SUSTAINABLE AVIATION FUELS FOR HELICOPTERS: CHALLENGES, OPPORTUNITIES, WAY FORWARD

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Abstract

Reduction of CO_2 emissions is key in limiting the effect of climate change and Sustainable Aviation Fuel (SAF) is one of the major enablers to achieve the challenging targets of the aeronautical industry. Since the use of blended SAF with conventional JET A-1 is already approved at a ratio of up to 50%, it is necessary to look ahead to understand how to make daily 100% SAF flight possible. Both drop-in and non drop-in pathways can be envisaged. The latter offers additional opportunities, like reduction of non CO_2 emissions, but also presents additional challenges. A first flight on a H225 helicopter using 100% HEFA fuel on one engine was performed in November 2021 followed by a second flight in May 2022 using 100% SAF on both engines. Preliminary findings indicate that even if the overall behavior was found acceptable, and that no immediate detrimental effect of the 100% HEFA fuel was observed, some differences in the engine gas turbine temperature dynamics during starting phases, or in the helicopter gauging system were identified. Some were expected due to the fuel characteristic differences, others were not and will need further investigations. In addition, mid and long term impacts of a daily usage of 100% SAF need to be further assessed. Airbus Helicopters already identified several topics among which are engine operation, gauging systems, material compatibility, fuel flammability and volatility, or flame characteristics. Airbus Helicopters' roadmap to achieve 100% SAF by the end of the decade does not privilege any solution and considers both drop-in and non drop-in pathways. For the first one, activities are centered on the work performed by the existing ASTM task force while for the second one, synergies within Airbus Group will be used to further investigate on the main topics identified previously.

1. INTRODUCTION

Reduction of CO_2 emissions is key to fight climate change. Sustainable Aviation Fuels (SAF) can reduce CO_2 emissions significantly, without major impact on the aircraft design or the infrastructure.
Helicopters from Airbus are already capable of using SAF at a blend ratio up to 50% with conventional JET A-1. To further reduce CO_2 emissions, Airbus Helicopters investigates the necessary steps to make our helicopters capable of using SAF up to 100%.
This paper presents the achievements already made as well as the challenges and opportunities with respect to 100% SAF usage on helicopters from Airbus.

2. SUSTAINABLE AVIATION FUELS

Fuels produced from non-conventional sources are called synthetic fuels or synthesized fuels. However, not all of these synthetic fuels are sustainable. Synthetic fuels can be derived from coal or natural gas via the Fischer-Tropsch synthesis, which is then not at all sustainable, as both sources (coal and natural gas) are fossil and the CO_2 emitted by such synthetic fuels is increasing the climate impact.

Sustainable Aviation Fuels (SAF) are synthetic fuels produced from non-fossil sources in a sustainable manner (not in competition with food industry, sustainable land and water use, …). The CO_2 which is emitted when SAF is burned in an engine, was extracted from the atmosphere shortly before. By this, SAF can reduce the climate-impact of their CO_2 emissions (net CO_2 emissions) by currently up to 90% depending on the type of SAF and the production process.

2.1. Already approved SAF-blends

Seven different production pathways for synthetic fuels are currently approved in ASTM D7566 [1], not all of them being sustainable (see previous chapter). For the moment, these approved SAF still must be blended with conventional fossil kerosene to fulfill the JET A-1 specification (maximum blend ratio is 50% SAF for most of the pathways). This blended SAF is then recertified as normal JET A-1 according to ASTM D1655 [2] or DEF-STAN 91-091 [3] and can be used on all existing helicopters for which JET A-1 according to these specifications is an approved fuel. All helicopters from Airbus therefore can already use these SAF blends.

Airbus Helicopters and operators flying with helicopters from Airbus have already used blended SAF on their helicopters and demonstrated that there are no differences to the use of conventional JET A-1. Regular use of blended SAF is now being started by some operators as well as by Airbus Helicopters for their flight operations in Donauwoerth and Marignane and therefore already allow to reduce the CO_2 footprint.

Fig.1: H145 from ADAC using SAF-blend (June 2021)

Due to the limited blend ratio of max. 50%, the net CO_2 reduction of blended SAF is currently limited to max. 45%. Also the max. achievable blend ratio of currently available SAF-blends is more in the range of 30-40% to make sure that the final blend is within the specification. This further reduces the possible net CO_2 reduction of the current blended SAF.

2.2. 100% SAF

To overcome the limitations of blended SAF, Airbus has started to investigate the use of 100% SAF on their aircraft and helicopters.
Such 100% SAF will most probably not match the current JET A-1 specifications, mainly due to the low aromatics content and the related low density of 100% SAF. Both characteristics are far below the current limits in the JET A-1 specifications for most of the currently approved pathways.

