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AEROSPACE INFORMATION REPORT

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HELICOPTER ENGINE FOREIGN OBJECT DAMAGE

1. SCOPE:

The purpose of this SAE Aerospace Information Report is to disseminate qualitative information regarding foreign object damage (FOD) to gas turbine engines used to power helicopters and to discuss methods of preventing FOD. Although turbine-powered, fixed-wing aircraft are also subject to FOD, the unique ability of the helicopter to hover above, takeoff from, and land on unprepared areas creates a special need for a separate treatment of this subject as applied to rotary-winged aircraft.

2. REFERENCES:

a) AIR947, Engine Erosion Protection (Helicopter), FEB71, SAE, Warrendale, PA

b) FAR 33.77, Foreign Object Ingestion

c) AV-E-8593D, Engine, Aircraft, Turboshaft and Turboprop: General Specification for

d) JAR-E, Joint Airworthiness Regulations - Engine

3. DEFINITIONS:

3.1 Foreign Object: A foreign object is any object that is considered to be an undesirable constituent of the incoming airstream to a gas turbine engine. Foreign objects may include sand, dust, rain, snow, ice, saltwater, birds, foliage, ground debris, rocks, fasteners, mechanic's tools, etc. Since sand and dust are adequately covered by other reports such as AIR947, they will not be treated in detail here.

3.2 Foreign Object Damage: In a narrow sense, foreign object damage is any physical damage to the gas turbine engine or its internal flow path resulting from the ingestion of foreign objects. Such damage may adversely affect the operating characteristics of the engine resulting in loss of performance, loss of operating stability, or failure of the engine.

In a wider sense, FOD can be considered to be any malfunction of the engine attributed to the ingestion of foreign objects whether or not physical damage to the hardware occurs. (Thus, a loss of output power due to inlet blockage would be considered to be FOD even if no physical damage occurs to any of the engine hardware.)

4. BACKGROUND:

Gas turbine engines have been used as primary sources of power for rotary-winged aircraft since the 1950's. 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 icing droplets through the use of alternate materials, inlet particle separators, and anti-icing subsystems. With the added advantage of these protective devices, the operational environment of gas-turbine powered helicopters has consequently expanded to include flight into "dirty" environments by both commercial and military users. As a result, engine damage caused by foreign objects such as rocks, foliage, ground debris, fasteners, 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 power plants are generally using fewer, but more critical airfoils, while the quantity of foreign objects creating the damage remains unchanged. This reduction in inlet and airfoil size coupled with no change in foreign object size has increased the risk of FOD.

5. POTENTIAL SOURCES OF HELICOPTER ENGINE FOD:

The sources of foreign objects ingested by helicopter gas-turbine engines can generally be divided into three areas: operating environment, installations, and maintenance.

5.1 Operating Environment: A helicopter can spend much of its operating time flying or hovering close to ground level. During search and rescue, medical evacuation, 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, rocks, pebbles, foliage (grasses, leaves, twigs, etc.) and other types of ground debris can be lifted into the air by the action of the rotors and ingested into the engine inlet.

During operation in icing conditions, ice that accumulates on the airframe can shed if aerodynamic and/or vibratory forces overcome the adhesive strength between the ice and the airframe structures. A slab or chunk of ice may then fall away from the aircraft or, on occasion, impact and damage the aircraft or be ingested and damage the engine.

5.1 (Continued):

During flight operations outside of landing zones, the helicopter engine is subject to the same sources of FOD as fixed-wing power plants. These sources include birds, rain, hail, snow, and ice.

5.2 Installations: The engine inlet duct system and areas in front of and over the airframe inlet can be a potential source of FOD. The resulting damage from such items may be referred to as "Bill of Materials Object Damage." Mechanical fasteners within the inlet duct flowpath or on doors and access panels in front of or over the inlet can work themselves loose as a result of vibratory forces or improper installation and migrate into the engine. 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 trap water which, when subjected to freezing conditions, will convert to the solid phase. Upon engine start-up or under warming conditions, chunks of ice may become dislodged and be ingested.

5.3 Maintenance: Aircraft 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.) removed during service may accidently be left in the inlet or engine or may fall into areas that are not easily visible only to be later discovered lodged between rows of damaged 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 foreign object damage to varying degrees.

People working around aircraft invariably have pockets containing loose personal items (pens, pencils, pocket reference books, six inch scales, notebooks, magnets, flashlights, mirrors, etc.) that can unknowingly fall out and 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.

Ground debris can be picked up by footwear and be deposited in the inlet system.

6. EFFECT OF FOD ON OPERATIONS:

The most common effect of foreign object ingestion is damage to the compressor section of the gas turbine engine. 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. Therefore, there are forms of FOD that may be considered to be "tolerable" and those that are entirely "intolerable."

6.1 Tolerable FOD: Tolerable FOD can, in a general sense, be classified as damage which does not degrade engine performance beyond the operating limits established by the engine manufacturer. The comparatively minor bending of compressor blade tips or actual loss of small pieces of the blade (tip leading edge) or minor local damage can be tolerated, but may reduce the life of the engine. The compressor pumping capacity and efficiency may be reduced, ultimately yielding an engine that runs hotter to produce the same output power as before the ingestion of foreign objects. Engine maintenance or overhaul manuals define the extent of damage that is acceptable and actions that can be taken to recover some of the lost performance and to reduce the potential for further damage due to crack propagation from FOD induced stress concentrations.

