



AEROSPACE RECOMMENDED PRACTICE

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Substantiation of Power Available and Inlet Distortion Compliance for Rotorcraft Engine Inlet Barrier Filter Installations

RATIONALE

This SAE Aerospace Recommended Practice (ARP) is intended to facilitate and safely improve the efficiency of the certification process for the installation of inlet barrier filters (IBFs) on rotorcraft.

FOREWORD

The SAE S-12 committee, which includes aerospace and defense industry subject-matter experts from engine, airframe, and inlet barrier filter (IBF) manufacturers, and government agencies, has developed this SAE Aerospace Recommended Practice (ARP).

Historically, there has been limited guidance on the certification of IBF installations. Each IBF certification was addressed on a case-by-case basis by the certification authorities. In order to standardize certification techniques for IBF installations, the FAA issued Policy Statement PS-ASW-27/29-07 which was intended to reinforce existing certification requirements. However, direct compliance with the policy statement can pose certain challenges to some applicants. Therefore, in an effort to provide more detailed guidance to the industry, the FAA requested that the SAE S-12 committee develop and recommend industry standard practices as acceptable means of compliance for power available and inlet airflow distortion regulations.

This ARP covers terminology, interpretation of the power available and inlet distortion regulations, and considerations for system safety and flight test.

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1. SCOPE

This SAE Aerospace Recommended Practice (ARP) identifies and defines methods of compliance with power available and inlet distortion requirements for rotorcraft with inlet barrier filter (IBF) installations. The material developed herein is intended to provide industry-recommended methods of compliance with civil airworthiness regulations. It is intended to serve as a basis for new or revised FAA advisory material describing acceptable methods for determining power assurance, establishing power available, and for substantiating acceptable engine inlet distortion for IBF installations. The ARP does not address other types of inlet protection systems such as inertial separator, electrostatic precipitators, or foreign object debris (FOD) screens. It is agreed to treat dust, ice, salt, water, and snow as contaminants to the IBF for the purpose of establishing power available and assessing inlet distortion, but any other effects of ice and snow on inlet airworthiness are outside the scope of this ARP.

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 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

AIR1419	Inlet Total-Pressure Distortion Considerations for Gas-Turbine Engines
AIR4083	Helicopter Power Assurance
AIR5867	Assessment of the Inlet/Engine Total Temperature Distortion Problem
AIR6345	Processing and Validating CFD Data for Estimating Inlet Dynamic Total-Pressure Distortion
ARP1420	Gas Turbine Engine Inlet Flow Distortion Guidelines
ARP1702	Defining and Measuring Factors Affecting Helicopter Turbine Engine Power Available
ARP4754/ED-79	Guidelines for Development of Civil Aircraft and Systems
ARP4761/ED-135	Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment
ARP6420	Guidelines for Characterization of Gas Turbine Engine Total-Pressure, Planar-Wave, and Total-Temperature Inlet-Flow Distortion

2.1.2 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

2.1.3 FAA Publications

Available from Federal Aviation Administration, 800 Independence Avenue, SW, Washington, DC 20591, Tel: 866-835-5322, www.faa.gov.

AC 27-1B Advisory Circular: Certification of Normal Category Rotorcraft

AC 29-2C Advisory Circular: Certification of Transport Category Rotorcraft

PS-ASW-27/29-07 Policy Statement on Certification of Engine Inlet Barrier Filter (IBF) Installation in Rotorcraft

2.2 Definitions

2.2.1 BLOCKAGE

The actual state of filter clogging which will result in a certain level of additional restriction as compared to a clean filter.

2.2.1.1 BLOCKAGE MONITORING SYSTEM (BMS)

A sub-system of the IBF or rotorcraft which monitors filter clogging, typically using pressure or differential pressure sensor(s). The system may be progressive giving real-time feedback of filter clogging status or may be a discrete indicator designed to annunciate when one or more blockage levels are achieved at a high engine power.

2.2.1.2 IMPENDING BLOCKAGE

A clogging level sufficient to cause the BMS to indicate that the maximum allowable restriction has been achieved. An IBF experiencing impending blockage will still allow enough airflow into the engine to achieve rotorcraft flight manual (RFM) performance without exceeding applicable engine limits.

2.2.1.3 INTERMEDIATE BLOCKAGE

A clogging level or levels which are less severe than impending blockage and do not cause the BMS to indicate maximum allowable restriction but may result in an observable reduction in engine performance.

2.2.1.4 NON-UNIFORM BLOCKAGE

A blockage which is not evenly distributed on the filter surface.

2.2.2 BASELINE AIR INTAKE

The existing reference inlet configuration against which a new IBF system is compared. For example, an A versus B comparison where A is the baseline.

2.2.3 BYPASS

Alternate air source typically provided via a mechanism that allows airflow to enter the engine without passing through the IBF. Generally used when the IBF has reached impending blockage.

2.2.4 CLEAN FILTER

A filter without any accumulation of contaminant (i.e., free of clogging). This represents the baseline restriction of an IBF system.

2.2.5 CLOGGING

A gradual process that results from the capture of contaminants from the airflow, which over time can increase pressure loss across the IBF compared to a clean (i.e., unclogged) filter.

2.2.6 CONTAMINANT

An airborne substance (i.e., sand, dust, ice, snow, grass, FOD) which could be ingested into the engine as part of the inlet airflow. Contaminants can clog the IBF. An environment rich in contaminants is called a contaminated environment.

2.2.7 DEGRADATION

A process that causes an impairment or loss of capability, function, or performance that is recoverable.

2.2.8 DETERIORATION

A process that causes an impairment or loss of capability, function, or performance that is not recoverable.

2.2.9 ENGINE DECK

A computerized engine performance model.

2.2.10 ENGINE INSTALLATION MANUAL

A set of approved instructions for installing and operating an engine in an aircraft. This includes data relevant to IBF certification such as inlet distortion definition and limits. This document is produced by the engine manufacturer as required by 14 CFR Part 33.

2.2.11 ENGINE POWER ASSURANCE CHECK

The process by which it can be determined if the engine(s) can produce enough power to meet the minimum performance listed in the RFM.

2.2.12 FUNCTIONAL HAZARD ASSESSMENT

A process by which rotorcraft safety is assessed by identifying functional failures of a system and determining the effect of the failure on the rotorcraft as a system. The functional failures are placed into hazard classifications ranging from “no effect” to “catastrophic” and are combined with a documented or calculated reliability to ensure that the occurrence of each failure does not exceed the maximum probability of failure limits for its designated hazard classification.

2.2.13 INLET BARRIER FILTER

An inlet protection system which utilizes porous filter media to remove contaminants from engine airflow through the mechanisms of interception, impaction, diffusion, and/or sieving.

