الهيئة العامة للطيران المدني
General Authority of Civil Aviation

ADVISORY CIRCULAR

Subject	Issuance Date	AC Number	Version
Guidance Material on Operational Improvements to reduce Greenhouse gas emissions	1-September-2024	156-01	1.0

Note: This Advisory Circular is published to provide additional information and recommended actions that further elaborates on provisions or concepts prescribed in GACAR Part -156.

1. Introduction

1.1 Purpose

The purpose of this advisory circular is to introduce ICAO's basket of measures for environmental protection and deep dive into discussing operational improvements to reduce Greenhouse gas emissions.

1.2 Applicability

This advisory circular is applicable to air navigation service providers, airplane operators, aerodrome operators and maintenance providers.

1.3 Cancellation

This is the first official version of this advisory circular, and it cancels no other advisory circular on the subject matter.

1.4 Related regulatory references

a) GACAR Part-156
b) GACAR Part-034

1.5 Related reading materials and references

a) Document 10013 Operational Opportunities to Reduce Fuel Burn and Emissions available at ICAO store at: https://store.icao.int/en/operational-opportunities-to-reduce-fuel-burn-and-emissions-doc-10013
b) Document 9931 Continuous Descent Operations (CDO) Manual available at ICAO store at: https://store.icao.int/en/continuous-descent-operations-cdo-manual-doc-9931
c) ICAO Doc 4444 PANS-ATM available at ICAO store at: https://store.icao.int/en/procedures-for-air-navigation-services-air-traffic-management-doc-4444

1.2 Approval

This advisory circular has been approved for publication by the Executive Vice President for Safety and Environmental Sustainability of the General Authority of Civil Aviation.

2. Background

a) In 2016, the ICAO Assembly adopted Resolution A39-2: Consolidated statement of continuing ICAO environmental protection and climate change policies. The assembly reaffirmed the two global aspirational goals established at the 37th Assembly in 2010 to improve fuel efficiency by 2% annually until 2050 and to achieve carbon neutrality by 2020. To achieve the two global aspirational goals and to promote sustainable growth of international aviation, ICAO is pursuing a basket of measures for environmental protection.

b) GACA has always been committed to international civil aviation environmental goals as well as the national targets for environmental sustainability. To steer the Saudi civil aviation industry toward environmental sustainability, GACA has developed the Saudi Civil Aviation Environmental Sustainability Program (CAESP). This program covers (7) environmental pillars, with GHG emissions on the top of this plan's priorities.

c) Hence, this advisory circular is aimed to raise the awareness of all affected stakeholders of the environmental protections measures to reduce the civil aviation industry emissions and its overall impact on the environment.

3. ICAO's basket of measures for environmental protection

ICAO's basket of measures for environmental protections has 4 elements that are supported with regulations and standards produced and updated by its Committee on Aviation Environmental Protection (CAEP):

d) Operational improvements:
Airspace management technologies and air navigation procedures are being adopted for operational improvements.

e) Aircraft technology:
It relates to the advancements in aircraft manufacturing processes, which are maintained through continuous updates to governing regulations and standards.

f) Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)
Implementation of CORSIA program to offset any carbon emissions beyond the agreed baseline by ICAO member states.

g) Sustainable Aviation Fuels
Utilization of sustainable fuels that have less carbon emissions and/or higher efficiency (e.g., SAF, LCAF, etc.).

4. Operational improvements to reduce Greenhouse gas emissions.

Operational enhancements have low contribution to the Net Zero goal on the long run, however in the short and mid-terms they have the most potential in limiting the environmental impacts of airport operations on societies. Operational improvements are classified into four main categories according to responsible stakeholders as follows:

a) Air traffic management
b) Airplane operators
c) Aerodrome operators and ground service providers
d) Maintenance providers

4.1 Air traffic management

ATM is the dynamic, integrated management of air traffic and airspace including air traffic services, airspace management and air traffic flow management — safely, economically and efficiently — through the provision of facilities and seamless services in collaboration with all parties and involving airborne and ground-based functions [1].

Regulation (EC) No 549/2004 of the European Parliament define ATM as the aggregation of the airborne and ground-based functions (air traffic services, airspace management and air traffic flow management) required to ensure the safe and efficient movement of aircraft during all phases of operations [2].

