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FAA T53-L-13L Turbine Fragment Containment Test

June 1998

Final Report

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16. Abstract

The result of the FAA T53-L-13L engine turbine disk fragment containment test is presented in this report. A containment ring was designed and fabricated by Pepin Associates, Inc. and provided to the Naval Air Warfare Center, Weapons Division by the William J. Hughes Technical Center. This ring was fabricated with a 0.014-inch titanium inner and outer sleeve. One-inch-thick Kevlar 29 ballistic fabric made up the primary structure of the containment ring. The ring was reinforced with titanium rods inserted through the fabric and laser welded to the inner and outer sleeves.

The engine and containment ring were installed in an UH-1 Huey helicopter. The second stage power turbine disk was notched so that the disk would rupture at approximately 20,400 rpm. The engine was started and immediately accelerated to minimize the chance of a premature rupture. The event was recorded on high-speed film at 4000 pictures per second.

The disk ruptured as the engine accelerated through 19,629 rpm. The disk ruptured into three equal sections (approximately 3.6 lbs. each). The result was a contained tri-hub burst with minor bulging of the containment ring and little sign of distress to the airframe. This test demonstrated the capability to contain a tri-hub burst on a medium sized turboshaft helicopter engine.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLE

EXECUTIVE SUMMARY

As a part of the Federal Aviation Administration's Aircraft Catastrophic Failure Prevention Program, the Naval Air Warfare Center Weapons Division under contract to the FAA William J. Hughes Technical Center conducted a turbine disk containment test. The purpose was to demonstrate the containment capability of the Kevlar ring against full-size T53 engine rotor fragments. A containment ring was designed and fabricated by Pepin Associates, Inc. and provided to the Naval Air Warfare Center, Weapons Division by the William J. Hughes Technical Center. The engine and containment ring were installed in an UH-1 Huey helicopter. The second stage power turbine disk was notched so that the disk would rupture at approximately 20,400 rpm. The engine was started and immediately accelerated to minimize the chance of a premature rupture. The event was recorded on high-speed film at 4000 pictures per second.

The disk ruptured as the engine accelerated through 19,629 rpm. The disk ruptured into three equal sections (approximately 3.6 lbs. each). The result was a contained tri-hub burst with minor bulging of the containment ring and little sign of distress to the airframe.

INTRODUCTION

This test was conducted as the final phase of the "Development of Lightweight Containment Structures" project sponsored by the FAA William J. Hughes Technical Center under the Aircraft Catastrophic Failure Prevention Program.

The objective of this effort was to develop and evaluate the aircraft rotor fragment containment materials and structures against a fully bladed T53 turboshaft engine second stage power turbine. The turbine disk was modified to burst at approximately 20,400 rpm to produce 1×10^6 in-lbs of kinetic energy. The T53 engine was selected to represent the medium turboshaft engines. Previous burst tests using modified T53 second stage power turbine disks were conducted in a vacuum spin chamber located at the Naval Air Warfare Center Aircraft Division in Trenton (NAWCAD-TRN), New Jersey. This test, as the final phase, was conducted at the outdoor test site at the Naval Air Warfare Center Weapons Division at China Lake, California. Kevlar, S-2 fiberglass, and polybenzbisoxazole (PBO) fabrics and cylindrical structures with reinforcements were evaluated and spin tested for disk fragment containment during the early phase of the program. Some of the tests were configured with the engine case and combustor as installed in the actual engine. The most promising material was PBO followed by Kevlar. Due to the time and funding constraints, the Kevlar material was used for the final phase. Pepin Associates, Inc. (PAI) fabricated the containment rings described in this report.

TEST OBJECTIVES

The primary objective of the test was to demonstrate the containment capability of the Kevlar ring that was designed and fabricated by PAI to contain the full-size T53 engine rotor fragments. A secondary objective was to study the effect of absorbing the rotor fragment energy on the aircraft during the containment event. This includes the interaction of the impacted containment ring, rotor fragments, and the engine accessories such as the combustor, vane, and case.