2.2.14 INLET FLOW DISTORTION HARMONICS

Inlet flow distortion is characterized by spatial variations in the total pressure at the inlet/engine interface plane. These spatial variations can be present over a radial span or circumferential extent. Flow distortion harmonics are characterized as the circumferential low-pressure spatial frequency content of the measured total pressures at this interface plane over one engine rotor revolution. Flow harmonic coefficients can be quantified by determining the Fourier components of a given planar total pressure profile and can provide insight relative to engine compressor aeromechanical stimuli.

2.2.15 INSTALLATION EFFECT

A change to power available that results from operation of an engine installed on a rotorcraft. In the context of an IBF, this refers specifically to changes in total pressure, total temperature, and/or vorticity/angularity of engine inlet air that affects power available.

2.2.16 MINIMUM SPECIFICATION ENGINE

A minimum specification engine is one that, on a test stand under conditions specified by the engine manufacturer, will produce the certified horsepower values at specification temperatures and speeds. This normally reflects the minimum power capability the engine manufacturer has approved for continued service and is called by the equivalent term, “fully deteriorated engine.”

2.2.17 MINIMUM SPECIFICATION POWER

The certified horsepower values that a minimum specification engine will produce at specification temperatures and speeds. Uninstalled minimum specification power is produced on a test stand under conditions specified by the engine manufacturer. Installed minimum specification power includes the effects of installation losses and forms the basis for RFM performance.

2.2.18 RESTRICTION

A loss of working pressure resulting from air flowing through the IBF system. Restriction can be influenced by air flowrate, clogging level, type of contaminant(s) and atmospheric conditions.

2.3 Abbreviations and Acronyms

AC	Advisory Circular
AEO	All Engines Operating
AIP	Aerodynamic Interface Plane
AIR	Aerospace Information Report
AL	Amendment Level
ARP	Aerospace Recommended Practice
BAI	Baseline Air Intake
BMS	Blockage Monitoring System
CFD	Computational Fluid Dynamics
CFR	Code of Federal Regulations
EIM	Engine Installation Manual
EPAC	Engine Power Assurance Check
FAA	Federal Aviation Administration
FHA	Functional Hazard Assessment
FOD	Foreign Object Debris
FOM	Figure-of-Merit
HEI	Harmonic Excitation Index
HIGE	Hover In Ground Effects
HOG	Hover Out of Ground Effects

IBF	Inlet Barrier Filter
IE	Installed Effect
IFSD	In-Flight Shut Down
MCP	Maximum Continuous Power
MGT (MGTc)	Measured Gas Temperature (Corrected)
NG (NGc)	Gas Generator Speed (Corrected)
OAT	Outside Air Temperature
OEI	One Engine Inoperative
OEM	Original Equipment Manufacturer
RFM	Rotorcraft Flight Manual
RFMS	RFM Supplement
SAE	Society of Automotive Engineers
SHP	Shaft Horsepower
STC	Supplemental Type Certificate
TBO	Time Between Overhauls
TC	Type Certificate

2.4 Symbols and Subscripts

2.4.1 General Symbols and Subscripts

A	Area
$a_{n,i}$	Fourier series coefficient, nth order
$b_{n,i}$	Fourier series coefficient, nth order
f_{ij}	Off-axis tensor amplification factor
h	Height from annulus hub
H	Height of annulus
HEI_n	Harmonic excitation index, nth order
$HEI_{n,i}$	Harmonic excitation index for ring i, nth order
HEM_n	Harmonic excitation moment, nth order
i	Radial index, probe
j	Circumferential index, probe
k	Number of probes at constant radius

k_1	Viscous permeability, principal direction
K_1	Viscous permeability tensor
k_2	Inertial permeability, principal direction
K_2	Inertial permeability tensor
N	Order of Fourier series
n	Harmonic excitation order
P	Pressure, see subscripts for type
Q_{avg}	Face average velocity head
$\dot{Q}$	Volume flowrate
r_h	Annulus hub radius
r_i	Ring i radius
$\vec{S}_p$	Momentum source, porous region
T	Temperature; see subscripts for type
u_s	Superficial velocity, principal direction
$\vec{v}$	Velocity vector
V_c	Calibrated airspeed
$V_{n,i}$	Forcing magnitude, nth order
$\vec{v}_s$	Superficial velocity vector
V_{TOSS}	Take-off safety speed for Category A departures
V_Y	Best rate-of-climb speed
x	Principal direction

2.4.2 Greek Symbols

δ	Pressure ratio
δ_{T2}	Inlet pressure recovery ratio
θ	Temperature ratio
θ_j	Circumferential probe position
θ_{T2}	Inlet temperature differential
μ	Dynamic viscosity
ρ	Air density

τ Deviatoric stress tensor

2.4.3 Subscripts (Pressure and Temperature)

a Ambient

p Porous

S Static

SSL Standard sea level

T Total (stagnation)

1 Engine inlet

2 Compressor inlet

3. GENERAL CONSIDERATIONS

The following sections summarize the certification basis and safety concerns related to the installation and certification of an IBF system as well as discussion on the involvement of rotorcraft and engine Original Equipment Manufacturers (OEMs) in the process.

3.1 Certification Considerations

Generally, the certification basis of a rotorcraft, including the engine installation, consists of the necessary 14 CFR Part 27 or 29 requirements, equivalent international certification standards, or in some cases (e.g., with legacy rotorcraft), early civil aviation requirements to the amendment level declared on the rotorcraft type certification data sheet. This includes the installed engine performance characterization. There has been some methodology variation between engine and rotorcraft manufacturers for quantifying installed power available and engine inlet airflow distortion. Regulatory agencies have found these methodologies acceptable if they demonstrate compliance with the applicable certification basis.

The installation of an IBF can substantially impact the inlet characteristics of an engine installation and therefore compliance with the necessary paragraphs from 14 CFR Part 27 or 29 requirements (or equivalent) must be established. Typical post-certification modifications may include a new installation or a modification of an existing IBF. Alternatively, if the original certified rotorcraft included an IBF, a modification may be to remove such a device. In any case, engine installed power available and distortion must be determined for all engine installations and any subsequent modifications.

Applicants using the Supplemental Type Certificates (STC) process for IBF installation must also comply with all requirements defined in 14 CFR Part 27 or 29 or equivalent international certification standards to the amendment level that will be declared on the STC for the rotorcraft.

3.2 System Safety

The following sections summarize the safety considerations related to the installation of an IBF system on a rotorcraft including a discussion on the Functional Hazard Assessment (FHA) process and a summary of the system configurations that should be considered during certification.