An efficient ATM system can result in significant fuel and emissions savings. The three basic elements of air traffic management should be addressed and optimized in order to ensure both environmental and operational efficiency: airspace management, air traffic services, and air traffic flow management. It is possible to improve ATM efficiency through the utilization of new and established technologies and concepts in communications, navigation and surveillance (CNS), such as data link communications, performance-based navigation (PBN), automatic dependent surveillance (ADS), flexible use of airspace (FUA), and airport collaborative decision making (A-CDM).

The purpose of this section is to describe both the current opportunities and the strategic work underway to improve the efficiency of the global ATM system with the goal of reducing fuel consumption and emissions. It describes the opportunities of achieving fuel-optimized operations in each phase of flight, as well as practical initiatives that can be implemented.

a) Ground operations

The airport plays a crucial role in ATM efficiency and has the potential to reduce delays, fuel consumption, and CO2 emissions significantly. To ensure that a balance is maintained between operational and environmental needs, it is imperative to analyze the use of the airport's assets (runways, stands, taxiways, tugs, etc.) to identify fuel and emissions savings. By introducing collaborative decision-making (CDM) processes, which integrate all airport data and share it with all stakeholders, technology can accelerate the continuous improvement of ATM as well as improving ground operations efficiency. CDM can also save fuel and emissions during departure, en-route, and arrival phases of flights. It is possible to absorb known delays by performing collaborative actions among airspace users, airport operators and ATM stakeholders rather than keeping aircraft in the air where they burn more fuel due to delay or inefficiency. Particular examples would be:

- Consider gate-holds instead of taxi-holds, if possible.
- Flight crews should be informed of pushbacks and departure delays at the departure gate/stand. By doing so, they will be able to use the most efficient form of ground power.
- The flight crew can safely and efficiently, upon notification in advance, shut down an engine(s) during taxiing, which reduces fuel consumption and may reduce taxiway congestion caused by late engine starts or checklist completions.

b) Departure operations

Flight departure is a crucial phase of the flight since aircraft are at their heaviest weight when taking off. This leads to higher fuel burning rates and emissions. Hence, any efforts to reduce inefficiency during this phase of flight, by minimizing the restrictions on the aircraft's climb-out to their cruising level, will lead to proportionally greater savings in fuel and emissions.

Increasing aviation demand results in increasingly complex airspace terms around airports. To manage this complexity, airspace design uses additional track miles and periods of level flight to ensure traffic flows are strategically de-conflicted. For this reason, aircraft climb in a series of steps separated by periods of level flight to avoid interference with arrival traffic flows and aircraft from other airports. Pilots must increase drag if they need to level off at low altitudes or climb at a speed below what is operationally efficient. In such settings, additional thrust is needed to maintain control, resulting in increased fuel consumption.

A possible ATM solution for the climb phase would be to ensure that an aircraft is able to climb continuously from the runway to cruise altitude. By designing the airspace in a way that strategically de-conflicts arrival and departure flows, it may be possible to achieve better performance in terms of continuous climb procedures, which in turn will lead to a reduction in fuel consumption.

A PBN departure route may be able to while reduce the number of flight track miles at lower altitudes while also optimizing the noise performance of departing aircraft. As a result, aircraft may be able to optimize their fuel uplift. Adding extra fuel to an aircraft can have a significant impact on its weight and therefore the efficiency of its fuel burn. Flight planning tools are increasingly designed to reduce the amount of fuel carried by airlines, and shorter performance-based navigation routes can reduce the amount of fuel carried.

c) En-route operations

Weight, range, meteorological conditions, and airspace characteristics affect aircraft cruise performance. On-board flight management systems can determine the most efficient cruise altitude and speed to minimize fuel consumption. Air traffic management can assist in this process by offering aircraft the cruise levels and speeds they request while en-route.