2.2.1. Aromatic Content

Most 100% SAF (e.g. FT, HEFA, ATJ) contain only a low amount or even no aromatics, whereas conventional JET A-1 normally has an aromatic content of 10% to max. 25% allowed by the fuel specification ASTM D1655 (see figure 2).

ASTM D7566 [1] requires a minimum aromatic content of 8% for the final SAF-blend in order to keep the blend similar to conventional JET A-1, whereas the max. allowed aromatic content for most of the pure SAF components itself (e.g. FT, HEFA, ATJ) is only 0,5%.

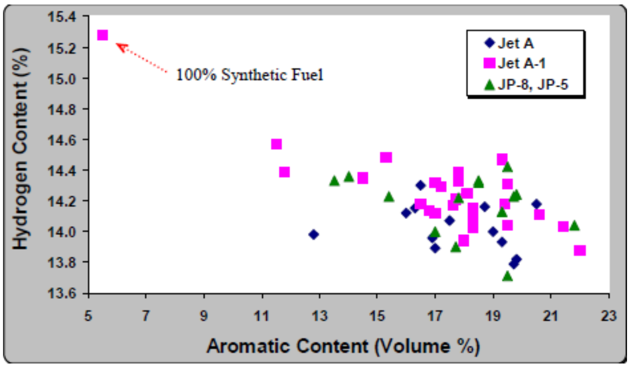

Fig.2: Aromatics Content of different Fuels (CRC Report 647 [4])

Aromatics are important for the behavior of elastomeric materials (seals, o-rings, rubber hoses, tank liners, ...) The absence of aromatics may have detrimental long-term effects on these materials.

2.2.2. Density

Due to the missing aromatics, the density of most 100% SAF is much lower than for conventional JET A-1. The JET A-1 specifications [2][3] require a minimum density of 775kg/m^3 @ 15°C, whereas the density of a pure FT, HEFA or ATJ component is just 730-770kg/m^3 according to ASTM D7566 [1]. Low density may have an impact on the fuel quantity indication system and would reduce the maximum range of the helicopter as lower density means less fuel mass for a given maximum volumetric capacity of the fuel tanks.

2.2.3. Other Characteristics

Other fuel characteristics like sulfur content, dielectric constant, viscosity, water and air lubricity etc. can also be different for a 100% SAF compared to a “normal” JET A-1 and may have an impact on the performance of the helicopter fuel system or engine.

2.2.4. 100% SAF Specification

There is no specification available yet for a 100% SAF. This is another topic to be looked at and where the OEMs can actively influence how such fuel will look like. There are two possible directions for a 100% SAF:

- A drop-in fuel, which is defined to be within the existing JET A-1 specification. Such a fuel would require some aromatic and sulfur content and would therefore not be as "clean" as a 100% SAF without aromatics and sulfur.

- A new fuel specification which is different from the current JET A-1 and would then allow a SAF fuel without aromatics and sulfur. This, however, may require design changes on the helicopter fuel system or the engine and may therefore not be usable on all existing helicopters.
  Airbus has started to work on such a new fuel specification within the ASTM.

As the global fuel consumption of helicopters is negligibly small compared to fixed-wing transport aircraft, the helicopter industry cannot really influence the decision whether there will be a “drop-in” or a new specification for 100% SAF. This decision is mainly driven by transport aircraft OEMs, airlines, government regulations and the oil industry.

Airbus Helicopters follows the evolution of 100% SAF to prepare our helicopters for the future.

2.2.5. Why 100% SAF?

Apart from the net CO_2 reduction, a 100% SAF fuel without aromatics and sulfur can have other positive effects:

The absence of aromatics leads to a reduction of soot particle emissions. For transport aircraft, flying at high altitudes, the reduction of soot particles can reduce the formation of contrails, which contribute to the climate impact. First test results from Airbus on an A350 powered with 100% SAF have shown positive results in this direction [7].

For helicopters the formation of contrails is not of importance. However, the reduction of soot particle emissions can also have a positive effect on local air quality. In addition, a 100% SAF without sulfur will reduce SOx emissions. It is known that non-CO_2 emissions like soot and SOx have negative impacts on health (e.g. respiratory / cardiovascular symptoms) as well as on the environment (e.g. acid rain, visibility reduction). A reduction of such emissions is particularly interesting for helicopters which are flying at low altitude over cities (e.g. EMS and police helicopters). This is another advantage of 100% SAF without aromatics and sulfur.

The energy content of certain 100% SAF is higher than for conventional JET A-1, which can partly counterbalance the lower density with respect to range and endurance. This, however, would require new gauging technologies to allow to utilize this advantage.