3.2.1 Safety Considerations

IBF systems can increase the overall safety of a rotorcraft by improving the reliability and durability of the engine. This is accomplished by protecting the engine against ingestion of airborne contaminants including sand, dust, ice, snow, grass, or FOD. Excessive ingestion of contaminants can erode and degrade compressor blades, clog fuel nozzles, and cooling passages, and affect turbine nozzle area resulting in permanent loss of engine performance and compressor stability margins. A properly designed and integrated IBF system can prevent the vast majority of these contaminants from being ingested, thereby preventing permanent loss of available engine power. However, the filter installation and the buildup of contaminants on the filter both result in increased restriction of airflow entering the engine. The buildup of contaminants (clogging) causes a temporary loss of installed engine performance margin until the filters are cleaned or replaced. Experience has shown that over the life of a well-designed filter installation, the losses associated with temporary clogging of the IBF are usually no more severe than the permanent losses to which the engine would have been subjected with an unprotected inlet under the same operational conditions.

3.2.2 Functional Hazard Assessment

An FHA should be conducted as per ARP4754/ED-79 and ARP4761/ED-135 or later revisions. Starting from functional breakdowns at the rotorcraft level down to the IBF level, the analysis should identify relevant functional failures which need further assessment for hazard severity level and probability. The safety assessment should cover these failures individually and in combination with other failures. Depending on the systems used, combined failure conditions may involve, for example, the engine, EPAC, BMS, and/or IBF bypass system.

Normally the worst-case outcome of an IBF system failure would be loss of engine power, unless it is possible to affect another system, for example if IBF structural failure can cause damage to the rotor system or flight controls. A rotorcraft FHA will normally have already addressed the functional hazard effect of losing power on one or multiple engines and have considered Category A, Category B, or other single engine operations. The rotorcraft FHA will normally have covered the hazard effect for erroneous or lost indication to the pilot about the capability of the engines to provide power.

IBF system failures should be considered as contributing causes to the higher rotorcraft level effect of loss of engine power or failed indication of the engine capability to provide power. Therefore, the functional hazard effect of IBF system failures should align with what the rotorcraft has assessed for loss of engine power or failed indication of engine power whether it is a single engine, or multi-engine Category A or Category B operation.

Rotorcraft turbine engines generally do not achieve loss of power reliability better than 10^{-5} per engine flight hour. Using the guidance of AC 29-2C (Section 29.1309, Figure 1309-2) for a Part 29 rotorcraft, this would correspond to the reliability necessary for severity level "major." As such, a single engine loss of power would normally not be categorized with severity level greater than major. Because the IBF is part of the engine installation, an IBF system failure on one engine would not be expected to have hazard severity greater than failure of the engine itself.

The FHA should also normally consider whether the failure is detected or undetected. An undetected failure is typically less probable than a detected failure. However, a detected failure typically has less hazard severity if the pilot is aware of the failure and can take action to mitigate the hazard.

A hazardous or catastrophic failure level could occur from failure of an IBF system in combination with other failures such as concurrent failure of the other engine. The safety assessment would then consider the probability of the failure combination and whether the combined probability achieved the levels specified by AC 29.1309 for the respective hazard level. Depending on the safety allocation to each event and the type of rotorcraft (single- or twin-engine Category A or Category B), such analysis may have a direct impact on the bypass reliability and the BMS architecture. Table 1 provides a portion of a functional failure example which normally contains additional columns such as phase of flight, failure effect, and hazard classification (not shown; refer to ARP4754).

Table 1 - IBF functional failure example

Function	Sub-Function	Functional Failure
1.0 Ensure sufficient inlet air flow characteristics necessary for the engine to provide power required	1.1 Provide sufficient primary inlet air flow	1.1.1 Detected failure to provide sufficient primary airflow for engine to provide power required
		1.1.2 Undetected failure to provide sufficient primary airflow for engine to provide power required
	1.2 Provide bypass inlet air flow	1.2.1 Detected failure to provide bypass inlet air flow when necessary for the engine to provide power required (primary path obstructed)
		1.2.2 Undetected failure to provide bypass inlet air flow when necessary for the engine to provide power required (primary path obstructed)
2.0 Provide pilot indication of IBF condition affecting engine capability to provide power required	2.1 Provide indication of IBF clogging level	2.1.1 Detected erroneous or lost indication of IBF clogging level
		2.1.2 Undetected erroneous or lost indication of IBF clogging level
	2.2 Provide indication of bypass operation	2.2.1 Detected erroneous or lost indication of bypass operation
		2.2.2 Undetected erroneous or lost indication of bypass operation

Some examples of failure combinations are provided:

- a. Failure to provide the necessary inlet airflow for one engine to provide power required (item 1.0) combined with failure of the other engine during takeoff phase of CAT A operation could be catastrophic requiring $<10^{-9}$ probability. Since failure probability of the other engine failure is $<10^{-5}$, the probability of item 1.0 should be $<10^{-5}$ (major) so that the combined probability is $<10^{-9}$.
- b. In the above example, depending on system design, item 1.0 could result in various combinations of sub-function failures. For example, item 1.0 could be caused by a combination of items 1.1 and 1.2 on an IBF system with a bypass, or a combination of items 1.1 and 2.1.2 for an IBF with no bypass or for a bypass system that requires pilot awareness and action to activate. The failure probabilities of the contributing items must result in combined probability that meets the 10^{-5} probability required for item 1.0 (major).
- c. Undetected failure of the BMS on one engine could be minor to major depending on the system architecture. For example, if the bypass system automatically opens with mechanical pressure differential, the BMS would only be a maintenance tool. The hazard severity of failure is minor since the bypass would open regardless of BMS operation for a blocked filter. However, if opening of the bypass depends on BMS pressure level detection, then failure to open in case of blocked filter could lead to loss of engine power and BMS failure hazard severity could increase to major.

The same kind of event on a Category A design versus single engine or Category B design may result in different failure classification.

The safety analysis should also consider the independence between engines and the possibility of common mode failure cause. For example, if there is a single point failure in the BMS that can cause loss of power or erroneous blockage indication on both engines then the severity assessment of that failure is necessarily higher than it would be if only affecting indication on one engine. This would increase the need for redundancy and separation in the BMS design. The IBF on multi-engine rotorcraft certified under Part 29 are required to be separated and independent. Part 27 certified rotorcraft do not have the same requirement, but the IBF design should preserve inlet system separation if the baseline rotorcraft has independent inlets. However independent inlets could be affected by common external causes of engine power loss since both engines can experience the same inlet conditions with high contaminant level or FOD. These are random events and safety analysis typically does not assign a probability number. A safety analysis may assume 100% probability of an external cause and assess the impact of that occurring in combination with various IBF system failures. The IBF installation should not increase the hazard severity or probability of these external events causing engine power loss relative to the hazard severity or probability for the same external condition without IBF installed.

3.2.3 System Configurations

When considering the impact of the IBF system on safety and performance of the rotorcraft, it is important to consider all the various operating states of the IBF system. The position of the bypass door/mechanism (if present), including transitional phases, coupled with varying filter clogging levels can result in an array of possible operating states. [Table 2](#) is a guide as to whether safety and performance assessment is necessary for a particular state but is not limited to the operating states shown.