ATM may enable continuous descents and reduced required time of arrival (RTA) as aircraft approach the end of their en-route phase of flight (top of descent). In particular, these actions include:

- Allow cruise or stepped climbs at the pilot’s discretion where traffic permits;
- Approve higher altitudes when available and requested;
- Approve speed variances when requested;
- Cancel speed restrictions when no longer required;
- Offer direct or wind-optimized routes where available; and
- If a coordination mechanism is in place, offer direct routing through special-use airspace when not in use.

d) Arrival operations

Several opportunities exist for reducing fuel consumption and emissions during the descent phase through ATM facilitation, including delaying the aircraft’s descent from cruise, where fuel burn rates are optimal, and utilizing sophisticated arrivals management tools to optimize aircraft sequencing and flow so that holdings are minimized. In the descent phase, balancing emissions reduction, fuel consumption, and noise while expediting traffic and meeting airport capacities safely.

If any descent solutions are considered, it should be noted that inefficiencies introduced in another flight phase should not outweigh their potential savings. Such interdependencies include:

- between climbing and descending aircraft (e.g. interference with continuous climb operations);
- with other simultaneous descent operations; and
- with operations using adjacent airspace or airports.

Continuous descent operation, ideally from cruise flight levels, offers significant fuel savings, reduced emissions, quieter operations, and improved safety. The optimal vertical profile is a continuously descending path with minimum level flight segments that are only needed to decelerate and configure the aircraft or to establish the aircraft on the final approach segment. The configuration should be tailored to the aircraft's capabilities, with low engine thrust settings and, if possible, a low drag configuration. The execution of a continuous descent will be enabled by appropriate ATC clearances based on the airspace and procedure design.

The ATC should abstain from interfering with the lateral and vertical flight paths during the execution of a continuous descent. In case vectoring is unavoidable, providing the pilot with timely and accurate

distance-to-go information will facilitate the resumption or continuation of an optimum descent profile. It is estimated that a continuous descent can save 150 to 600 kilograms of CO_2 per arrival.
To minimize fuel consumption during descent, the following recommended actions should be considered:

- Offer speed control as far ahead as possible rather than radar vectoring in sequencing.
- "Path-stretching" in lieu of holding when feasible.
- Design PBN STARs for continuous descent.
- Allow pilot discretion descents when traffic permits, ideally at the top of the descent.
- avoided late descent clearances due to the fact that height energy must be dissipated through drag.
- Minimize holding at low altitude and provide pilots with realistic holding times.

The following considerations should be considered when landing:

- Provide advance taxi information to allow pilots to plan for fuel-saving techniques with respect to the landing roll;
- Publish coded taxi route instructions for efficient runway exit and reduced ATC radiotelephony;
- If possible assign the runway that is closest to the passenger terminal and minimizes taxi time; and
- Clear to vacate the runway via a high-speed taxiway.

4.2 Airplane operators

The purpose of this section is to discuss opportunities that can be taken to reduce fuel consumption and emissions during all phases of a flight. Optimization of the flight trajectory is the main element in efficiency enhancement.
In an ideal situation, when planning and operating a flight, the trajectory should be considered as a whole, since changes in one segment of the trajectory can impact the performance (e.g., fuel consumption) in other portions of that trajectory or limit the trajectory of other flights. A flight or phase of flight should not be optimized at the expense of another flight or phase.
Noise reduction and fuel burn and emissions reduction are interdependent near most airports. Often, environmental regulations need to accommodate these interdependencies when reducing fuel burn and emissions during climb and descent in airport proximity. As an example, noise preferential arrival and departure routes add track miles and therefore increase fuel use, whereas both CCOs and CDOs reduce fuel consumption and emissions.
When considering operational opportunities to reduce aircraft fuel consumption and emissions, the following general principles should be followed:

- Safety must not be affected negatively;
- Operational procedures must be certified and incorporated into daily operations;
- Actual flight procedures must be developed in accordance with the appropriate ICAO or regulatory guidance and manufacturer’s and operator’s capabilities;
- Proposals should be considered within the context of the entire flight trajectory and the trajectories of other flights;
- Consultation and/or collaboration with appropriate affected stakeholders should be part of the process from an early stage;
- Adverse or disproportionate trade-offs should be avoided to the extent possible;
- Opportunities to optimize the performance of the initiative through positive impacts other than fuel use and emissions (i.e. synergies) should be considered, such as flight safety, flight predictability and capacity;
- Appropriate assessment methods, tools, data and assumptions should be used.

a) Fuel reserves.