2.2.6. 100% SAF Achievements at Airbus Helicopters

On 9th Nov. 2021 an Airbus H225 performed the first ever helicopter flight with 100% sustainable aviation fuel (SAF) powering one of the SAFRAN Makila 2 engines. The helicopter flew with 100% SAF (HEFA) from Total Energies derived from used cooking oil, which reduces the net CO_2 emissions by 90% compared to conventional JET A-1.

The next step was a flight with the Airbus H225 with 100% SAF on both Safran Makila 2 engines in May 2022. This flight was the first ever helicopter flight powered completely by 100% SAF.

Fig.3: H225 in flight powered by 100% SAF

The flights were carried out by the flight test team of Airbus Helicopters under Permit to Flight (PtF) conditions. PtF clearance activities included an impact assessment of 100% HEFA on the fuel system operation, material compatibility, a safety assessment and a flight clearance from the engine manufacturer SAFRAN.

During both test flights, the helicopter and engine dynamic behavior as well as performances were observed. The fuel gauging system accuracy was assessed as well.

All details are presented and discussed in the following chapter.

3. H225 FLIGHT TEST RESULTS

During the first 100% SAF flight test campaign in November 2021, two flights were performed for a total flight time of 2 hours and 15 minutes.

The first flight was performed with both engines fed with conventional JET A-1 while on the second flight, the left engine (i.e. engine 1) was fed with 100% HEFA fuel and the right one (i.e. engine 2) still with conventional JET A-1.

3.1. Engine Performance

The same tests were performed during both flights and aimed at checking the overall engine performances to identify any possible unusual behavior that could result from the usage of 100% HEFA fuel.

Several flight phases were performed to cover most of the operational range of the helicopter. The following ones are presented here after:

- Engine start on ground
- Engine start in altitude
- Collective pitch maneuvers
- Level flight
- Engine power check

Each time, a comparison of some of the engine parameters is proposed. For each graph, the following color coding is used for engine parameters:

	100% JET A-1	100% HEFA
Engine 1		
Engine 2		Not Applicable

Table 1: Engine parameters graphs legend

3.1.1. Engine Start on Ground

Engine starting procedure requires a close monitoring of the engine parameters by the helicopter crew in order to ensure they remain within the acceptable range defined by the engine manufacturer. It is therefore necessary to ensure that the use of 100% SAF will not significantly change the engine temperature (i.e. T4), gas generator speed (i.e. N1) and power turbine speed (i.e. N2) parameters dynamics during the acceleration phase while its T4 temperature remains within its acceptable limit.

The following curves are for a second engine start, meaning that the other engine is already running when this engine is started. When looking at the different engine parameters in figure 4 below, one can see some differences between both situations, nevertheless, the overall engine temperature limit (i.e. top black line) is not exceeded regardless of the fuel used.

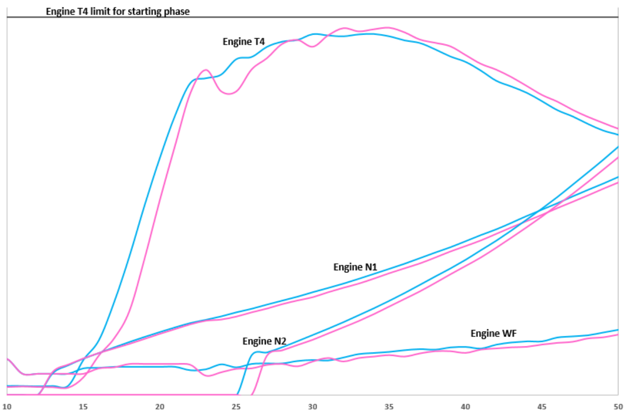

Fig.4 – Engine parameters evolution during starting phase

Indeed, although the temperature profile remains similar, one can see that there is a change in the profile dynamic during the initial temperature increase phase. This seems to be linked to the slower temperature increase in the first moment of the engine starting phase that is compensated at some point by an engine fuel flow (i.e. WF parameter) increase. In turns this leads to the T4 temperature increasing more rapidly while approaching the temperature limit when the engine is fueled with 100% HEFA. This finally induces a strong fuel flow correction conducting to a stronger T4 correction than with a JET A-1 configuration. The remaining temperature curve profile is then similar until the end of the starting phase.

The gas generator and power turbine speeds profiles are very similar. The only difference is the delay in the N2 speed increase when the engine is fed with 100% HEFA fuel. This phenomena can be explained by the difference in the N1 curve shape seen around 23 seconds, itself being the consequence of the fuel flow decreases done by the engine control system to limit the engine T4 temperature with 100% HEFA fuel as discussed above.

This behavior was not reported by the helicopter crew as being a concern. It nevertheless needs to be further addressed with the engine manufacturer to assess the potential long term effects on the engine.