Table 2 - Need of safety and performance assessment for various IBF operating states

	Bypass Closed/No Bypass Design	Bypass Open	Bypass Transition
Clean IBF	Required ⁽¹⁾	Conditional ⁽²⁾	Conditional ⁽²⁾⁽⁴⁾
Intermediate Blockage	Conditional ⁽²⁾⁽³⁾	Conditional ⁽²⁾⁽³⁾⁽⁴⁾	Conditional ⁽²⁾⁽³⁾⁽⁴⁾
Impending Blockage	Required ⁽¹⁾⁽³⁾	Conditional ⁽³⁾⁽⁴⁾	Conditional ⁽³⁾⁽⁴⁾

⁽¹⁾ Performance and Safety Assessment Required.

⁽²⁾ Performance and Safety Assessment Conditional—depends on IBF design; may have been sufficiently covered by analysis of other states.

⁽³⁾ May require consideration of nonuniform blockage conditions.

⁽⁴⁾ Depends if and how this state can occur with IBF design.

3.3 Rotorcraft and Engine Manufacturer Involvement

The involvement of rotorcraft and engine OEMs in the certification process of IBF installations is important; however, in practice, such cooperation is not always possible. While TC applicants enjoy the direct involvement or leadership of the rotorcraft OEM and the data available through their agreements with the engine OEM, STC applicants often face challenges which complicate the path to certification. Compliance with power available and inlet distortion regulations requires information and intellectual property which can be difficult to obtain. In some cases, this may be unavailable due to a lack of legacy documentation or equipment. In others, the business interests of the IBF manufacturers may conflict with those of the OEMs making cooperation impractical. However, there are also many examples of successful cooperation across the industry and all reasonable efforts should be made to involve OEMs before resorting to alternative means of compliance which do not rely on direct OEM involvement.

For TC applicants, the information and equipment required from OEMs to successfully certify an IBF installation comes in the form of the engine performance computer program and the engine installation manual (EIM) which contains installation requirements, rated engine performance and limitations, as well as maximum allowable inlet distortion conditions. An inlet rake that conforms to the EIM is also typically required and may be obtained from the engine OEM or in some cases from the rotorcraft OEM, depending on the platform in question. An STC applicant should have this same data and equipment set available along with the RFM which contains important information such as operating envelope, drivetrain or power limitations and power assurance procedures.

Compliance of the engine installation to the EIM is a direct requirement of current civil certification regulations. However, in the absence of some or all of the installation requirement information or verification equipment, it may still be possible for an alternate means of compliance to maintain the intent and assumptions of the OEM design regarding installation and operation and show an equivalent level of safety.

4. MEANS OF COMPLIANCE FOR POWER AVAILABLE AND POWER ASSURANCE

The objective of this section is to provide a summary of the considerations affecting power assurance and installed performance with IBF installations, including fixed and variable installation effects, the certification process, and applicable regulations, as well as pilot awareness and management of the effects of IBF installations and a summary of flight-testing requirements. Generally, compliance with 14 CFR 27.45/29.45 requires performance charts corresponding to the approved engine power, less installation effects, and other considerations, and subject to the approved range of atmospheric conditions, as well as a means for the pilot to confirm that the engine(s) can produce power required to meet those declarations.

An engine power assurance check (EPAC) is the process by which the pilot can determine if the engine(s) can produce enough power to meet the minimum performance listed in the RFM. Most engines are delivered with surplus power margin which provides margin to accommodate FOD damage, deterioration, and normal wear and tear, thus allowing them to periodically operate in dusty or dirty environments without jeopardizing the rotorcraft's ability to meet RFM performance. The inclusion of an IBF system will often reduce the rate of damage and deterioration due to erosion, engine component clogging and accretion, but can result in changes to installed power that must be considered. The main factors affecting power available at the engine output shaft, including installation effects, accessory power extraction, and operational effects, are discussed in ARP1702, with associated theory and terminology for power assurance covered in AIR4083. These two documents are companions and share the same concepts of power available and power margin.

There are two distinct approaches used in modern industry for dealing with power assurance and performance with IBF, either to generate dedicated IBF power assurance charts or to re-use existing charts from another configuration. The creation of dedicated IBF power assurance and performance charts or algorithms does not differ substantially from the process historically used to certify inlets or other types of inlet protection devices. However, the additional installation effects associated with the filter and its clogging characteristics leads to the possibility for variation in how the installation effects are accounted. The severity of these effects and how they are factored into performance and power assurance charts can take several forms.

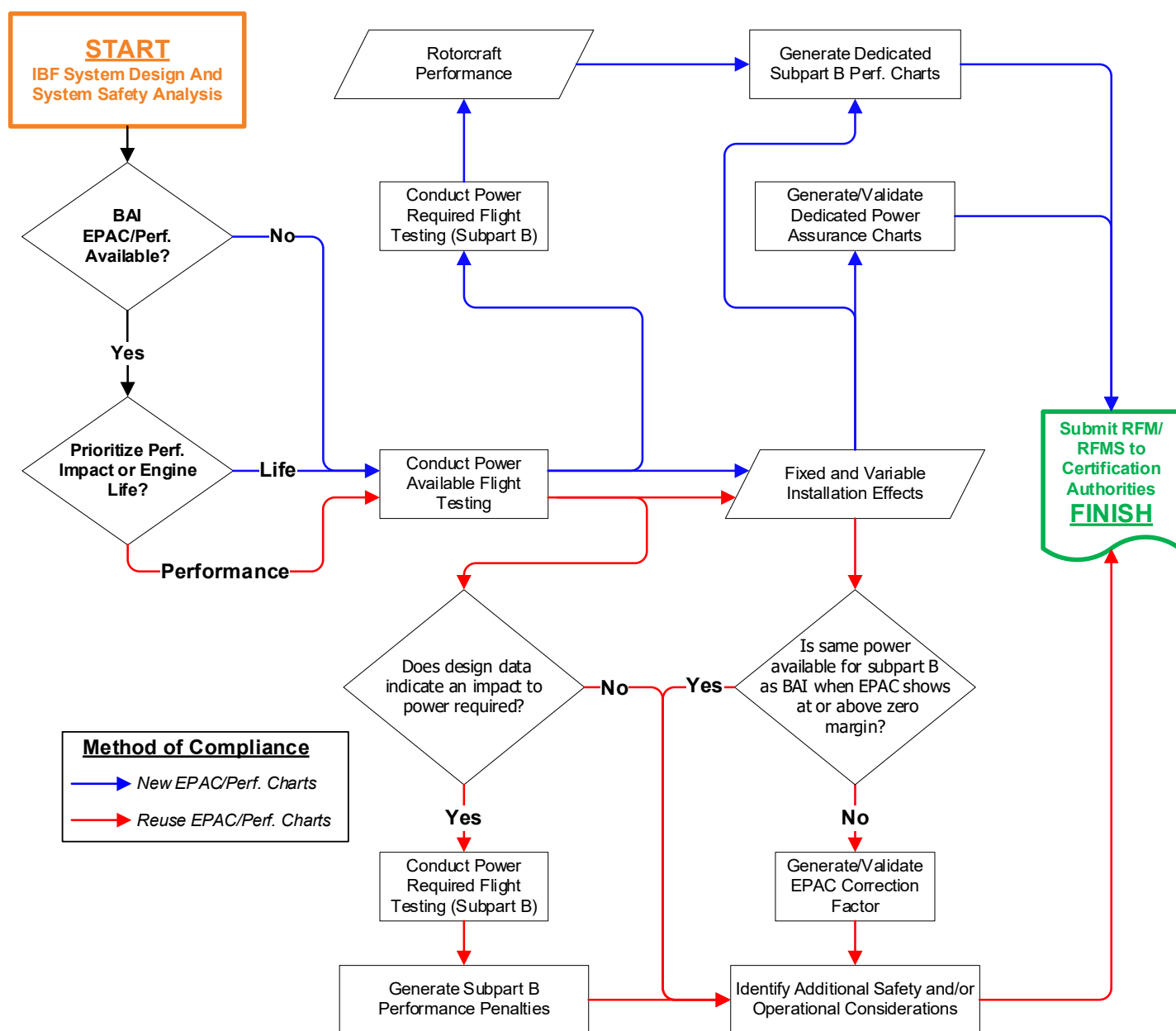
For rotorcraft which already have performance and power assurance charts predicated on a specific inlet, additional performance losses due to the IBF may be undesirable and might be mitigated through careful management of engine EPAC margins. Any degradation below the minimum power available on which existing rotorcraft performance charts are based will require an evaluation of the remaining Subpart B performance requirements (i.e., hover, takeoff, climb, and landing).