With fuel mass reaching as much as ten times the passenger mass, even a small decrease in the fuel carried will result in significant reductions in fuel burn. The additional mass of fuel carried per hour of flight can result in a total increase in hourly fuel burn of **2.5 to 4.5 percent** of the additional mass of fuel carried, depending on the aircraft type, mission length, flight profile, and speed. Therefore, reducing fuel consumption can be achieved by keeping fuel reserves to the safest minimum.
According to ICAO's Doc 9976, minimum fuel requirements include amounts to cover:

- Engine start, auxiliary power unit (APU) use and taxi out;
- Flying to the destination aerodrome and executing an approach and landing;
- Performing a missed approach and conducting an approach and landing at the nominated destination alternate aerodrome, if required;
- En-route contingency (discussed below);
- Final reserve fuel; and
- Additional fuel if required.

Contingency fuel for any unforeseen factors during the flight planning phase, should account for:

  - Unforecast meteorological conditions;
  - Unplanned or unanticipated routings, cruising levels and traffic delays; and
  - Other unexpected operational issues that could increase fuel consumption or delay.

b) Fuel Tankering

The purpose of fuel tankering is to carry fuel for subsequent flights, which airlines do for several reasons, including:

- operational reasons, for example where rapid turnaround is required or where the aircraft is required to complete several flight segments without adequate time for refueling.
- Fuel prices being significantly higher at the destination airport than the departure airport.
- Lack of availability of appropriate fuel; and
- Uncertainty about fuel quality at the destination airport.

When making decisions about tankering, aircraft operators should consider the full cost of carrying extra fuel. In addition, aircraft operators should monitor fuel prices frequently to ensure that any fuel price differentials still justify tankering.

c) Centre of gravity

Effective management of the aircraft's Center of Gravity (CG) can optimize fuel consumption along the flight. CG varies depending on the distribution of loads on each flight. As the center of gravity moves forward, the aircraft's fuel consumption increases due to the greater degree of downward force required from the tailplane/horizontal stabilizer, which must be counterbalanced by increased lift from the wings, thereby increasing induced drag (trim drag). When loaded to the most forward CG limit, an aircraft's drag can rise by up to 3% (source: IATA) compared to when loaded to the most rearward CG limit. In general, a more aft center of gravity will reduce drag and improve fuel efficiency. Center of gravity ranges are, however, limited by aircraft stability considerations. CG calculations must take into consideration the fact that burning fuel gradually reduces the weight carried and shifts the CG; an aircraft can take off with the CG in a position that allows full control yet later develop imbalances that exceed control authority.
CG can be expressed in terms of its impact on a specific range of fuel consumption. Depending on the type of aircraft, the effects may differ. In some types of aircraft, CG has a negligible effect on range. If a maximum forward CG is used at optimum altitude, specific range may decrease by up to 1.8 percent,

and a maximum aft CG may increase by up to 1.8 percent. Many aircraft have an automatic CG management system that optimizes the CG position in flight based on the aircraft's load distribution. CG can sometimes be moved closer to the optimum position by redistributing cargo or passengers. It is also possible to achieve a more efficient CG position by mounting a fuel tank in the tail (also known as trim tank). Trim tank transfer systems allow fuel to be transferred into and out of the trim tank during flight to maintain CG

d) Extended Diversion Time Operation (EDTOs)

Extended diversion time operations (EDTOs) provide the flexibility to fly more direct routes and take advantage of any beneficial en-route conditions, such as tailwinds. An EDTO, however, is subject to the maximum diversion time approved by the State of the Operator. In general, the longer the maximum diversion time, the greater the flexibility and therefore the potential for minimizing fuel consumption.

e) Punctuality monitoring and reporting

Internationally, punctuality performance is monitored and reported based on departure time and time an aircraft departs an airport gate. Consequently, airlines seeking to improve their punctuality key performance indicator (KPI) may request early or on-time pushback from the gate, even at times of heavy congestion on taxiways and runways. The practice will result in additional taxi and/or ground holding time with engines running, resulting in excess fuel consumption and emissions.

To achieve a balance between punctuality and environmental performance, regulators must consider the interaction between these two potentially competing objectives when setting their environmental and punctuality KPIs. Alternatively, punctuality should be measured in a way that doesn't lead to operational behaviors that increase fuel burn and emissions unnecessarily.

f) Fuel freezing point.

