Aerospace Science and Technology 68 (2017) 37–45

Contents lists available at ScienceDirect

Aerospace Science and Technology

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# Research on centrifugal compressor disk containment of auxiliary power unit

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ARTICLE INFO

*Article history:*
Received 4 January 2017
Received in revised form 22 April 2017
Accepted 3 May 2017
Available online 5 May 2017

*Keywords:*
Auxiliary power unit
Disk containment
Connecting bolt
Numerical simulation
Containment test

ABSTRACT

To investigate the centrifugal compressor disk containment of auxiliary power unit (APU) in gas turbine, research on specific compressor is conducted in combination of simulations and tests. Nonlinear explicit finite element analysis of tri-hub fragments impacting containment assembly is carried out using LS-DYNA. Impacting characteristics in each period are discussed. Strength of the outer cover, the back shroud and the connecting bolts between them is further studied through simulation. The results show that the fragments interact with the outer cover and the back shroud both in rotating plane and axial direction. The internal energy is mostly composed of the strain energy of the impeller. Insufficient strength of each component leads to an uncontained result. Potential failure modes are discussed. Verification tests on high-speed spin tester revealing both contained and uncontained cases have been conducted and showed that the outer cover, the back shroud and the connecting bolts between them all play a significant role to containment. Adequate strength of these components is essential. Otherwise the outer cover will detach away and the back shroud will be damaged.



## 1. Introduction

American Federal Aviation Administration (FAA) Technical Standard Order (TSO) set requirements for containment in Subject C77b, Gas Turbine Auxiliary Power Units [1], in which hub containment must be demonstrated for fragments resulting from a failure that produces the maximum translational kinetic energy. Corresponding clauses are also put forward in European Aviation Safety Agency (EASA) Certification Specifications for Auxiliary Power Units (CS-APU) [2]. Failed high speed rotor can be released as high-energy fragments, affecting flying performance in a number of direct and indirect ways and even leading to the loss of airplane [3]. Even though disk burst accidents happen infrequently nowadays, they are not completely avoidable. Thus, a number of investigations on high-energy disk fragments containment are carried out. Hagg et al. [4] carried out tests which showed that containment of missile-like disk quarter fragments by a steel cylindrical shell is a continuous two-stage process. Eric Stamper et al. [5] proposed a simulation method of using ANSYS/LS-DYNA to develop an analysis method that could provide more accurate predictions of containment failure limits for a wider range of disk and containment geometries. The models used a piecewise linear plasticity material law with strain rate dependence, segment based eroding contact, nonlocal failure methods, and a consistent element size. Because of their convenience and low cost, numerical methods were further studied and used in containment issue. He et al. [6] conducted a number of simulations with different mesh sizes and different values of both the contact penalty factor and the friction coefficient. Li [7] investigated the numerical evaluation methods for ring/disk containment using LS-DYNA. Results showed that factors including disk rotating speed, ring wall thickness and the clearance between disk margin and ring inner wall influences the result of the containment.

Compressor rotor assembly works dissimilarly due to its structure. Liu et al. [8] carried out compressor disc containment test of aircraft cooling turbine, numerical results and test results indicate that due to the centrifugal structure, the compressor disc fragments impact the diffuser in an extensive area. Jin et al. [9] carried out experiments on a certain turbocharger, the results showed that increasing the flange area and depth of the connecting screw is beneficial to enhancing the containment performance of the compressor end. However, exhaustive research of centrifugal compressor disk containment is rare in open publications. As a result, no directive design criteria could be consulted.

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http://dx.doi.org/10.1016/j.ast.2017.05.002

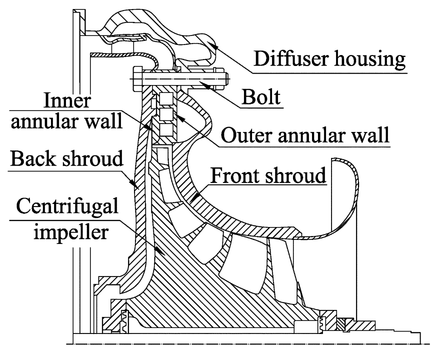


**Fig. 1.** Centrifugal compressor hub containment assembly.

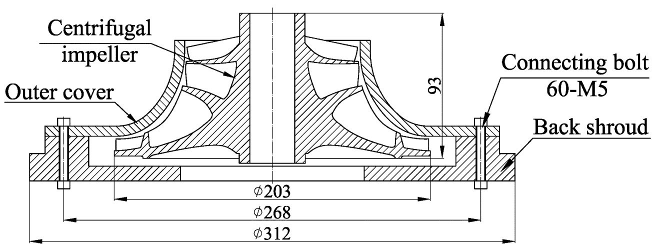


**Fig. 2.** Sketch of the containment assembly in simulation.

In typical structure of APU, two stages of compressor rotor, turbine rotors and corresponding containing installation are equipped. To contain high energy fragments generated by a hub burst, reference [10] put forward a compressor containment assembly including a front shroud, diffuser housing, a concave back shroud, annular wall, etc. The components were connected with bolts, as shown in Fig. 1. In this paper, centrifugal compressor disk containment ability of homologous assembly is studied.