Any changes in the performance or flight characteristics may result in the need for modified performance charts or performance decrements as well as additional operational considerations in the RFM or RFM supplement (RFMS). Extrapolation from or comparison to designs with similar installation characteristics will require ground and/or flight testing. Some aspects of ground and flight testing may be difficult without direct assistance and information from the engine and airframe manufacturers as discussed in [3.3](#).

[Table 3](#) summarizes strengths and challenges of two approaches to IBF power assurance and performance. Examples of each approach are provided in [Appendix B](#) along with appropriate design considerations and limitations. Direct compliance with PS-ASW-27/29-07 results in the application of impending blockage effects on performance charts and results in maximum utilization of engine power margin/engine health. This level of performance may not be suitable for all rotorcraft/IBF combinations; therefore, additional considerations can be made to manage blockage through EPAC margins if the clogging rate can be shown to be gradual. It may also be possible to reuse existing power assurance and performance charts if it can be demonstrated that sufficient power margin is present to account for the IBF installation effects. These strategies are not exhaustive and might be combined or altered to suit the needs of a particular IBF installation. The validation process for any power assurance and performance strategy with IBF will follow the general outline described in [Figure 1](#).

**Table 3 - Strengths and challenges of methods of compliance
for power assurance and performance**

Approach to EPAC and Performance	Example(s) of Compliance	Strengths	Challenges	Examples
Dedicated EPAC and Performance	Minimum specification at impending blockage (PS-ASW-27/29-07)	Leverages most if not all of available engine power margin toward engine life. Provides the most conservative approach to power assurance.	Most severe rotorcraft performance based on impending blockage losses irrespective of clogging state. Requires additional flight test and analysis for reduced power available.	Section B.2
	Blockage managed as progressive EPAC deterioration	Retains most of available engine power margin less reduction for clean filter losses. Rotorcraft performance is assured when engine margin is positive. Positive margin is maintained by progressive monitoring and cleaning as needed to recover losses from clogging. Minimizes performance penalty by decrementing for clean filter only.	Rotorcraft performance lowered to penalize for clean filter losses. Requires additional flight test and analysis for reduced power available. Requires means for continuous pilot awareness in flight that clogging has not reduced power available below that required for minimum RFM performance.	Section B.3
Reuse of Existing EPAC and Performance	Use of previously certified rotorcraft performance	Retains same minimum rotorcraft performance. No decrement to power available or rotorcraft performance penalty due to IBF installation. All IBF losses managed as reduction of power assurance margin rather than a performance decrement. Reduces the amount of performance flight testing and analysis.	Leaves some portion of engine life unused. May require frequent maintenance with low margins to maintain operable status.	Section B.4



NOTE: These are recommended paths to certification, but alternative combinations may be used to show compliance with 14 CFR Part 27/29.

Figure 1 - Design and validation process summary for power assurance and performance with IBF system

4.1 Fixed Installation Effects

The pressure and temperature recovery of the airflow reaching the engine compressor face is the measure of inlet recovery characteristic. These recoveries can be characterized as changes to inlet pressure and temperature and can vary throughout the IBF service cycle and operational envelope. For a newly installed or freshly cleaned IBF, these are called fixed installation effects. The changes in pressure and temperature that best define the impact of the IBF on the air flow at the engine compressor face are the inlet pressure ratio and the inlet temperature differential which can be found from Equations 1 and 2.

$$\delta_{T2} = \frac{P_{T2}}{P_{SSL}} = \left(\frac{P_{T2}}{P_a} \right) \left(\frac{P_a}{P_{SSL}} \right) = \left(\frac{P_{T2}}{P_a} \right) \delta \quad (\text{Eq. 1})$$

where:

δ_{T2} = inlet pressure ratio

P_{T2} = inlet absolute total pressure

P_{SSL} = absolute static pressure, standard sea level

P_a = absolute static pressure, ambient

δ = inlet pressure ratio relative to standard sea level

$$\theta_{T2} = \frac{T_{T2}}{T_{SSL}} = \left(\frac{T_{T2} - T_a}{T_{SSL}} \right) + \left(\frac{T_a}{T_{SSL}} \right) = \left(\frac{T_{T2} - T_a}{T_{SSL}} \right) + \theta \quad (\text{Eq. 2})$$

where:

θ_{T2} = inlet temperature differential

T_{T2} = inlet absolute total temperature

T_{SSL} = absolute static temperature, standard sea level

T_a = absolute static temperature, ambient

θ = inlet temperature ratio relative to standard sea level

It is acceptable to use P_{T1} and T_{T1} (station 1) if they offer a better representation of the temperature or pressure recovery. In forward flight, the degree of free stream total pressure or “ram” recovery achieved by the rotorcraft intake must also be considered. Both δ_{T2} and θ_{T2} vary as a function of calibrated airspeed V_c and mass flow in a non-linear fashion. Effects on inlet pressure recovery ratio P_{T2}/P_a and the inlet temperature differential $(T_{T2} - T_a)/T_{SSL}$ as a function of V_c must be accounted for with respect to installed power available and associated impacts to RFM performance charts as well as any in-flight EPAC solutions.