3.1.2. Engine Restart in Flight

There are two objectives of this test sequence. First, it is a complement to the previous ground starting phase discussed above. This allows having an additional reference point to check the altitude effects on the previously observed behavior. For convenience reason, the altitude starting behavior was in fact checked by in flight restarting at 5000 and 10000 ft. This is considered reasonable for a first approach as the test performed allowed the engine to be completely shut down (i.e. until its gas generator speed dropped to a no speed situation). Thus, from this point of view, there is no difference between the in-flight and the ground situations. One could however argue that the initial engine temperature was higher than in the case of a cold start situation. However, this is considered acceptable compared to a first ground start in which the engine would be soaked at the ambient temperature.

The second objective of this test is to check the engine restart capability in flight as required by rotorcraft regulation in §903 of either CS27 or CS29. This allows ensuring an engine can be restarted after an engine flameout for example. This is, indeed, an interesting condition to consider for the flight tests sequence as it was not performed by the engine manufacturer. Indeed, this would have required a dedicated test in an altitude test chamber which was not possible in the time frame prior to the flight tests activities

The following figure presents the same engine parameters as for the ground start sequence discussed just above.

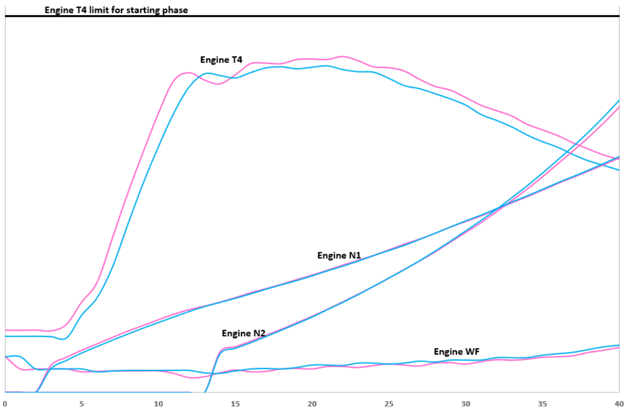

Fig.5 – Engine parameters evolution during starting phase at 10000 ft

One can see that the overall behavior is identical to the ground start sequence. Indeed, the engine T4 temperature dynamic seems again to be impacted by the use of 100% HEFA fuel even if the first oscillation amplitude is smaller than during the ground start. N1 and N2 profiles are, as expected from previous discussion, similar. The power turbine speeds N2 rise in a synchronous manner as, this time, there is an overlap of the N1 values in both cases. This difference in behavior would have to be further investigated.

Further transient phases were then tested with the engine delivering power to the helicopter main gearbox. Indeed, during the previous starting sequences, the considered engine is actually not providing power to the main rotor as the other engine is always on.

For the next test sequences, several typical maneuvers usually performed in the frame of the helicopter operability demonstration during the helicopter certification demonstration (CS27 and CS29 §939(a)) were repeated with an engine fed either with conventional JET A-1 or with 100% HEFA fuel.

3.1.3. Collective Pitch Increase on Ground for HIGE

For this twin engine configuration, we will compare different engines on the same flight, while previously we were comparing the same engine on different flights. The objective is to check there is no significant difference during this transient phase between the engine fed with 100% HEFA fuel from the one fed with conventional JET A-1. Most importantly, the engines should neither surge nor flameout.

The maneuver presented in this section is a quick and significant collective pitch increase while the helicopter is operated in a HIGE condition. Figure 6 below presents the actual collective pitch movement performed by the pilot.

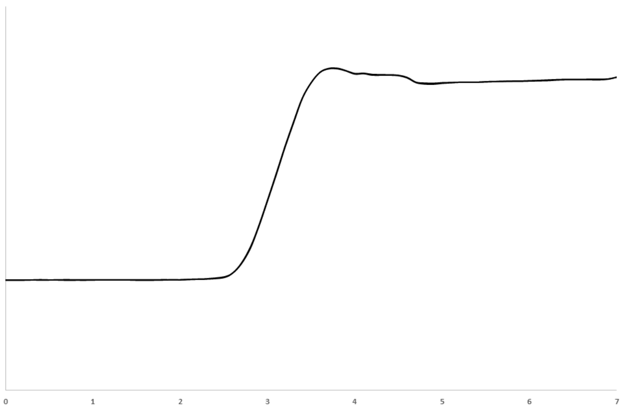

Fig.6 – Collective pitch (XPC) increase in HIGE condition

Considering the following engine parameters:

- Engine temperature T4 (figure 7)
- Engine gas generator speed N1 (figure 8)
- Engine output shaft delivered torque TQ (figure 9)
- Engine output shaft speed N2 (figure 10)

It clearly appears that there is no significant difference between both engines while they are fed with different fuels.