Bolts are the most frequently used joining elements in machine construction. The bolted jointing technique in simulation has been studied. Kim et al. [11] introduced four kinds of finite element models: a solid bolt model, a coupled bolt model, a spider bolt model and a no-bolt model. The solid bolt model provided the best accurate responses compared with the experimental results. Narkhede et al. [12] described modeling methodologies for bolted joint representation in crash models with beam elements and solid hexa elements. Bolt joint simplified methods in past research include: spring-mass element, beam element, merging node and so on. But these methods just considered force and vibration between parts and condition of bolt impact damage wasn't considered. Jin et al. [13] created a bolt simple model using anisotropic material and plastic strain damage rule based on anterior calculated results.

Following this brief introduction, numerical simulation of centrifugal impeller fragments impacting on the containment assembly is presented in section 2. Characteristics in each period are discussed in detail in combination with energy–time and force–time histories of each component. Strength of the outer cover, the back shroud and the connecting bolts between them are further studied in section 3. Section 4 shows verification tests on high-speed spin tester revealing both contained and uncontained cases. Based on the findings, conclusions are made at the end of this paper. In this paper, centrifugal compressor disk containment assembly is firstly studied by analyzing each component respectively and conducting contrast tests on high-speed spin tester. This paper also puts forward a reliable simulating method by establishing detailed bolt model.

## 2. Numerical simulation of containment process

Before testing, numerical simulations are carried out to study centrifugal impeller fragments impacting on the containment assembly.

### *2.1. Geometric and mesh model setup*

A centrifugal compressor assembly in APU of full size is regarded as research object in this paper. Rotor presents tri-hub burst with 110% working speed. For a certain disk, the maximum translational kinetic energy of a single fragment occurs [14]. A centrifugal impeller is modeled with blades and hub, which is disposed between an outer cover and a back shroud. The outer cover is slightly spaced from the outer edges of the impeller and couples to the back shroud at outer rim of the impeller by 60 connecting bolts of M5. Sketch of the containment assembly in simulation is shown in Fig. 2.

Reliable numerical models are established for nonlinear explicit finite element method (FEM) that implemented in the LS-DYNA. In this paper, solid bolt model is established with the aim of accurately predicting the physical behaviors of the structure with a bolted joint. Elements of the impeller fragments are set to be tetrahedron element. The mesh size is 1 mm and 180000 elements are built. FEM models of the containment components have a very fine mesh that the elements are set to be 8-node hexahedron element which can observe the failure mode through the thickness. The element number of the outer cover and the back shroud is 440000, with a size of 1.5 mm × 1.5 mm. The bolts consist of 108000 elements, of which the size is 1 mm × 1 mm. Mesh models are presented in Fig. 3.

### *2.2. Material model*

Due to the highly dynamic deformation processes during the simulation, a strain rate dependent material model is necessary. Johnson–Cook (J–C) model is selected to describe the large deformation, nonlinear and elastic–plastic during impacting process. The J–C constitutive relation [15] can be expressed as follows:

$$\sigma_e = [A + B(\varepsilon_e^p)^n][1 + C \ln \dot{\varepsilon}^*][1 - T^{*m}] \quad (1)$$

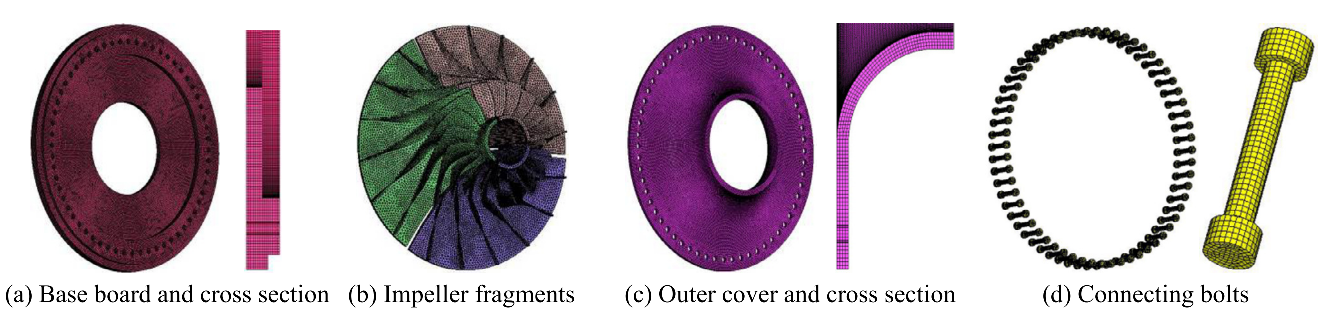


**Fig. 3.** Finite mesh models.