4.2 Variable Installation Effects

As the IBF filters the air, it gradually becomes clogged and restricts the airflow to the engine intake. The corresponding changes to inlet pressure and temperature are called variable installation effects. A corrective maintenance task may be required to clean or replace the filter to recover lost margin by removing the variable effects. It is the installer's responsibility to determine the maintenance frequency based on the tolerance of the system to continue accumulating contaminants before reaching impending blockage.

4.3 Development of Power Assurance Check with IBF

14 CFR 27.45(f) and 29.45(f) require that, “for turbine-engine-powered rotorcraft, a means must be provided to permit the pilot to determine prior to takeoff that each engine is capable of developing the power necessary to achieve the applicable rotorcraft performance.” AIR4083 defines the theory and methods for turbine-engine-powered rotorcraft power assurance. AIR4083 states that the FAA type certification rules and policy do not require that a pre-takeoff power check be performed, only that a means be made available to the pilot. The frequency of EPAC is influenced by operational experience and minimum intervals may also be prescribed or recommended by the engine OEM. 14 CFR 29.45(c) directs that the horsepower used to complete the flight manual performance must be based on horsepower values no greater than that available from the uninstalled minimum specification engine after it is corrected for installation effects.

ARP1702 provides methodology for measuring the installation factors that affect installed power available. It explains that when installation effects are correctly assessed, the installed power check will give an identical measure of performance index (i.e., ratio of power available to minimum specification level) as would be achieved in an engine acceptance bench test. ARP1702 further explains the result of over or underestimating installation effects. On one hand, if installation effects are incorrectly assessed to be less than actual (underpredicted installation effects) then the EPAC will indicate a lesser engine performance index than would be found on the engine test bench (overpredicted engine deterioration). This could result in premature engine removal before the engine had fully deteriorated to minimum specification power. On the other hand, if the installation effects are incorrectly assessed as higher than actual (overpredicted installation effects) the EPAC would indicate a greater performance index than what would be found on the engine test bench (underpredicted engine deterioration). This could result in an engine remaining in use after deteriorating below minimum specification power.

The EPAC determines the net power margin by measuring the actual power that the installed engine is producing at the power condition the EPAC is conducted and comparing it to what a minimum specification installed engine would produce under same conditions. The algorithm then extrapolates the margin to rating conditions. In the case of low EPAC margin, the pilot cannot assume that the performance losses are coming from the installation, from a contaminated filter, or from other causes of engine deterioration. Whereas underprediction of installation effects is a maintenance/cost concern of premature engine removal, overprediction of installation effects is a much greater concern of flight safety. This is because when installation effects are overpredicted, an engine could deteriorate well below minimum specification power while the EPAC is still showing positive margin. As a result, performance shown in RFM performance charts can no longer be guaranteed.

The performance of an engine which has deteriorated below minimum specification cannot be assured. Performance non-linearities can occur which could result in different effects of limiters and maximum fuel control stops that are not reflected in the engine performance deck. Also, there may be hardware distress causing the deterioration below minimum specification which would not allow the engine to achieve rated power. Other characteristics such as stability margin and restart capability may not have been assured by the engine manufacturer for a below minimum specification engine. Therefore, an EPAC based on overpredicted installation effect cannot assure the engine is capable of safely developing power to achieve specified rotorcraft performance and therefore does not comply with 14 CFR 27.45(f) and 29.45(f).

EPAC development methodology for non-IBF inlets is normally based on known fixed installation effects that are accounted such that the installed EPAC margin matches the uninstalled EPAC margin in the engine test cell. In addition to inlet and exhaust losses, effects such as bleeds or accessory loads are handled by conducting the EPAC in a known controlled state (i.e., bleeds and accessory loads turned off during the EPAC) or alternatively indicated levels of bleeds or accessory loads could be input into the EPAC algorithm.

However, IBF clogging is a variable progressive effect and the level of that effect at any particular time is typically unknown and not able to be accounted as an input to EPAC algorithm.

It is generally not acceptable to develop the EPAC assuming installation effects with the IBF at impending blockage condition. This is because the installation effects will be overpredicted for the majority of operation with anything less than impending blockage resulting in an underprediction of engine deterioration. When such an EPAC shows above zero margin, a clean IBF condition may mask deterioration of the engine itself below minimum specification to a condition where it cannot deliver rated power.

An acceptable alternative is to develop the EPAC assuming installation effects of clean IBF condition. The EPAC would show a progressively clogging IBF as deteriorating engine margin. It would underpredict installation effects as the IBF progressively clogs resulting in conservative overprediction of engine deterioration. It would always indicate zero margin or less if the engine itself had fully deteriorated to minimum specification. This conservatism should not be an issue for premature engine removal because the first maintenance action an operator would perform before engine removal would be to check condition of the IBF. Power margin would be restored with cleaning if the IBF was the cause of low margin and premature engine removal would be avoided.

More importantly, when the EPAC for an IBF installation is based on clean IBF effects, it is able to conservatively account the overall state of installed power available, whether a reduction in health is due to IBF clogging, engine deterioration, or both. So, when the EPAC gives a positive margin, it is assurance that the engine itself has not deteriorated below minimum specification, and that the installation is capable of providing the power necessary for published rotorcraft performance.

It may also be acceptable for the IBF installation to use the EPAC algorithm unchanged from the non-IBF installation if the extrapolation from the EPAC power to the critical rating is demonstrated to be unaffected by the IBF installation. The non-IBF EPAC algorithm will typically have less installation effect accounted than a clean IBF algorithm, and this would have the conservative result of overprediction of engine deterioration for EPAC conducted under consistent operational conditions. The outcome is that the IBF installation would show full engine degradation (prematurely) even though the IBF was fully cleaned. However, this may be an acceptable maintenance tradeoff since IBF installations typically reduce engine deterioration rate, so engines reach overhaul time with higher EPAC margins.

The accuracy of EPAC extrapolation must also be verified such that for a given IBF blockage condition, the EPAC performed at partial power never predicts greater margin than actually exists at any of the engine rating conditions. It must be considered that extrapolation from part power to maximum ratings might not remain parallel to the unfiltered engine run line due to non-linearities of engine component efficiency and the IBF pressure drop dependence on mass flow. As a result, the accuracy or at least the conservatism of the extrapolation must be verified in the IBF installation certification by flight test and analysis from the engine performance deck. One way to minimize extrapolation error is to conduct the EPAC at as high of a power setting as possible. [Figure 2](#) depicts the various run lines of an engine subject to the effects of an example IBF installation. The non-linearities of the IBF installation effects are purposefully exaggerated to illustrate the case of a part power extrapolation which yields a non-conservative EPAC result. Without an IBF, the relationship between power available and engine operating parameters (e.g., gas producer speed or exhaust temperature) follows a predictable trend characterized by a constant slope of the run line. An engine that is above minimum specification will produce rated power but may operate at a higher Ng or higher temperature than a new engine; however, it will always be characterized by the same slope. With an IBF, the run line may shift and appear as a degradation in engine condition and the relationship between power available and engine operating parameters can no longer be characterized by a line with constant slope. Consider an EPAC conducted on an in-service engine at partial power under impending blockage; the operating point of the engine falls on the corresponding run line. However, extrapolation from the partial power EPAC condition to maximum power using the assumed engine run line slope yields an optimistic estimate of available engine margin because of the non-linearities associated with the IBF. The restriction of the IBF is characterized by a 2nd order polynomial that is a function of flowrate and atmospheric conditions, which progressively worsens with clogging. This can affect the slope of the run line and lead to a falsely optimistic EPAC prediction of actual power available, with a worst case being if actual power available was less than RFM performance.