TEST SETUP

NAWCAD-TRN personnel modified the second power turbine and used the New Jersey Army National Guard facility for engine disassembly and installation of the disk. The second stage power turbine disk was weakened by removing three turbine blades, 120° apart. Then radial slots were machined from the blade firtree groove down into the disk. The tri-hub burst design and procedure are explained in detail in "Evaluation of Lightweight Material Concepts for Aircraft Turbine Engine Rotor Failure Protection" FAA Report DOT/FAA/AR-96/110. The notch created a stress concentration in the disk sufficient to cause an overload failure at normal operating speed.

The containment ring was developed and fabricated by Pepin Associates Inc. The ring was fabricated with a 0.014-inch titanium inner and outer sleeve. One-inch-thick Kevlar 29 ballistic fabric made up the primary structure of the containment ring. The ring was strengthened with titanium rods which were inserted through the fabric and laser welded to the inner and outer sleeves (figure 1). The ring weighed approximately 25 lbs. The containment ring was installed on the test engine and loosely connected to the engine case. The ring was centered on the second stage power turbine.

FIGURE 1. CONTAINMENT RING SECTION

The T53 engine was then installed in an UH-1 Huey helicopter (figure 2). The helicopter was mounted on two 2-foot-thick cement blocks and cabled down to three 1-foot-thick cement blocks (figure 3). The rotor head was removed to simplify the test setup and preparation. The engine was remotely started and operated. An emergency shutoff valve was located near the engine interface.

FIGURE 2. PRETEST INSTALLATION

FIGURE 3. TEST SETUP

HIGH-SPEED CAMERA TIMING

Even though the disk was notched, there was no way of determining exactly when or at what speed the disk would fail. To capture the event on high-speed film, a speed trigger circuit was used. There were approximately 8 seconds of film at a camera speed of 4000 pictures per second, 2.5 seconds of which were used as the cameras came up to speed. Prior to installing the test engine, a second engine was tested to determine the power turbine acceleration time from idle to maximum (figure 4). Multiple runs were conducted, and it was determined that the acceleration from idle to maximum was approximately 10 seconds. Idle speed was approximately 10,400 rpm and maximum was 22,500 rpm. Based on the engine acceleration times and the target rupture speed (20,400 rpm) and considering the camera time required to come to speed, a trigger speed of 14,000 rpm was chosen.

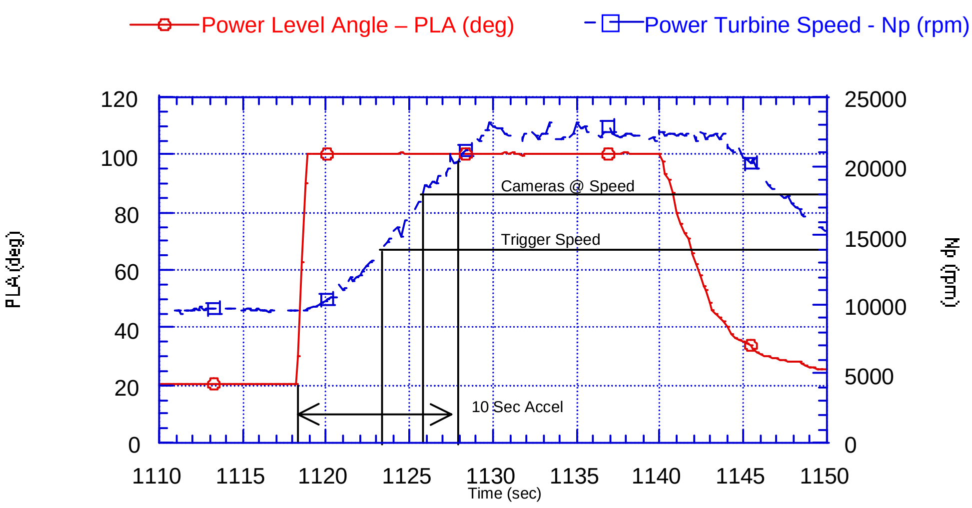

FIGURE 4. ENGINE ACCELERATION CALIBRATION

TEST PROCEDURE

The test was successfully conducted per the following checklist and procedure.

