Aerospace Science and Technology 61 (2017) 35–44

Contents lists available at ScienceDirect

Aerospace Science and Technology

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Containment tests and analysis of soft wall casing fabricated by wrapping Kevlar fabric around thin metal ring

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ARTICLE INFO

Article history:
Received 29 June 2016
Received in revised form 20 November 2016
Accepted 22 November 2016
Available online 25 November 2016

Keywords:
Fan blade out
Containment test
Soft wall casing
Kevlar fabric
Composite structure

ABSTRACT

To investigate the containment mechanism of the soft wall casing, a series of tests were conducted on a high-speed spin tester. A special testing method using spin tester for the containment of soft wall casing is developed. The subscale casing was fabricated by wrapping multiple layers of Kevlar49 plain woven fabric around the inner thin aluminum ring. The projectile was designed as rectangle to simulate the fan blade. Impacting process in each test was recorded by a high-speed digital camera. A numerical simulation model was developed to analyze the containment process quantitatively by using the explicit transient dynamic code LS-DYNA. It is found that the containment process of soft wall casing can be divided into three stages, and the Kevlar fabric absorbs most impact energy of blade. Also some comparisons in energy and force are conducted and discussed.

1. Introduction

Blade out event is the main risk of aero-engine containment system, especially the fan blade with large mass and energy. If the barrier does not have enough resistance, the high energy fragments can penetrate and damage fluid lines, control system, the airframe, or power transmission equipment [1], which is catastrophic. Traditionally "Hard Wall" containment system has been to provide a sufficiently thick solid metallic skin that the blade cannot penetrate [2], which is obviously heavy. To reduce weight, composite materials are incorporated in the engine containment systems by wrapping multiple layers of high strength composite fiber fabric around thin metallic structure. This is called "Soft Wall" containment. Currently the only woven fabric that is widely used in engine containment systems is Kevlar49 fabric developed by DuPont [3]. The "Soft Wall" containment structure has been used in lots of fan engines, such as Trent700, PW4084, GE90, etc. [4]. In this containment structure, the released fan blade is arrested by the outer fiber fabric after penetrating the inner thin metallic wall. The damage area is localized and the fan casing can maintain sufficient structural integrity [5]. Compared with traditional metallic containment system, this fabric wraps structure has lighter weight and lower manufacture cost, which is more appropriate for modern high thrust-weight engine.

According to the Federal Aviation Administration's [6] aircraft engine certification regulations, a full scale engine blade-out test must be performed to demonstrate that an engine has ability to contain a fan blade released at full operating speed. But such tests are extremely expensive. Thus ballistic impact tests and component containment tests are usually conducted before the full scale engine test as the first two steps [7] to analyze the containment capability.

Stotler et al. [8] carried out containment tests on lightweight containment system wrapped with Kevlar fabric and developed relationship between the fabric thickness required and the energy of released blade. Shockey et al. [9] performed a series of ballistic tests of fabric barriers, including fabric corner failure tests and large scale impact tests, and developed a simplified finite element fabric model. Pereira et al. [10] conducted a program of ballistic impact tests to provide validation data for the development of numerical models and comparison between two different fabrics, using flat rectangle projectile to impact on an inclined fabric wraps ring. Sharda et al. [11] made an effort to study the containment capability of fabric wraps system by conducting static tests with a blunt nose steel penetrator slowly pushing against the fabric.

Test data of soft wall containment system is scarce in published literature due to the high cost and difficulty. Most of the tests are

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http://dx.doi.org/10.1016/j.ast.2016.11.018
1270-9638/

ballistic impact tests, which lack consideration of some key issues of engine containment, such as the cylindrical casing, the blade rotation, etc. Carney [12] indicated that the curved geometry target has better containment capability, about 15% increment in ballistic limit velocity. In real case, the failure blade fragments fly out in the centrifugal direction, with large oblique angle and yaw angle, meanwhile tumbling around itself. These factors are all ignored in ballistic impact test. Pepin [13] indicated that the yaw angle of the fragment projectile affects the ballistic limit velocity obviously. Compared to ballistic impact test, containment test on spin tester can take these important issues into consideration and simulate the real containment situation more closely.

Many researchers have made efforts to develop the numerical simulation model of fiber fabric. Taibiei [14] utilized the micro-mechanical approach and homogenization technique to develop a numerical model for Kevlar129 fabric to analysis the deformation of fabric and displacement of projectile. This model which includes reorientation of yarns and the fabric architecture shows a good agreement between the simulation and experiment. Iannucci [15] presented an energy based damage mechanics model for woven carbon composites under high strain loading. Plain stress shell unit was used to represent the composite material and the evolution of damage is controlled via a series of damage-strain equations. Chocron [16] modeled full-scale body armor targets at the yarn level through the observation of the fiber fabric micro-architecture. The predictions of the model in yarn impact was investigated and compared with test results. Stahlecker [17] developed a strain-rate dependent and anisotropic material model for dry fabrics. The developed model was implemented as a user-defined subroutine in a commercial finite element program LS-DYNA, and then used to simulate a suite of ballistic tests.