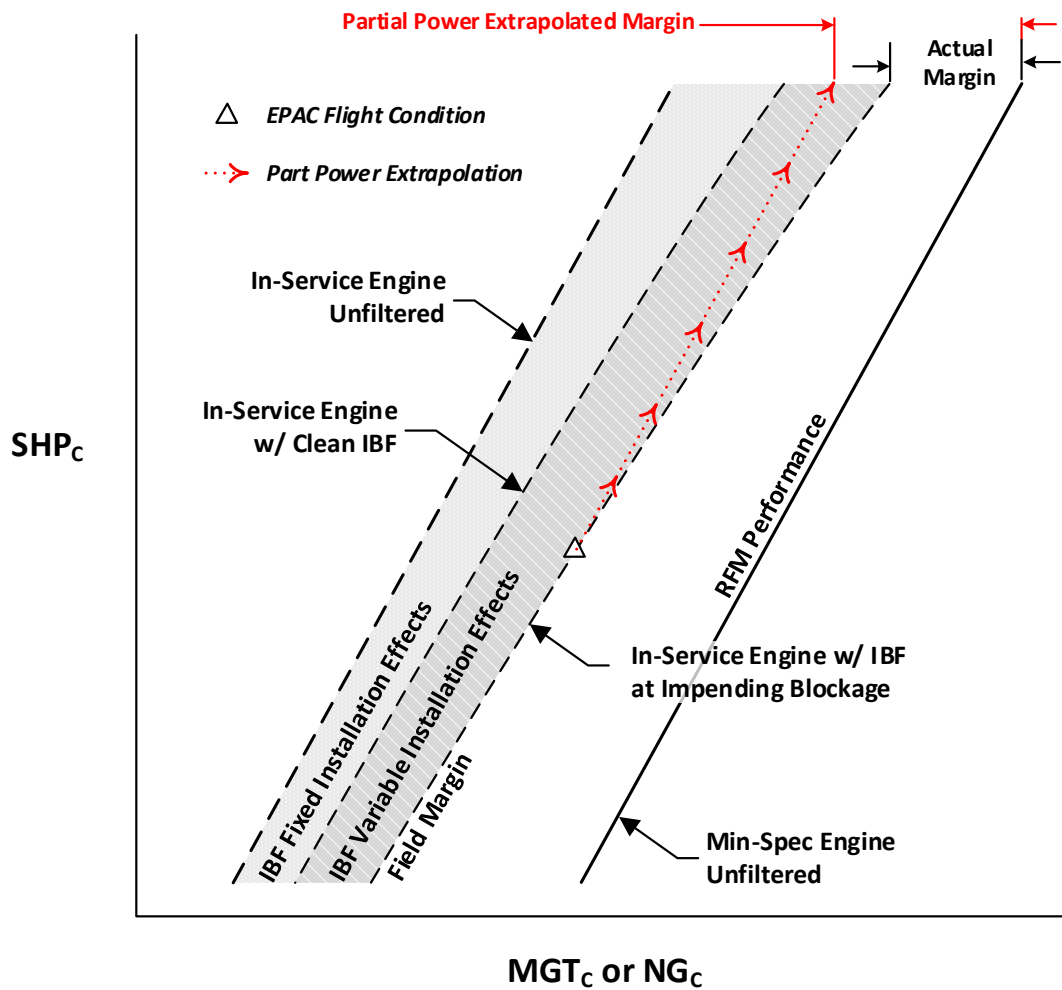


Figure 2 - Installed engine run line and partial power extrapolation

4.4 Certification Power Assurance and Performance with IBF

[Figure 3](#) shows the airworthiness requirements for rotorcraft performance and power available based on category, such as normal or transport, single (Category B) or multi-engine (Categories A or B). The requirements apply to all methods found in Appendix B. While basic requirements are similar for 14 CFR 27 and 14 CFR 29, additional requirements apply in the case of multi-engine installations and isolation requirements (Categories A or B), in accordance with the additional operating capabilities and regimes. In the case where a rotorcraft is certified for both Categories A and B, the assessment of [Figure 3](#) would need to be done for each category.