For the engine operated with 100% HEFA, as shown in the figure 7 below, the temperature increase, during the maneuvers, is slightly faster and higher than for the one fed with JET A-1. However, it remains well within its normal range of operation below the maximum transient temperature limit. In any case, a similar difference on the temperature parameter between engine 1 and engine 2 is also present for a similar maneuver when both engines are fed with JET A-1.

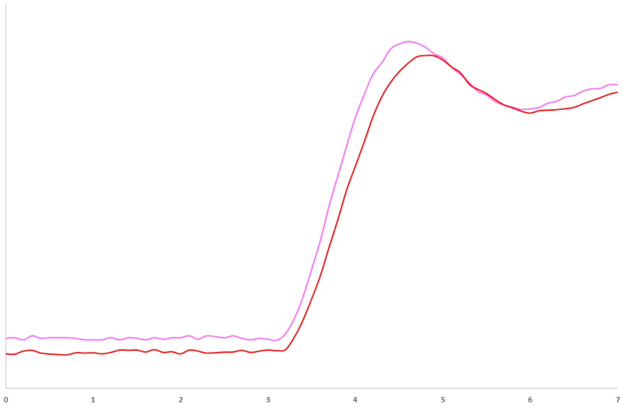

Fig.7 – Engine temperature (T4) evolution during XPC increase in HIGE

The engine gas generator speeds are also well aligned during and after the maneuver regardless of the type of fuel considered. So here again, there is no noticeable effect linked to the fuel used.

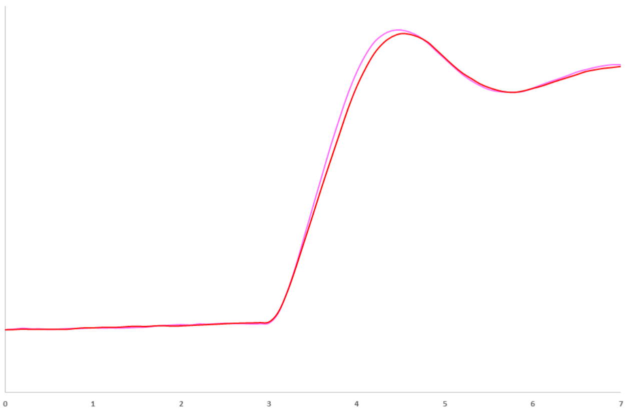

Fig.8 – Engine gas generator speed (N1) evolution during XPC increase in HIGE

As far as the torques are concerned, just as the T4 temperature parameter, there is a slight difference between both engines but the overall behavior remains the same. One should also keep in mind that there is no engine torque matching function for this aircraft, thus torque overlapping between both engines is not to be considered as a criteria. Furthermore, similar differences can be seen when both engines are fed with JET A-1. Thus, this effect is not linked with the use of the HEFA fuel.
The torque delivered by the engines to the aircraft rotor can be considered as not being impacted by the type of fuel.

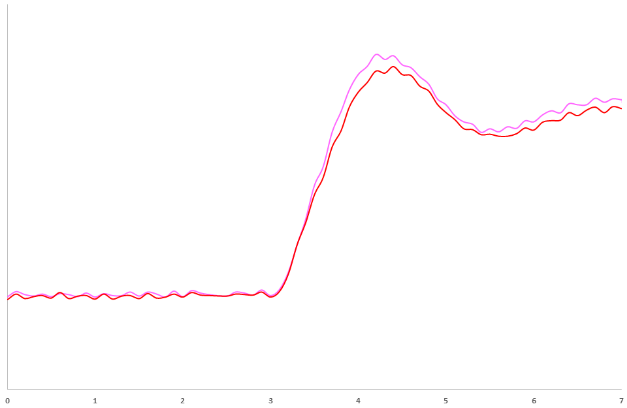

Fig.9 – Engine output shaft torque (TQ) evolution during XPC increase in HIGE

Finally, looking at figure 10 here under, the engine output shaft speeds, even more than the gas generator speeds, are again very well aligned. It is therefore clearly demonstrated that there is no effect on engine output shaft speed when the engine is fed with 100% HEFA.

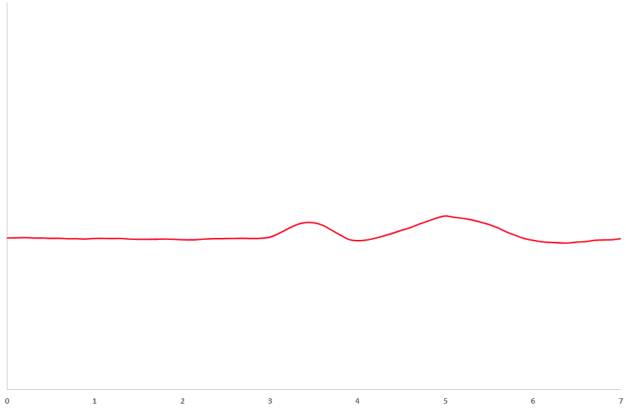

Fig.10 – Engine output speed (N2) evolution during XPC increase in HIGE

As a conclusion for these specific maneuvers, there is no effect on either engine or helicopter behavior to be expected when using 100% HEFA fuel. Furthermore, neither engine flameout, nor engine surge were encountered, thus not questioning, at this stage, the compliance to §939(a) of the regulation.