The trend to fly longer and higher altitudes has highlighted one limitation that may occasionally prevent flying in the most fuel-efficient manner: the need to maintain aircraft fuel above the freezing point. As a general rule, the temperature of the fuel in an aircraft tank is always well above the local ambient temperature. The freezing point of some jet aviation fuel (e.g., Jet A fuel) is –40°C, so instances can arise when cold-soaked fuel approaches these temperatures with typical atmospheric temperatures as low as –55°C. Consequently, the aircraft may fly at a lower altitude or at a higher speed to warm the fuel. In both cases, fuel consumption will be increased.

Certain airlines test samples of fuel prior to departure to determine the actual freezing point of the on-board fuel to reduce the fuel burn penalty associated with flying at less-than-optimum altitudes due to low temperatures. This information, along with operational considerations such as fuel temperature monitoring, is provided to the flight crew, allowing them to fly their aircraft at the most efficient altitude. A dedicated software program can also predict or avoid routes where low fuel temperatures could be a limitation.

g) Meteorological information

Real-time weather information and accurate forecasts enable efficient flight planning. These effects are particularly significant for ultra-long-haul flight planning. Forecasts must cover en-route winds as well as forecasts for destination and alternate airports at a given time, location, and altitude. It prevents "extra" fuel being loaded for unanticipated changes during the flight, which in turn reduces fuel consumption. Up linking of accurate real-time weather data in flight allows for optimal flight management, including selection of cruising altitude, cruise and descent speeds, and top-of-descent speed. The location of severe or hazardous meteorological conditions is critical for safe and efficient flight operations.

h) Aircraft engine and fuel monitoring

Monitoring aircraft and engines' performance is essential to minimizing fuel consumption and provides benefits that tend to reduce fuel carried and fuel used. Data analysis should be part of a closed-loop system that includes maintenance, engineering, flight performance, flight planning, and flight training. Leading to specific aircraft performance criteria being utilized operationally to improve safety and efficiency.

To provide flight crews with confidence, fuel monitoring and reporting should present flight performance statistics. Every flight, some airlines collect cruise performance data. In the flight planning system, the deviation from the nominal performance is calculated. Each aircraft has a unique deviation. In this way, contingency fuel may be reduced based on applicable regulations.

i) Minimum Equipment List/Configuration Deviation List (MEL/CDL) items

A further source of fuel consumption can be aircraft dispatched with permissible minimum equipment lists (MEL) or configuration deviation lists (CDL). There may be fuel, performance, and/or operational penalties associated with these defects.

- Fuel penalties: higher fuel consumption as a result of the increased drag or using non-standard systems.
- Performance penalties: restricted payload and cruising altitude.
- Operational penalties: non-compliance with area operational requirements for Communication, navigation, and surveillance (CNS), e.g. EDTO, RVSM, MNPS, PBN, and airborne collision avoidance systems (ACAS) may limit efficient flight planning.

Therefore, the longer the aircraft keeps flying without rectifying MEL and CDL defects, the more fuel it will burn. Flight time with outstanding MEL and CDL items that carry a direct or indirect fuel penalty should be minimized.

j) Single-engine taxiing

Taxiing operations are a significant source of energy consumption and emissions associated with aircraft. The taxiing phase of a flight is a relatively short part of the flight, but jet engines are not at their optimal use during this phase.

There are several measures that can be taken to reduce fuel consumption on the ground. An improvement would be to taxi with one (or several) engines shut down.

There is a wide range of estimated benefits associated with single-engine taxiing. Table 1 shows the fuel savings potential when taxiing with one engine off, depending on aircraft type.

Table 1: Potential fuel saving per aircraft type from taxiing with one engine off

Aircraft type	Saved fuel (kg/min)
A320	5
B737	5
E190	4
A330	10
B777	13

Source: SESAR

It is important to pay attention to the following points when taxiing with one engine off:

- Engine warm-up and cool-down times must be respected in addition to the fire hazard at departure.
- It is necessary to respect the maximum parameters of the running engine(s).
- Modifications in the aircraft's maneuverability and balance.