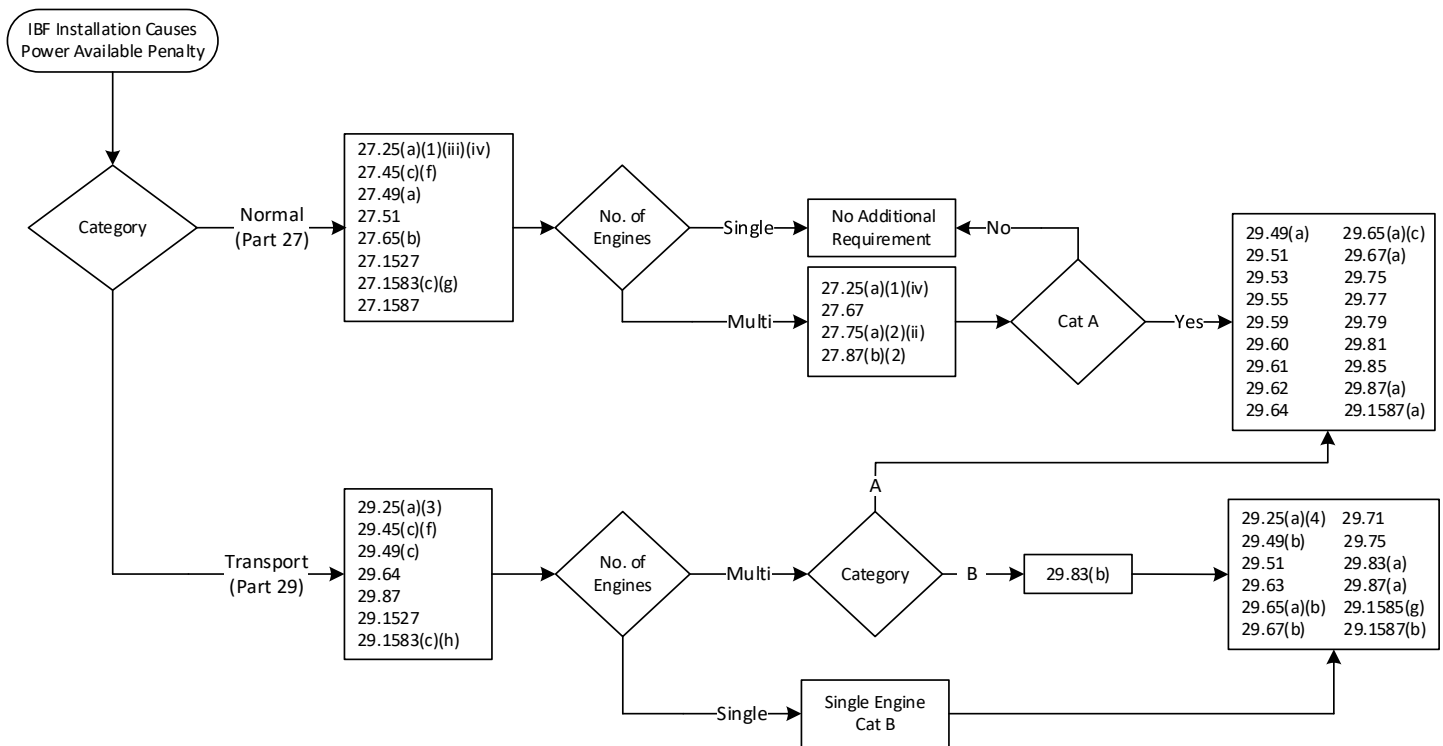


Figure 3 - Power available impact to 14 CFR requirements

4.5 Pilot Awareness of Reduced Performance Due to IBF Variable Installation Effects

The flight crew must be aware of the impact that variable installation effects can have on the performance capabilities of the rotorcraft. These are accounted for as part of the power assurance and performance management strategy, and depending on the strategy used, are communicated in a variety of ways either through the RFM or displayed in the cockpit. If displayed in the cockpit, the performance information must be updated at an appropriate rate, granularity and precision to meet 14 CFR 27/29.1301 function requirements, and a human factors assessment should be part of the design and approval process. Blockage monitoring systems are a common means of displaying qualitative information about IBF blockage in flight, and depending on the sophistication of the system, may be able to provide a quantitative indication of performance capabilities. Whatever means are employed, pilot workload should be minimized, particularly for Category A (multi-engine) rotorcraft.

4.5.1 Blockage Monitoring System

The following describes specific uses of a blockage monitoring system as an alternative or supplement to an impending blockage/bypass indicator. An impending blockage/bypass indicator is based on the delta pressure threshold corresponding to a maximum blockage condition which is typically reached at high power conditions. However, a progressive blockage monitoring system offers the advantage of being able to indicate relative blockage levels at any power setting.

A progressive blockage monitor may in some applications be used to directly indicate the effect of blockage on power available or it may indirectly advise the pilot of possible effect on power available due to incremental changes to restriction with follow-on action to check power available with EPAC. Alternatively, it may simply serve as a maintenance indicator.

If the progressive blockage monitor is used to directly indicate the effect of blockage on power available, the information must be displayed in the pilot's primary field of view and should be representative of an appropriate power setting (i.e., extrapolated to the maximum power condition or otherwise assure the ability to quantify the effect on power available at different operating conditions). It must be clear and unambiguous to the aircrew that the power available is deteriorated, and the performance impact must be easy to interpret.

If the progressive blockage monitor is used to indirectly advise the pilot of the possible effect on power available due to changes in blockage condition, the system must be able to detect and report in increments which are easily translatable to the latest EPAC result. For example, one incremental change of indicated blockage might correspond to 0.1% margin so that a previous EPAC result of +1.1% plus the blockage monitor reading of three increments would be understood to represent $1.1\% - 0.3\% = +0.8\%$ margin.

If the progressive blockage monitor is not in the pilot's primary field of view, it may be possible to establish an equivalent level of safety by tying the monitor to the rotorcraft caution warning advisory system which does alert the pilot in primary field of view to check the monitor and perform follow-on action to check EPAC as applicable. An initial blockage increase is typically annunciated as an advisory and more severe blockage annunciated by caution or warning.

4.5.2 Pilot Workload for Category A

Due to the high pilot workload during a Category A one engine inoperative (OEI) event, the pilot is not allowed to manipulate the alternate air source controls, such as a manual IBF bypass mechanism, until attaining V_{TOSS} and a positive rate of climb or completing the aborted takeoff. 14 CFR 29.59(a)(4) and 29.903(b)(2) must also be considered when establishing Category A procedures and performance. Automatic operation of the alternate air source following an engine failure is an acceptable method to provide the necessary Category A airflow for complying with the regulatory requirements.

4.6 Management of Power Available

The management of power available is a critical component of any power assurance and performance strategy. Because the effects of impending blockage can be more severe for certain maneuvers or operating conditions, the impact on power available must be assessed under the appropriate blockage conditions. The effects of any bypass or alternate air sources should be included especially if they have an adverse impact.

4.6.1 Filter Bypass System

If there is a way to provide bypass air to the engine, then the EPAC and the rotorcraft performance may be based on the bypass open position. During the flight and ground test, the IBF must be blocked to at least the impending bypass annunciation level associated with the bypass closed condition. It cannot be assumed that the bypass open performance is equivalent to the clean filter condition. The applicant must also measure the installation effects with bypass door open for all relevant blockage levels, flight regimes and maneuvers, particularly Subpart B performance and EPAC.

Some IBF-equipped Category A rotorcraft use a bypass to restore an acceptable level of engine installation effects when clogging has reached impending blockage. If the system is designed for automatic bypass operation during OEI, the reliability of the system shall be shown to have an equivalent level of safety during the OEI mode (i.e., no single monitoring system failure may lead to an unsafe system performance level). This may be demonstrated by an appropriate safety analysis.

If included, the bypass configuration should be considered as a full air intake and certified accordingly. If any limitations exist compared to the baseline air intake (BAI), they should be addressed in the flight manual. If the bypass is open during operation in icing or snow, then the certification should demonstrate successful operation of the bypass in those conditions.

4.6.2 Hover Performance

Hover performance charts are produced by calculating the weight that would cause the power required to match with the minimum specification power available at MCP or TOP rating for value sets of altitude, temperature, and wind conditions. Performance charts complying with 14 CFR 27.49/29.49 relate weight, altitude, and temperature, with identifiable areas of maximum power available limited by either the engine or the main gear box (the IBF affects only the former). Options for incorporating IBF performance effects depend on level of effort and desired exactness:

- Regenerating a new hover performance chart.
- Adding a new set of performance lines to an existing performance chart.
- Specifying a weight or altitude penalty as a function of ambient pressure and/or temperature.
- Specifying a single value weight or altitude penalty (highest value) over the entire domain.