This first encouraging conclusion shall be confirmed on complementary transient maneuvers. For this, additional checks were performed in altitude and are discussed in the next section.

3.1.4. Collective Pitch Increase and Decrease in Altitude

Additional collective pitch maneuvers were performed during the flight tests in order to further assess the engine dynamic behavior when fed with 100% SAF. This time both collective pitch increases and decreases were performed in the following conditions:

Altitude (ft)	Maneuver	Duration (s)
5000	XPC increase	2
5000	XPC decrease	4
10000	XPC increase	4,5
10000	XPC decrease	4,5

Table 2 – Typical XPC maneuvers performed during altitude flight tests

All tests performed show similar conclusions to the one from the HIGE maneuvers detailed above. There is no significant difference between the engine fed with JET A-1 and the one fed with 100% HEFA fuel.

The same way as previously, during all the different maneuvers performed in altitude, there was no engine surge nor engine flameout.

The overall helicopter behavior remained unchanged compared to a situation in which both engines were operated with conventional kerosene.

3.1.5. Level Flight Phase

Having looked at different unsteady behavior (i.e. starting, collective pitch maneuvers), it seems reasonable to have a check on a more steady state flight condition.

For this, the following figure 11 presents, all at once, the main engine parameters and the helicopter TAS during a level flight phase at 5000 ft for which engine 1 is fed with 100% HEFA fuel.

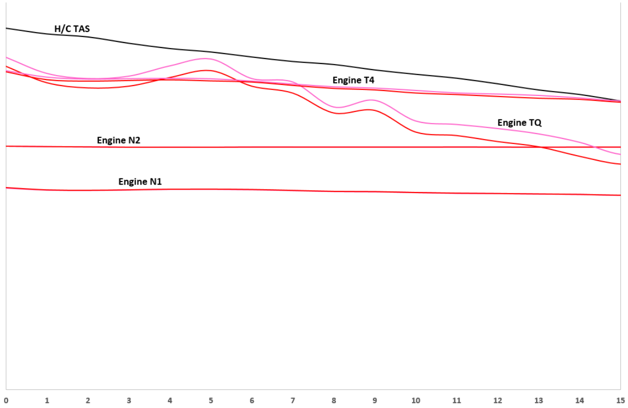

Fig.11 – Level flight phase at 5000 ft with one engine fed with SAF

This can be compared with the figure 12 below presenting a similar configuration but for which both engines were fed with conventional JET A-1 fuel.

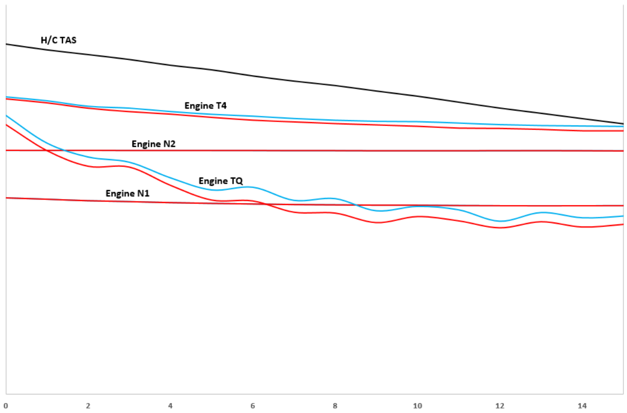

Fig.12 – Level flight phase at 5000 ft with both engines fed with conventional JET A-1

This shows that engine parameters profiles are not significantly impacted by the fuel used. Indeed, both engines' T4 temperatures are very close with engine 1 always slightly above engine 2. Engine torques show a gap (as already discussed previously) with, as for temperature, engine 1 always above engine 2. Gas generator speed and power turbine speeds remain very well aligned regardless of the fuel used.

This shows that engine level flight steady state conditions should not be affected by the use of 100% HEFA fuel.

3.1.6. Engine Power Check

The Engine Power Check (EPC) procedure allows the crew to ensure that the engines fitted on the helicopters are capable of developing the power necessary to achieve the certified rotorcraft performances. It is a mandatory procedure to be applied on a regular periodicity in the frame of the continued airworthiness of the helicopter. It is therefore crucial to ensure the results are not impacted by the use of 100% SAF.

