ICAO Standards and Recommended Practices: Annex 16, Volume II

By ICAO Secretariat

Since the late 1970s, the International Civil Aviation Organization (ICAO) has been developing measures to address emissions from aircraft engines in the vicinity of airports and from relevant airport sources. The objective is to attain a primary environmental goal "to limit or reduce the impact of aviation emissions on local air quality (LAQ)". Relevant Standards and Recommended Practices (SARPs) are contained in Annex 16 — *Environmental Protection*, Volume II — *Aircraft Engine Emissions*, and technical guidance is provided in the Environmental Technical Manual (Doc 9501), Volume II — *Procedures for the Emissions Certification of Aircraft Engines*, and other technical documentation. Provisions on LAQ deal with liquid fuel venting, smoke, non-volatile particulate matter (nvPM) and the main gaseous exhaust emissions from jet engines, namely: hydrocarbons (HC), oxides of nitrogen (NOx), carbon monoxide (CO).

Engine emission certification

The engine certification process is based on the aircraft's landing and take-off (LTO) cycle, which consists of four operating modes with characteristic thrust settings and time-in-modes, as shown in Figure 1. This LTO cycle is procedurally similar to the aircraft engine operating modes in the airport vicinities, and is performed by the engine installed on a test bed. For each thrust setting, pollutant emissions are measured in line with Annex 16, Volume II. This certification data is collected and stored in ICAO's publically available engine emissions databank[1].

SARPs Maintenance

During the last three years, the global pandemic affected the aviation sector worldwide in an unprecedented manner. Nevertheless, ICAO Committee on Aviation Environmental

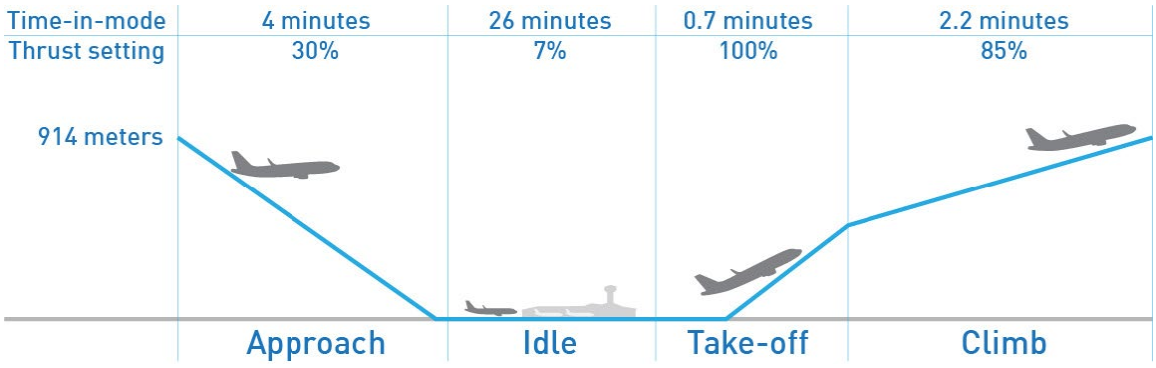

FIGURE 1: ICAO engine emission certification LTO cycle.

1 https://www.easa.europa.eu/easa-and-you/environment/icao-aircraft-engine-emissions-databank

Protection (CAEP) continued conducting its work in a non-disruptive mode, and, amongst other, completed under the environmental Standards and Recommended Practices (SARPs) maintenance task an extensive exercise on restructuring Annex 16, Volume II in accordance with ICAO Doc 8143 — *Directives to Divisional-type Air Navigation Meetings and Rules of Procedure for their Conduct*, Part II — *Formulation of Proposals for International Standards, Recommended Practices and Procedures*. The relevant sections of this Volume were either introduced as the new paragraphs of the Appendices or formed the new Attachments to the Annex 16, Volume II, depending on their contents. The work on Aircraft Engine Emissions SARPs also included language updates, consistency check across all the Annex 16 volumes, ensuring the validity of the technical basis underpinning the Standards and an overview of the current state of the science regarding LAQ.

New nvPM Mass and Number Standards

At the aircraft engine exhaust, particulate matter emissions mainly consist of ultrafine soot emissions. They are present at high temperatures at the engine exhaust, and are preserved as they mix and dilute with the ambient air. These particles are invisible to the human eye and are ultrafine; their mean diameter is much smaller than 2.5 microns (μm) (Figure 2). Gaseous emissions from engines can also condense to produce new particles, coat the emitted soot particles, and react chemically to produce secondary particulate matter.

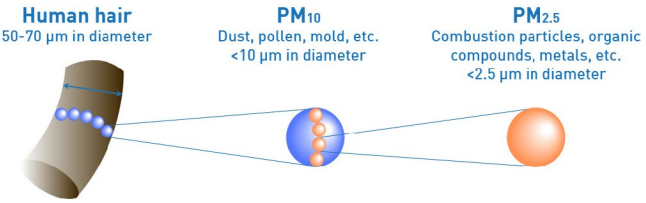

FIGURE 2: Comparison of particle sizes from various sources.