Pretest Checklist	
1.	Install break-paper
2.	Check fuel valve operation
3.	Check camera views
4.	Fuel system checkout. Reroute and protect fuel line – shutoff valve
5.	Ignitor checks
6.	Camera line checkout
7.	Define the power turbine speed (Np) trigger speed 14,000 rpm
8.	Load cameras

Test Procedure	
1.	Open fuel valve
2.	Verify cameras ready
3.	Verify camera lines are unarmed
4.	Begin data collection
5.	Starter power ON and ignitors ON
6.	Power level angle (PLA) to 25 deg
7.	Disengage starter and ignitors at N2 = 50 %
8.	Reset trigger system
9.	Arm camera lines
10.	Verify good start
11.	Advance PLA to 100 deg
12.	Ensure trigger is activated as Np passes 14,000 rpm
13.	Ensure Np is accelerating to 20,000 at approximately 1500 rpm/sec Should take approximately 4 seconds
14.	If Np reaches overspeed limit 22,000 rpm, continue engine running until disk ruptures.
15.	After event close fuel valve.
16.	Secure the pad; allow firefighters access to the pad as needed.

TEST RESULTS

The test was completed as planned. The cameras were triggered as Np passed through 14,000 rpm. The disk released at 19,629 rpm. Test data are provided in figures 5 through 7. The disk ruptured into three nearly equal sections that were contained by the containment ring. The outer titanium shell split due to the tensile load resulting from the disk fragments pulling the Kevlar into a triangular shape. All three disk fragments penetrated the engine combustor case. The fuel lines located between the containment ring and combustor case were penetrated, resulting in a small fire. Secondary blade fragments exited the engine exhaust nozzle and a few fragments appeared to exit through the holes created by the disk fragments. These fragments were low-energy releases. Post event pictures are provided in figures 8 through 11.

The engine stayed within its mounts, with little apparent duress caused from the disk fragment energy being absorbed. The only noticeable sign of high vibration or loading was a broken throttle linkage.

The disk fragments were recovered and weighed (table 1). The original weight of 10.8 lbs included blades which were broken off during impact. Approximately 2.65 lbs of debris was released.

TABLE 1. WEIGHT OF DISK FRAGMENTS AFTER BURST

Disk Fragment Number	Fragment Weight After Burst (lbs)
1	2.66
2	2.70
3	2.79
Total Large Disk Fragments	8.15