Indeed, improper results could result in either early removals of the engines leading to customer dissatisfaction, or even worse, to a potential safety concern by keeping below minimum power engines on the helicopter while it should have been removed due to negative EPC results.

To check potential impact, the existing EPC procedure was applied on the same engine either fueled with JET A-1 or with 100% HEFA. It was found that the EPC results remained within the acceptable scatter of the results for engines fed with JET A-1. This confirms that the current EPC procedure would not be impacted by the introduction of 100% HEFA fuel.

This finding is consistent with the one of the previous section as EPC procedure is performed in a level flight condition during which engine parameters are stabilized (i.e. steady state flight conditions).

3.1.7. Conclusion on Engine Behavior and Performance

All the above flight tests verification together with the experience gained by the engine manufacturer on the test bench, in the frame of the flight clearance activities, indicate there is today no show stopper for a possible future usage of 100% HEFA fuel on turboshaft engines.

Some specific aspects around the engine starting sequence should be looked at in greater detail with the engine manufacturer in order to gain a more detailed understanding of the phenomenon at stake. Nevertheless, this is not considered as a blocking point.

Furthermore, the absence of any negative short term effects on the overall engine dynamic behavior and performances is positive output and shall lead the way to complementary investigation.

However, considering the limited amount of test points performed or the absence of extremely severe environmental conditions (i.e. hot & cold), one should remain cautious and wait for further data to be available before coming to a final and positive conclusion.

3.2. Fuel System Performance

No abnormal behavior was observed on the helicopter fuel system using 100% HEFA fuel.

The fuel distribution and engine feed system performed as expected, except for a slightly lower fuel pressure at the engine fuel inlet of the engine powered with 100% HEFA.

On the fuel gauging system an under-reading was observed for the 100% HEFA fuel, which was expected due to the lower fuel density and dielectric constant of this fuel.

3.2.1. Fuel Pressure at Engine Inlet

Figure 13 shows the fuel pressure at engine inlet for both engines when powered with conventional JET A-1. There is a slight difference between the two engines, which can be explained by a difference in the fuel pump performance.

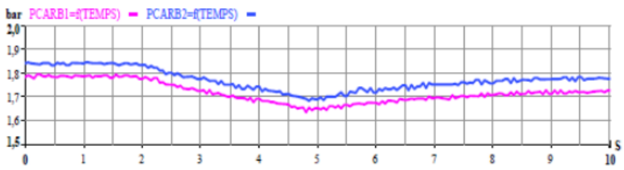

Fig.13 – Engine fuel inlet pressure - both engines with conventional JET A-1

Compared to this baseline, the fuel pressure at engine inlet was approx. 50-70mbar lower when engine no.1 was powered with 100% HEFA (see figure 14).

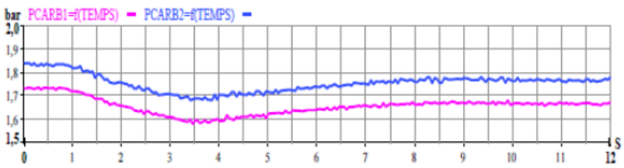

Fig.14 – Engine fuel inlet pressure - no.1 engine with 100% HEFA and no.2 engine with conventional JET A-1

This difference in the fuel pressure can be explained by the lower density of the 100% HEFA fuel (752kg/m^3) compared to the conventional JET A-1 (792kg/m^3) used during this flight. The fuel booster pumps on the H225 are centrifugal pumps and the pump outlet pressure is influenced by the density of the pumped fuel. With lower fuel density, the outlet pressure of the pumps is lower and therefore also the fuel pressure at the engine fuel inlet.

The fuel pressure, however, was still within the required range for proper engine operation.

3.2.2. Fuel Gauging System

A test of the fuel gauging system was performed first with both groups of the fuel system being filled with conventional JET A-1. The indication of the fuel gauging system was nearly on nominal with only a few percent deviation (max. 3%). The indicated fuel volume was matching the filled fuel volume quite well and within the required accuracy of +/- 6% (see figure 15).

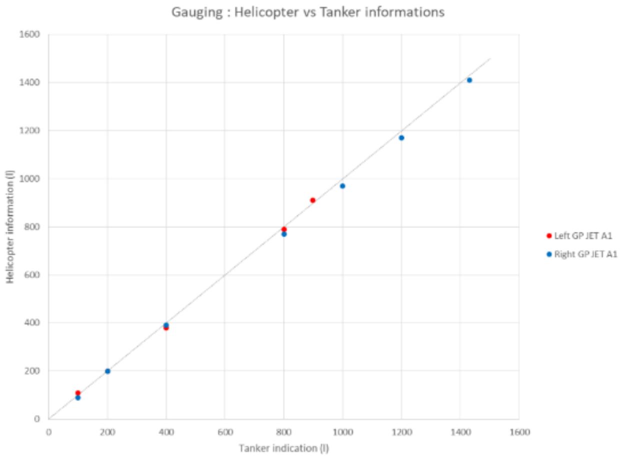

Fig.15 – Fuel Indication - both groups with conventional JET A-1

The test was repeated with the 100% HEFA fuel filled in the left group of the fuel system. The fuel gauging system indicated less fuel than filled. The deviation was approx. -5% during the first test in November 2021 (see figure 16) and up to -10% during the test with 100% HEFA on both groups in May 2022 (see figure 17).

