



AEROSPACE INFORMATION REPORT

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Superseding AIR4096

(R) Rotorcraft Engine Foreign Object Debris and Damage

RATIONALE

This SAE Aerospace Information Report (AIR) has been revised to align with modern industry practices by updating references and by clarifying common terms and definitions. Discussions on foreign object debris (FOD) ingestion prevention equipment and FOD tolerance have been updated to reflect modern advancements. Finally, depictions of rotorcraft FOD threats, its effects, and examples of FOD prevention equipment have been included.

1. SCOPE

The purpose of this SAE Aerospace Information Report (AIR) is to disseminate qualitative information regarding foreign object debris (FOD) damage to the gas path of rotorcraft gas turbine engines and to discuss methods of FOD prevention. Although turbine-powered fixed-wing aircraft are also subject to FOD, the unique ability of the rotorcraft to hover above, takeoff from, and land on unprepared surfaces creates a special need for a separate treatment of this subject.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

AIR947 Engine Erosion Protection

AIR4495 Helicopter Powerplant Corrosion Protection

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Documents

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2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Technical Report.

2.2.1 Code of Federal Regulations (CFR) Publications

Available from the United States Government Printing Office, 732 North Capitol Street, NW, Washington, DC 20401, Tel: 202-512-1800, www.gpo.gov.

14 CFR Part 27 Airworthiness Standards: Normal Category Rotorcraft

14 CFR Part 29 Airworthiness Standards: Transport Category Rotorcraft

14 CFR Part 33 Airworthiness Standards: Aircraft Engines

2.2.2 Other Publications

AV-E-8593D General Specification for Turboshaft Aircraft Engines

CS-27 Certification Specifications and Acceptable Means of Compliance for Small Rotorcraft

CS-29 Certification Specifications and Acceptable Means of Compliance for Large Rotorcraft

CS-E Certification Specifications and Acceptable Means of Compliance for Engines

MIL-HDBK-1783 Engine Structural Integrity Program

2.3 Definitions

2.3.1 FOREIGN OBJECT DEBRIS (FOD)

FOD is any object that is considered to be an undesirable constituent of, or may become entrained in, the incoming airstream to a gas turbine engine and in certain quantities have the potential to cause damage. FOD may include sand, dust, dirt, rain, snow, ice, saltwater, birds, foliage, ground debris, rocks, fasteners, mechanic's tools, etc. As sand and dust are adequately covered by other reports such as AIR947, they will not be treated in detail here.

2.3.2 FOD DAMAGE

FOD damage is any permanent physical change to the gas turbine engine or its internal flowpath resulting from the ingestion of FOD. Such damage may adversely affect the operating characteristics of the engine resulting in loss of performance, loss of operating stability, or failure.

2.3.3 FOD IMPAIRMENT

FOD impairment is any change to the operating characteristics of the gas turbine engine resulting from the ingestion of FOD which does not result in a permanent physical change (i.e., damage). The impact of FOD impairment on the operating characteristics of the engine can be as severe as, and indistinguishable from, FOD damage, but the effects of an impairment are reversible through simple maintenance actions, such as a compressor wash or cleaning of filter elements.

2.4 Symbols and Abbreviations

2.4.1 Acronyms

CFR	Code of Federal Regulations
CS	Certification Specification
FOD	Foreign Object Debris
IBF	Inlet Barrier Filter
IGV	Inlet Guide Vane
IPS	Inlet Particle Separator
LRU	Line Replaceable Unit
SLD	Supercooled Large Droplet
TBO	Time Between Overhaul

NOTE: The use of the acronyms IPS and IBF varies across the industry. IPS is often used interchangeably with acronyms like EAPS (engine air particle separator) or EAPPS (engine air particle protection system) and may even have alternative interpretations such as “inertial particle separator” or “inlet protection system.” A similar statement can be made for IBF, which are sometimes called EBF (engine barrier filter) or EIBF (engine inlet barrier filter).

3. BACKGROUND

Gas turbine engines have been used as primary sources of power for rotorcraft since the 1950s. As the airframe/engine system has matured, the engines have been made more tolerant to the ingestion of objects entrained in the incoming airstream such as sand, dust, rain, saltwater, snow, and supercooled large droplets (SLD) by means of geometric design improvements, protective coatings, the use of alternate materials, inlet particle separators (IPS), inlet barrier filters (IBF), and anti-icing subsystems. The added advantage of these protective improvements has allowed both military and commercial rotorcraft users to expand flight operations into “dirty” environments. The demonstrated mission benefits have increased demand for such operations. The protective improvements have not been implemented in sufficient degree to offset this increased exposure to FOD. As a result, engine damage caused by FOD such as rocks, foliage, ground debris, ash, etc., has continued to remain a prime reason for engine removal from the airframe.