Although the ingestion of "soft" foreign objects such as paper, plastic bags, leaves, grasses, etc. does not generally cause physical damage to the compressor, these items can become lodged in front of inlet guide vanes and support struts creating airflow blockages and distorted airflow profiles. Inlet blockage causes an inlet pressure loss and reduces engine output power. The distorted airflow caused by the blockage can, in the extreme, drive the compressor into surge which, depending upon the condition of the engine and severity of the surge, may cause physical damage to the engine. In all but those cases where the hardware is deformed, engine performance should be recoverable by removing the foreign objects causing the blockage.

The term "tolerable" as used in this section relates to the effect of the ingestion of foreign objects on engine performance. In economic terms, the effects of FOD may not be acceptable when consideration is given to the costs associated with the resulting increased fuel usage, reduced engine life, unscheduled maintenance and repairs, etc.

6.2 Intolerable FOD (Engine Failure): This refers to an engine shutdown resulting from physical damage to a mechanical or structural part or component of the engine. The damaged hardware must be replaced or repaired before the engine can be used again. Foreign object ingestion that causes the engine to be unable to perform within specification or service manual limits or to be unable to sustain stable operation is essentially an FOD induced failure. Mechanical failures of the engine are definitely within this classification which has here been expanded to include either blockage or damage short of complete failure that causes the engine to operate in an unstable manner or at a speed, temperature, or torque limit while producing unacceptable output power.

7. FOD PREVENTION TECHNIQUES:

The reduction and prevention of gas turbine engine damage due to the ingestion of foreign objects is the responsibility of the engine and airframe designers, the operators and the maintenance personnel.

7.1 Engine/Airframe Design: The engine designer is the first individual who must confront FOD as one of many factors affecting the engine design. In order to be tolerant of foreign objects, the number of parts projecting into the airflow path should be minimized (e.g., inlet temperature and pressure probes, mechanical fasteners, etc.). The use of captive bolts, retained nuts and washers, self-locking fasteners (versus lockwire) and other devices which limit the number of free small parts will enhance an FOD resistant design philosophy.

The engine designer may wish to consider use of wide chord compressor blades having comparatively blunt leading edges that can more readily survive the abuse of impacting foreign objects. Similarly, variable inlet guide vanes (VIGV's) can help increase engine tolerance to FOD by acting as a crude fence to prevent the object from reaching the rotating machinery. This assumes that the object does not cause the VIGV's to break loose and collide with downstream rotor blades. Of course, the selection of a specific blading design is governed by many other considerations such as aerodynamic performance, weight, cost, producibility, reliability, and maintainability. FOD tolerance can be only one constraint on the selection of a specific compressor configuration.

An engine design objective of reducing the number of tools required for user level maintenance would have the effect of reducing the likelihood of FOD.

Both the engine and airframe designer have the responsibility to assure that no liquid collection areas exist in the engine and airframe inlet ducting. Should potential pooling areas be unavoidable, adequate drainage should be provided. The design should also be such that leakage of flammable fluids into the engine intake system is not possible. The airframe inlet ducting should not have mechanical fasteners of any kind in the airflow path. Access panels or doors in front of or over the airframe/engine inlet should have retained fasteners. Airframe inlets should be located as high as possible on the aircraft in order to reduce the chances of ingestion of ground debris lifted into the air by the action of rotor downwash. The airframe inlet duct itself should be pitched away from the engine inlet such that it cannot be used as a shelf or surface on which service personnel may place parts. If angled away from the engine inlet, the airframe duct will not have the tendency to act as a chute which can naturally direct any object entering the duct into the engine. The airframe inlet duct should be capable of being "easily" inspected up to the engine inlet face.

7.2 Foreign Object Ingestion Prevention Equipment: There are numerous devices available that can help reduce the potential for gas turbine engine FOD in rotary-winged aircraft. Some of these mechanisms are used exclusively for FOD protection, while others are used primarily for other purposes but provide FOD protection as an additional benefit.

7.2 (Continued):

Many aircraft include "FOD screens" at either the airframe inlet duct entrance or at the interface plane between the airframe inlet duct and the engine inlet. These screens are generally 4 mesh (4 openings per inch) and are constructed from 0.03 to 0.06 inch diameter wire. The openings generally become nonuniform over the screen surface during forming such that they are quite small in some areas and large in others. Provisions are made to allow airflow to bypass the screens in the event of blockage. Inlet screens should themselves be able to withstand the impact of foreign objects and should be constructed so as to preclude the possibility of loose strands of screen wire becoming a foreign object that could be ingested. Additionally, these screens should be easily and routinely inspected.

Airframe/engine inlet ducting can be protected against ice formation and/or accumulation by the use of anti-icing systems. These systems usually involve heating of duct surfaces with engine bleed air or electrical energy. The duct surface temperature is maintained sufficiently high to provide anti-icing capability. Heat rates and temperatures required are dependent on the particular application.

Inlet particle separators (IPS) of various designs are examples of components that are not specifically designed to prevent engine FOD but which do tend to reduce it. Although IPS flow areas are larger than the engine inlet area, the annulus gap is typically smaller and, therefore, prevents the larger foreign objects from reaching the engine core inlet. In addition, separators that are designed to use inertial separation of particulates will allow fewer foreign objects to reach the engine core inlet. These comments generally apply to engine mounted particle separators, the larger scale airframe particle separators, vortex tube assemblies, and plenum chamber type inlet systems. Plenum chamber inlet systems have been included here as crude separators in that they act as settling chambers.

FOD prevention can be considered during the design of engine mounted IPS systems. Splitter lip radial location and scavenge vane spacing/throat area, for example, can influence foreign object ingestion rates.

7.3 Maintenance Cleanliness: Conscientious maintenance and flight personnel can affect a significant reduction in engine FOD. People that are trained and aware of the potential hazards associated with allowing loose objects to exist in helicopter engine inlet systems are more likely to check for such items prior to releasing the aircraft for flight.