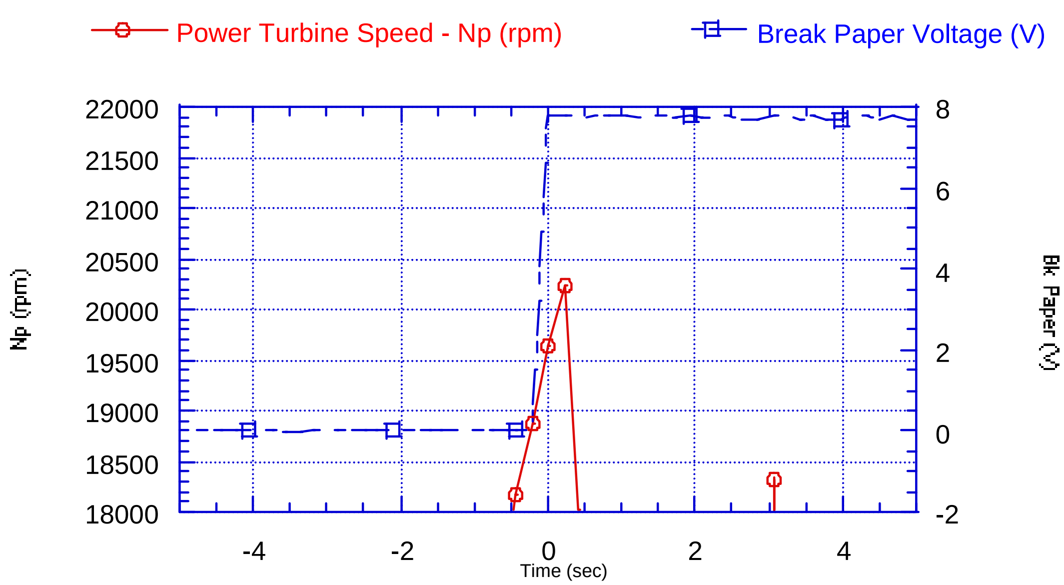

FIGURE 5. POWER TURBINE SPEED AND BREAK PAPER VOLTAGE VERSUS TIME TEST DATA

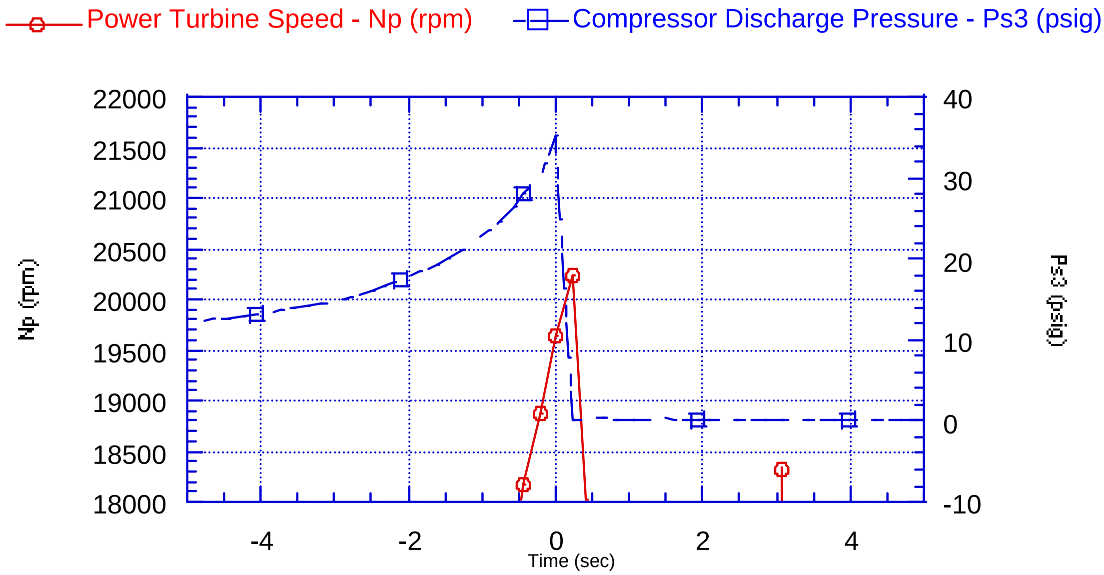

FIGURE 6. POWER TURBINE SPEED AND COMPRESSOR DISCHARGE PRESSURE VERSUS TIME TEST DATA

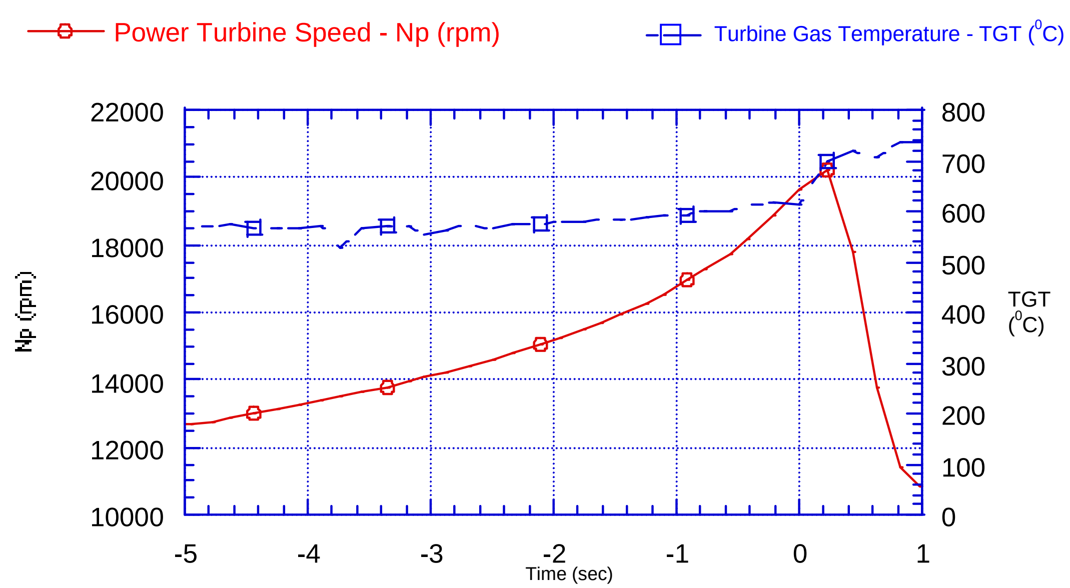

FIGURE 7. POWER TURBINE SPEED AND TURBINE GAS TEMPERATURE VERSUS TIME TEST DATA

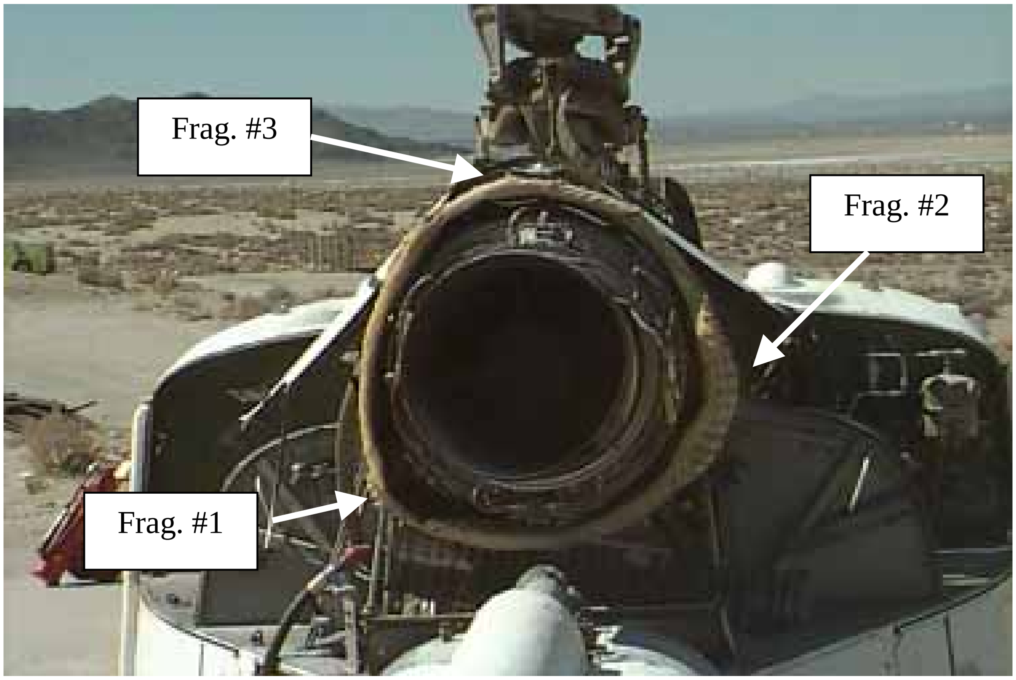

FIGURE 8. POSTTEST ENGINE

FIGURE 9. POSTTEST LEFT SIDE OF ENGINE

FIGURE 10. POSTTEST RIGHT SIDE OF ENGINE

FIGURE 11. DISK FRAGMENTS

CONCLUSIONS

The Pepin containment ring successfully contained the T53 second stage power turbine fragments. This fiber material, Kevlar 29 reinforced with titanium rods at 45° angles, is a good baseline ballistic fabric for containment structures. This is based on the specific containment fragment energy of the containment ring.