- It is not possible to perform this operation on certain taxiways, such as turns, slopes, cross-active runways, etc.
- It is not possible to perform this operation under certain conditions such as rain, winds, visibility, etc., and it is simply prohibited at certain airports.
- Due to the design of some aircraft's power systems architecture, this procedure can be difficult to perform.
- There is a greater workload associated with single-engine taxi-out at departure than with taxi-in at arrival, as the engine start procedure is conducted before taxi-out.

It is imperative that safety remains the ultimate consideration before performing the single engine taxiing procedure.

4.3 Aerodrome operators and ground service providers

This section provides an overview of opportunities through which airports can minimize fuel consumption and emissions from aircraft, ground support equipment (GSE) and ground transportation. These opportunities vary between airport infrastructure-related and ground service equipment-related.

a) Aerodrome design and facilities

It is possible to minimize the fuel consumption of aircraft and ground equipment by effectively designing the airport. Airport expansions are always a good chance to improve the airport design/layout and increase the overall operational efficiency. This process should consider the buildings’ layout, service stations, runways, taxiways, rapid exit taxiways, pavement, as well as other facilities related to capacity.

Examples of airport features that minimize fuel usage and emissions may include:

- An efficient runway, taxiway, and apron layout will minimize taxiing and congestion and facilitate more efficient ground movements (taxiway design, rapid exit taxiway location and design, aircraft passing/holding bays, etc.)
- Improve low visibility take-off and landing capabilities, to reduce congestion and delay, and reduce the need for diversions in adverse weather.
- Provide 400-Hz fixed electrical ground power (FEGP) and, where necessary, pre-conditioned air (PCA) at gates/maintenance areas and encourage their use. This measure will reduce or eliminate APU, GPU and air-conditioning unit usage. Typically requires substantial capital investment, but often realizes fuel/maintenance savings.

b) Ground support equipment.

"Ground support equipment" (GSE) refers to a wide range of vehicles and equipment that provide support services to aircraft, including those used to tow, maintain, load and unload passengers and cargo as well as provide electric power and fuel.

GSE emissions can be significantly reduced through the following mitigation options:

- Improve GSE operations by reducing driving distances through route planning and avoiding unnecessary idling of equipment in order to reduce fuel consumption.
- Retrofit of GSE engines, including the retrofit of gasoline engines with catalysts, as well as the reduction of Sulphur content in diesel fuel, is recommended.
- Replace uncontrolled gasoline and diesel engines with fuel-injected gasoline engines equipped with a 3-way catalyst or with new diesel engines equipped with a computer-controlled fuel delivery system, turbocharging, intercooling and timing retardation.
- Use electric GSE to achieve reduction of up to 100 percent in scope 1 emissions, but substantial investments in infrastructure may be required. Safety and reliability issues must be addressed in such improvements.

- Ensure the provision of fixed electrical ground power (FEGP) at gates/maintenance areas and, where necessary, pre-conditioned air (PCA) to eliminate or reduce the use of APUs, GPUs, and air conditioning units. In most cases, however, a substantial capital investment is required, but it often results in fuel and maintenance savings.

The implementation of a particular technology or measure may be limited by site-specific conditions. Therefore, airport operators and ground service providers should assess these measures on a case-by-case basis.

4.4 Maintenance

As an airframe or engine ages, aerodynamic and performance deterioration will lead to an increase in fuel burn and emissions. It is estimated that the drag of an aircraft can increase by up to two percent over the course of five years (Airbus, Getting Hands-on Experience with Aerodynamic Deterioration — A Performance Audit View, Issue 2, 2001).

The engine and airframe are designed for performance retention, and original performance is restored largely during overhauls, but continuous monitoring and regular maintenance are very important in detecting and correcting performance degradation. It is imperative to pay attention to the items highlighted in this section to prevent fuel consumption from increasing unnecessarily.

This section will discuss aircraft performance and engine trend monitoring, airframe maintenance and aerodynamic deterioration and engine maintenance and performance deterioration.

a) Aircraft performance and engine trend monitoring

An aircraft performance monitoring (APM) program provides valuable information regarding the degradation of aircraft fuel burn performance over time. The information provided in this section can assist the aircraft operator in identifying areas in which remedial actions can be taken. An aircraft's APM compares its cruise performance with the baseline aircraft performance, which is the performance specified when the aircraft is delivered new. The entire aircraft is monitored, including the airframe, engine, and systems. ACARS (Aircraft Communications Addressing and Reporting System) data can be processed using specialized APM software. Fuel burn deterioration can be predicted to some extent by APM software using aerodynamic and engine performance data.