In this paper, a series of small size soft wall casings were fabricated by wrapping multiple layers of Kevlar49 plain woven fabric around thin aluminum ring. The blade projectile was designed as flat rectangle to simulate fan blade. Tests were conducted on a high-speed spin tester with different Kevlar fabric layers number. Each impacting process was recorded in detail by a high-speed digital camera. A finite element model was developed to perform quantitative analysis. Failure mode and containment mechanism were discussed in detail through the analysis of test and numerical simulation.

2. Containment tests

2.1. Casing and blade

Casing was designed as a scale-down model of a fan casing used in turbofan engine. Each casing consists of two parts: inner thin aluminum ring and outer Kevlar fabric. Structural details of the actual engine fan casing are ignored and simplified in this model as the main purpose is to investigate the containment capability of soft wall casing. The inner aluminum ring is the stiffness supporter for the soft Kevlar fabric. The aluminum ring has thickness 2 mm, inner diameter 362 mm, with flange edges on top and bottom sides. A continuous 200 mm wide plain woven Kevlar49 fabric strip was wrapped around the metal ring. The plain woven Kevlar fabric is shown in Fig. 1 in mesoscale.

In order to control and keep the tension in a certain value during the fabric wrapping process, a winding device which is schematically showed in Fig. 2 was designed to accomplish the fabric wrapping. The inner metal ring driven by a motor rotated slowly. A magnetic powder brake provided a controllable torque to the Kevlar fabric roller. The fabric was wrapped onto the casing from the fabric roller, and moved around a roller tube mounted on a tension transducer in the middle way. The tension in fabric can

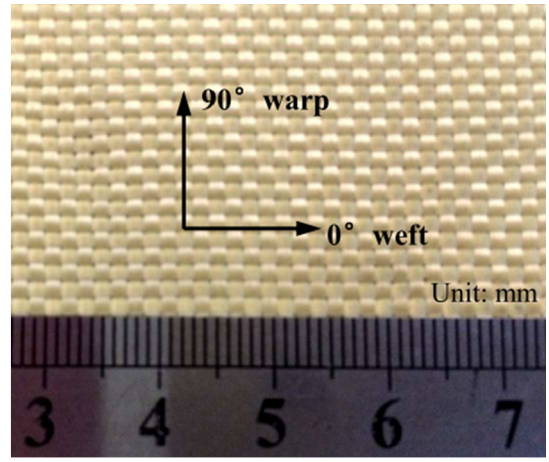

Fig. 1. Plain woven Kevlar fabric.

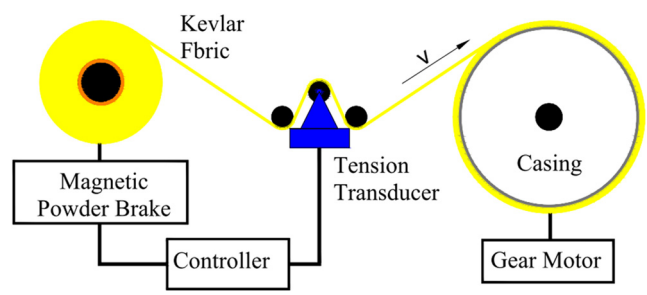

Fig. 2. Schematic of fabric winding device.

be adjusted by changing the input current of the magnetic powder brake. The tension was kept at about 40 N in each fabricate process to make sure that the fabric can be wrapped onto the casing tightly. The head and tail of the continuous strip were fixed by epoxy resin. The both sides in wide-direction of the Kevlar fabric were also impregnated by the epoxy resin. The wrapping process is shown in Fig. 3.

The blade was designed to be rectangular, with a triangle tenon in one side. Blade's material is 304L, which is the same as the material of projectile used in the ballistic impact tests described in Pereira's report [18]. The disk has the corresponding triangle groove. A dummy blade with smaller length and larger width was designed to be mounted on the opposite side of blade to provide a proper balance for the rotor. The assembly of disk and blade is shown in Fig. 4. The main properties of Kevlar fabric and blade are shown in Table 1.

2.2. Test facility

Tests were conducted on the ZUST6D high-speed spin tester at High-Speed Rotating Machinery Laboratory of Zhejiang University, Hangzhou, China. The basic structure of spin tester and test measurement system is shown in Fig. 5. Trigger wire was glued on inside of casing. As the released blade cut off the trigger wire, a pulse signal was transmitted to the control system to shut down the driver, and the high-speed camera was triggered to record the impact process at a rate of 25000 fps.

The detailed schematic diagram of test specimens is shown in Fig. 6a. The soft wall casing was embedded into the groove of a metal installation ring and fixed with bolts. The blade was notched at the root in both sides to the same depth, which is noted as a in Fig. 6a. The blade was estimated to be released at the speed of 20000 r/min as a is 7.9 mm [19]. The radius of the root of