Advances in technology by engine manufacturers have driven gas turbine engine designs toward smaller, lighter weight, more fuel-efficient turbomachinery with advanced airfoil geometry operating at higher rotational speeds. Modern gas turbine powerplants are generally using fewer, but more critical airfoils, while the quantity of FOD creating the damage remains unchanged. Additionally, advancements in manufacturing techniques have enabled the increased use of integrally bladed disks, also known as blisks, in modern turbomachinery systems. Since the performance of modern engines has greater dependance on this critical geometry, FOD damage to that geometry can have a greater impact to performance. At the same time FOD damage to the integrated geometry can mean replacement of an entire integrated component such as a blisk assembly at much higher cost than a simpler part such as a single blade, increasing the maintenance impact of FOD.

4. POTENTIAL SOURCES OF ROTORCRAFT ENGINE FOD

The sources of FOD ingested by rotorcraft gas turbine engines can generally be divided into three areas: environmental, installation, and maintenance.

4.1 Environmental FOD

A rotorcraft can spend much of its operating time flying or hovering close to the ground. During search and rescue, medical evacuation, firefighting, resupply, and scout and attack missions, it is quite common for rotorcraft to land, takeoff, and hover in ground effect over unprepared landing zones. In the process, dirt, dust, sand, rocks, pebbles, foliage (grasses, leaves, twigs, etc.), snow and other types of ground debris can be lifted into the air by recirculating rotor downwash and ingested into the engine inlet.

For flight operations beyond landing zones, the rotorcraft engine is subject to the same types of FOD as those affecting fixed-wing powerplants, including birds, rain, hail, snow, and ice. During operation in icing conditions, ice that accumulates on the airframe, rotors, and inlet can shed and be ingested into the engine.



Figure 1 - Examples of environmental FOD
(Source: Department of Defense)

4.2 Installation FOD

The engine inlet duct system and those areas of the airframe that are in front of and above the inlet can be a source of FOD. The resulting damage from such items may be referred to as installation FOD damage. For example, mechanical fasteners within the inlet duct or on doors and/or access panels near the inlet can work themselves loose because of vibration or improper installation and migrate into the engine. Protective covers can also pose a risk, even those meant to prevent engine FOD, if not removed prior to start-up. In the case of inlet ducts made of composite materials, pieces of the duct itself may delaminate and be drawn into the engine. Low areas within the inlet duct flow path can also trap water which, when subjected to freezing conditions, will become ice. Upon engine start-up or during warming ambient conditions, chunks of ice may become dislodged and be ingested by the engine.



Figure 2 - Examples of possible sources of installation FOD
(Source: U.S. Army)

4.3 Maintenance FOD

Rotorcraft mechanics and other service personnel, while performing their normal duties, may inadvertently leave hand tools such as screwdrivers, wrenches, sockets, inspection mirrors, etc. in the inlet ducting. Fastening hardware (nuts, bolts, cotter pins, safety wire, etc.) that have been removed during service may accidentally be left in the inlet or engine or may fall into the inlet. Such items can easily become lodged between rows of compressor rotor blades and stator vanes. Parts bags, tags, rags, maintenance instruction sheets, plastic and metal caps, and plugs are all examples of debris that have been left behind following service action only to become potential sources of FOD damage and/or impairment.

People working around rotorcraft invariably have pockets containing loose personal items (pens, pencils, pocket reference books, scales, notebooks, magnets, flashlights, mirrors, etc.) that can unknowingly fall out of the pocket into the inlet duct or engine. Rings, bracelets, necklaces, earrings, watches, and other types of personal jewelry and accessories can all cause extensive damage if allowed to enter the engine. Even ground debris can be picked up by footwear and inadvertently deposited in the inlet system.



Figure 3 - Examples of maintenance FOD
(Source: NASA and NTSB)

5. DETECTION AND EFFECT OF FOD ON OPERATIONS

The effects of FOD damage or FOD impairment, regardless of the source, may be evident in flight through changes to power assurance checks, increased exhaust gas temperatures, compressor surge or other noticeable changes to performance or operability, such as increased vibration or noise. The most common effect of FOD ingestion is damage to the compressor section of the gas turbine engine, however, fouling, erosion and/or corrosion of the turbine section is also a concern. In some cases, debris such as dust, dirt, or grass within the compressor flow path can migrate through cooling passages supplied by the compressor and impact other areas of the engine, including the turbine section. The effects may be so minor that the operator cannot detect any change in the engine's operating characteristics or be so extreme that the engine becomes inoperable. As such, there are forms of FOD damage and impairment that may be considered to be "tolerable" and those that are entirely "intolerable."

Detection of FOD, FOD damage, and/or FOD impairment will depend on the type(s) of FOD present and the effect(s) it has on the engine installation. The first line of defense can be a pre-flight visual inspection aimed at detecting maintenance and installation FOD. Detection of environmental FOD may rely solely on visual cues provided to the pilot or may be supplemented by systems such as icing detectors or blockage monitors.

In many cases, a single type of FOD can result in both damage and impairment. Atmospheric contaminants such as rain, snow, ice or SLD may temporarily impair performance and affect operating characteristics but may alleviate over time or after some maintenance action. However, the accumulation of these contaminants on the airframe may also result in potentially intolerable FOD damage if they shed and are ingested into the engine. Demonstration of ingestion and ice protection capabilities of the engine may be required to show that any resulting FOD damage or impairment is deemed tolerable.