APM results are used to update the operator's flight planning system and the aircraft's flight management computer system. For aircraft with higher-than-normal fuel burn deterioration, the APM results can also be used to trigger an aerodynamic inspection by the operator's maintenance department.

An engine trend monitoring system is used to determine the health and performance of an engine based on data collected from engine condition sensors. Maintenance can identify trends in engine performance, such as anomalously high fuel burn, by analyzing the data.

b) Airframe maintenance and aerodynamic deterioration

Poor airframe condition results in some of the greatest penalties in terms of excessive fuel consumption. The penalties differ according to location and extent, with different parts of the airframe more sensitive to changes in aerodynamic shape or smoothness. The following is an example of a zonal classification for drag sensitivity:

- Zone 1: High smooth aerodynamics are essential. It encompasses the forward fuselage, the engine cowl and pylon, the top wing from the leading edge to the spoiler (approximately half chord), the lower wing over its entire slat surface, as well as both stabilizer surfaces, including the rudder and elevator. Surface profile and rigging tolerance deviations in this zone can result in significant drag increases and adversely affect the aircraft's stability, controllability, and safety margin.

- Zone 2: Good smooth aerodynamics are essential. Consists of the center fuselage and the wings, empennage, and engines not included in Zone 1. Drag and fuel consumption can be increased by deviations in surface profile here.
- Zone 3: Normal smooth aerodynamics are essential. The aft fuselage is covered by this zone. A deviation in surface profile in this zone increases drag and fuel consumption, but the actual increase is small.

c) Engine maintenance and performance deterioration

Modern engines incorporate features that provide long-term clearance control, leakage control, and erosion resistance.

The main cause of deteriorating specific fuel consumption (SFC) in modern turbofan engines is erosion, which changes airfoil contours and surface finishes. Increased radial clearances between blades and vanes, as well as increased clearances between rotating and stationary seals, can also lead to performance loss. Figure 1 illustrates how each of these factors contributes to engine deterioration.

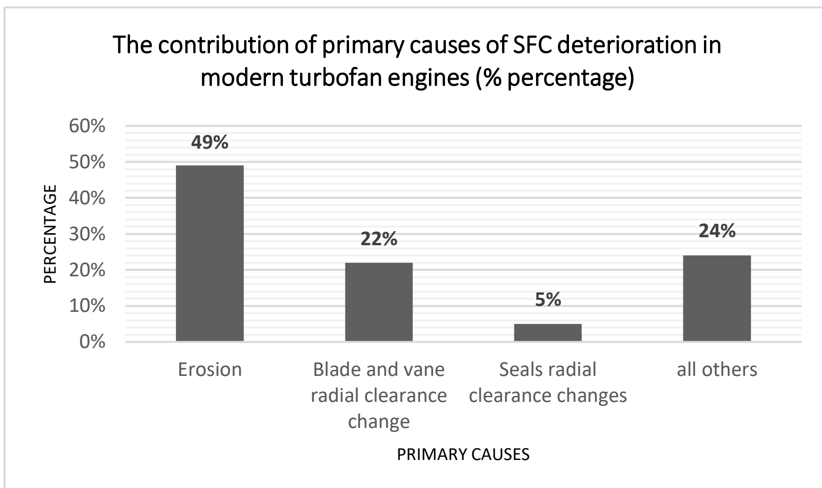

Figure 1: primary causes of SFC deterioration in a modern turbofan engine

5. Conclusion

Collaboration and coordination between different stakeholders are essential for achieving optimal results and implementing operational measures efficiently. It may be particularly important when resolving issues related to the interdependence among the different effects of operational measures.

Many of the operational procedures presented depend on factors other than environmental considerations. Safety is the most significant consideration in civil aviation operations, and the operator, along with the crew, is the ultimate judge of what can be done to minimize fuel consumption while maintaining the necessary safety requirements.

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