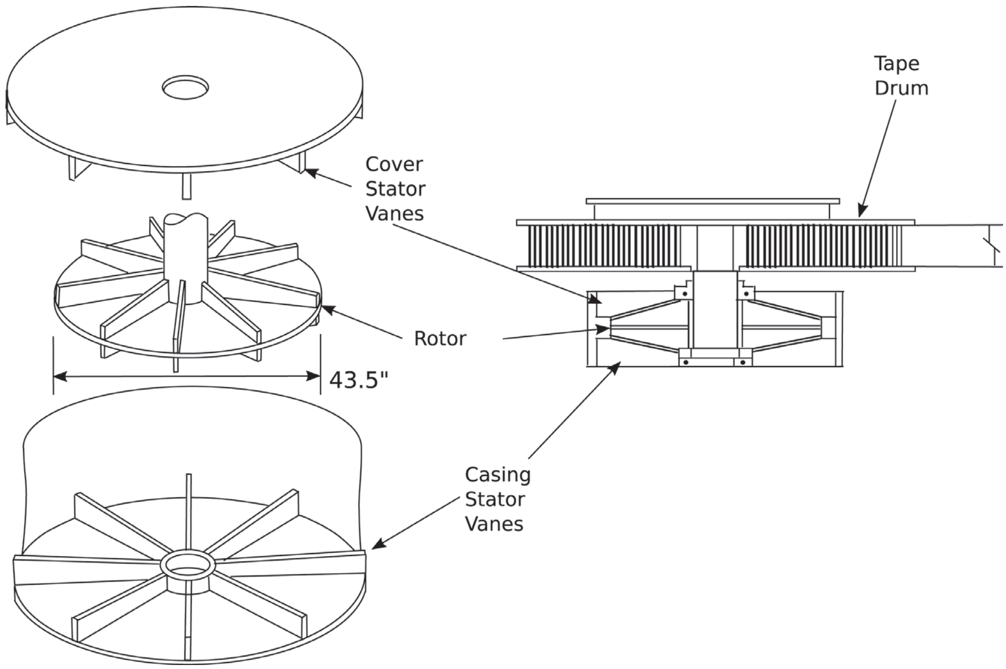

Fig. 1. Schematic representation of the VT hydraulic arresting gear [43].

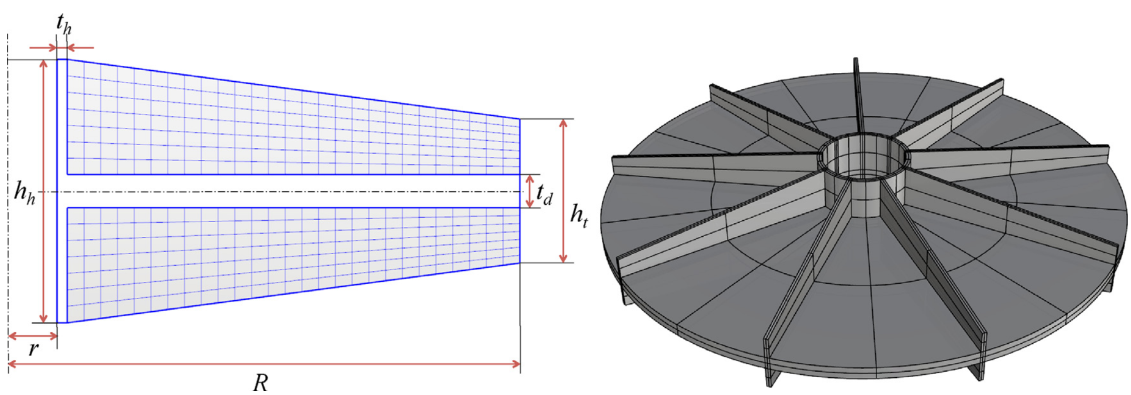

Fig. 2. Left: rotor cross-section with dimensions. right: rotor solid model.

arresting-gear geometric design. In Section 3, we present the governing equations involved in the FSI model and summarize the numerical formulations employed. In Section 4, we present the results of standalone fluid and structural mechanics, and FSI analyses of the VT arresting gear at full scale.

2. Geometry modeling and meshing for the arresting gear FSI analysis

In this work we simulate the VT arresting gear design described in [43] and shown in Fig. 1. We consider a full-scale model with slightly simplified geometry, but with all the important structural components represented. The VT model has experimental data available for hydrodynamic loads acting on the rotor operating at speeds ranging from 200 to 800 rpm, which are typical rotor speeds during the aircraft arrest. The availability of experimental data enables one to perform methods validation at full scale, and to assess the computational effort needed for this challenging problem class.

The VT arresting gear design includes two main parts: A rotating turbine (rotor) and a stationary reel (stator). The rotor diameter is 43.5 in. Looking at half of the rotor and stator, there are nine blades on the rotor side and eight vanes on the stator side, with a small gap present between the rotor blades and stator vanes. The rotor cross-section geometry is shown in Fig. 2, while the key rotor geometric parameters and dimensions are summarized in Table 1.

Table 1
Arresting gear rotor dimensions.

Parameter	Symbol	Unit (in)
Hub thickness	t_h	0.4
Hub height	h_h	7.96
Inner radius	r	3.48
Outer radius	R	21.75
Disc thickness	t_d	1.0
Tip height	h_t	4.35
Blade thickness	t_b	0.348

Using this data input, the arresting gear fluid-mechanics-domain geometry is created with the help of the interactive geometry modeling and parametric design platform described in [45]. The generative algorithm employed for the rotor design is depicted in Fig. 3. The algorithm, which is implemented using the visual programming interface Grasshopper, takes the rotor parametric input and, using the existing Rhino 3D functionality, constructs the underlying NURBS model of the arresting gear geometry. The