The first nvPM mass concentration Standard was adopted by ICAO in 2017. An important component of this Standard was the mandatory reporting of health and climate-relevant nvPM emissions measured during the certification process for in-production engines. This data was then used to set future regulatory limits.

In March 2020, ICAO adopted new Standards for nvPM mass and number, which were the culmination of six years of efforts. The new nvPM Standards will apply to new type and in-production engines with rated thrust greater than 26.7 kN. The limits for nvPM mass and number will provide some alleviation for engines with rated thrusts below 150 kN. These Standards are less stringent for engines in production, and a supplementary "no-backsliding" measure prevents less nvPM-efficient technologies from re-entering aircraft fleets.

Additionally, extensive calculations have been performed to ensure that the nvPM mass Standards maintain the limits for engine exhaust smoke number contained in Annex 16, Volume II. In March 2020, ICAO also set an end date for the Smoke Number (SN) Standard for engines with rated thrust greater than 26.7 kN.

This milestone achievement on nvPM SARPs completed a suite of environmental Standards for the certification of aircraft and engines, namely, for noise, LAQ and CO_2, making the aviation industry the only sector with mandatory global environmental certification requirements for the operation of equipment. As of 1 January 2023, all new aircraft will have to meet the Standards in order to be certified and enter operation.

Innovations in Aviation Technology Improving LAQ

The extensive ICAO Stocktaking process showcased and demonstrated multiple technologies improving fuel efficiency and hence mitigating aviation impact on LAQ. The incremental improvements in the convenient tube-and-wing aircraft designs are made in various elements of the aircraft. For propulsion systems, the improvements in contemporary turbofan combustion engines are focused on increasing efficiency of all elements of the engines, including thermal management and low-emission combustors, while the propeller-driven layouts are being advanced as well. The engine manufacturers are also advancing on maximum Sustainable Aviation Fuel (SAF) compatibility for their products, of which during implementation decreases the nvPM emissions.

In regards to the aerodynamics and airframe, lighter and more reliable materials in combination with the structural upgrades using additive manufacturing in production result in decreased airframe weights. The aircraft manufacturers also investigate measures to minimize airframe drag using various technologies, such as, implementation of the laminar flow fuselage, or the transonic truss-braced wings.

More challenging novel aircraft concepts are being designed to meet the unprecedented fuel and therefore emission reduction benefits. Amongst these projects are: the flying wing aircraft, hybrid and electric-powered airships, cryogenic hydrogen-based and liquefied natural gas-powered transport.

Consideration of the new paradigm of routing allows early introduction of the novel concepts such as the short-range small hybrid, electric or hydrogen-powered aeroplanes, and the E-VTOL projects. These aircraft types allow zero-emission flights, but need scaling-up for pertinent contribution to the emissions reduction. All new aircraft technological solutions and concepts require corresponding certification procedures to ensure their entry into market.

Updates to ICAO Doc 9889

ICAO is continuously updating its *Airport Air Quality Manual* (ICAO Doc 9889), which focuses on the estimation of emissions from airport operations, specifically aircraft combustion engines. Other considered sources of airport emissions include ground service vehicles and airside ground transportation, as well as de-icing and refueling operations, which produce evaporative emissions of non-volatile organic compounds.

The latest edition of ICAO Doc 9889 contains methods to estimate the nvPM emissions more accurately from aircraft engines and aircraft handling operations. Data that had been collected during the Standard-setting process were used to develop improved methods for estimating nvPM mass emissions and the first method for estimating nvPM number. In the long term, these methods can also be used when nvPM measurement data cannot be obtained during certification, for example, for engines that are no longer in production but still in operation.

Future Work

The future work on LAQ related issues embraces a vast majority of topics and directions. Despite the current circumstances, ICAO continues to develop measures aimed at mitigating the impact of aviation on LAQ, by developing Standards, guidance material, and technical documents. This includes the maintenance of Annex 16, all volumes of ICAO Doc 9501, the ICAO engine emissions databank.

ICAO will continue to monitor and review developments in combustion technologies and engine combustor design, including the results from Combustion Technology Review Workshop planned for the new ICAO Assembly Triennium, to better understand how new technologies can affect gaseous and nvPM emissions in the future. ICAO will also further monitor trends in aviation fuels, including fuel composition and sustainable aviation fuels, since synthetic fuels with low aromatics content can help to reduce nvPM mass and number emissions at low thrust conditions.

During the ICAO Committee on Aviation Environmental Protection (CAEP/13) cycle, it is also planned to assess the existing NOx and nvPM LTO metrics for relevance to modern engine designs and to full flight emissions, and to explore other metric systems that will ensure improvements in aircraft engine emissions in airport and cruise operation. With this regard, ICAO will conduct a scoping study on a possible integrated standard setting process that could be undertaken later in the CAEP/14 cycle for NOx and nvPM emissions.

ICAO remains fully committed under its strategic objectives to reduce aviation's environmental impacts and achieve the United Nations Sustainable Development Goal 3 – *Ensure healthy lives and promote well-being for all at all ages,* by mitigating aviation's adverse effects on human health across the globe. The environmental work programme for the coming three years ensures that ICAO's leadership in this area will be accelerated with a high pace.