All three fragments penetrated through the combustor case and were embedded inside the containment ring. Minimum interactions between the immediate engine components and fragments were observed.

This test demonstrated the capability to contain a tri-hub burst on a medium sized turboshaft helicopter engine. Practical issues related to clearance for maintenance on a day to day basis as well as design for ring expansion during the failure are difficult challenges that must be considered for production of this type of a system.

Appendix – List of FAA Technical Reports Published in FY98

Report Number	Title
R&D Highlights 1998	Highlights of the major accomplishments and applications.
DOT/FAA/AR-TN97/50	Comparison of Radial and Bias-Ply Tire Heating on a B-727 Aircraft
DOT/FAA/AR-97/99	Fire-Resistant Materials: Research Overview
DOT/FAA/AR-95/18	User's Manual for the FAA Research and Development Electromagnetic Database (FRED)
DOT/FAA/AR-97/7	Advanced Pavement Design: Finite Element Modeling for Rigid Pavement Joints, Report II: Model Development
DOT/FAA/AR-97/26	Impact of New Large Aircraft on Airport Design
DOT/FAA/AR-97/64	Operational Evaluation of a Health and Usage Monitoring Systems (HUMS)
DOT/FAA/AR-TN98/15	Fire Testing of Ethanol-Based Hand Cleaner
DOT/FAA/AR-95/111	Stress-Intensity Factors for Elliptical Cracks Emanating from Countersunk Rivet Holes
DOT/FAA/AR-97/9	An Acoustic Emission Test for Aircraft Halon 1301 Fire Extinguisher Bottles
DOT/FAA/AR-97/37	Development of an Improved Magneto-Optic/Eddy-Current Imager
DOT/FAA/AR-97/69	Automated Inspection of Aircraft
DOT/FAA/AR-97/5	Marginal Aggregates in Flexible Pavements: Field Evaluation
DOT/FAA/AR-97/87	A Predictive Methodology for Delamination Growth in Laminated Composites, Part I: Theoretical Development and Preliminary Experimental Results
DOT/FAA/AR-TN97/103	Initial Development of an Exploding Aerosol Can Simulator
DOT/FAA/AR-97/56	Applications of Fracture Mechanics to the Durability of Bonded Composite Joints

Report Number	Title
DOT/FAA/AR-96/97	Stress-Intensity Factors Along Three-Dimensional Elliptical Crack Fronts
DOT/FAA/AR96/119	Vertical Drop Test of a Beechcraft 1900C Airliner
DOT/FAA/AR-98/22	FAA T53-L-13L Turbine Fragment Containment Test
DOT/FAA/AR-97/85	Response and Failure of Composite Plates with a Bolt-Filled Hole
DOT/FAA/AR-98/26	A Review of the Flammability Hazard of Jet A Fuel Vapor in Civil Transport Aircraft Fuel Tanks
DOT/FAA/AR-TN97/108	Effects of Concentrated Hydrochloric Acid Spills on Aircraft Aluminum Skin
DOT/FAA/AR-TN98/32	Cargo Compartment Fire Protection in Large Commercial Transport Aircraft
DOT/FAA/AR-98/28	Statistical Loads Data for Boeing 737-400 Aircraft in Commercial Operations
DOT/FAA/AR-97/47	Development of Advanced Computational Models for Airport Pavement Design
DOT/FAA/AR-98/34	Health Hazards of Combustion Products From Aircraft Composite Materials
DOT/FAA/AR-97/81	Bioremediation of Aircraft Deicing Fluids (Glycol) at Airports
DOT/FAA/AR-TN97/8	Heats of Combustion of High-Temperature Polymers
DOT/FAA/AR-95/29 ***FACT SHEETS***	Fiber Composite Analysis and Design: Composite Materials and Laminates, Volume I Note: This document's PDF is unique from the above documents in that some of the Adobe navigational tools cannot be used such as searching and bookmarking. To navigate in this document, page down to the Table of Contents, List of Figures, and List of Tables where the entries are linked to the body of the document.