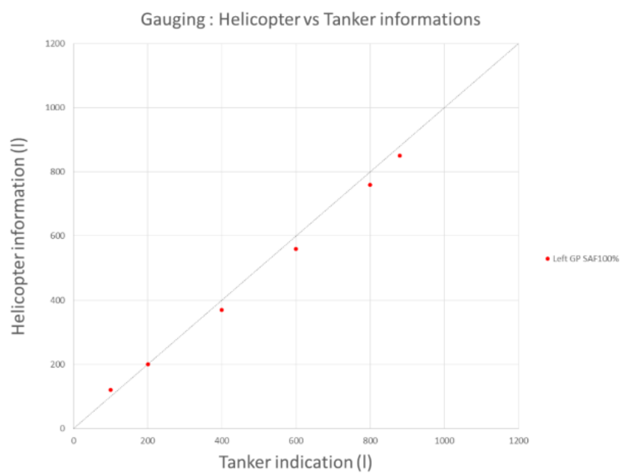

Fig.16 – Fuel Indication - left group with 100% HEFA (Nov. 2021)

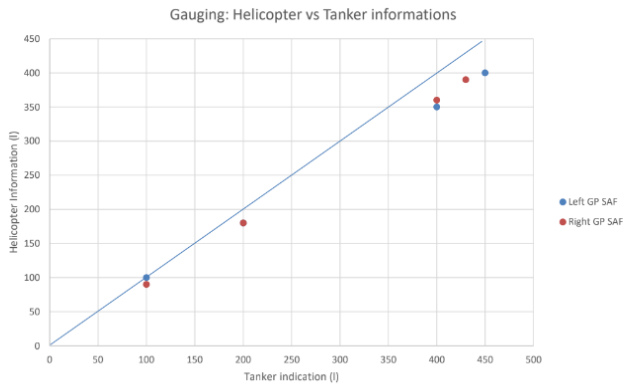

Fig.17 – Fuel Indication - both groups with 100% HEFA (May 2022)

This deviation in the fuel gauging system was expected as the density and dielectric constant of the 100% HEFA fuel are lower compared to the conventional JEA A-1 (see figure 18). The fuel gauging system of the H225 is a simple capacitive gauging system without dielectric compensation, as used on many legacy helicopters. Therefore the different dielectric constant has an immediate effect on the fuel gauging system and the fuel indication is showing less fuel than actually on board.

As the fuel temperature was higher during the second flight test in May 2022 as in November 2021, the dielectric of the HEFA fuel was even lower and the deviation in the fuel indication was larger.

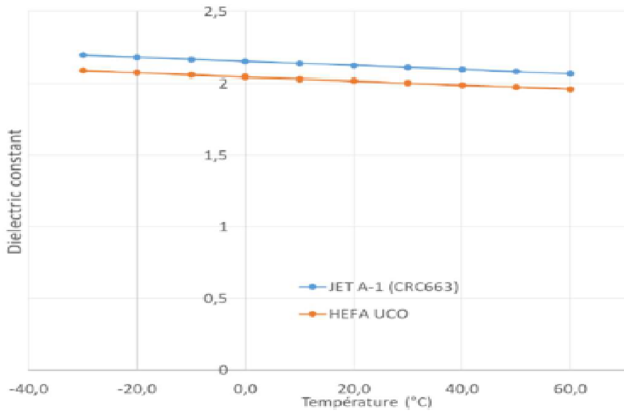

Fig.18 – Dielectric constant vs. Temperature

3.2.3. Conclusion on Fuel System Behavior and Performance

No immediate detrimental effect of the 100% HEFA fuel on the fuel system was observed. The fuel system behavior and performance was as expected for this fuel. The deviation of the fuel indication was expected due to the different dielectric constant and density of the 100% HEFA fuel.

Mid and long term effects (e.g. on fuel bladder material or seals) could not be determined due to the short duration of the two test campaigns.

The lower density of the 100% SAF fuel will have an effect on the maximum range/endurance of the helicopter, as the maximum tank capacity is limited by the physical space (volume) inside the fuel tanks. With a lower fuel density, this maximum volumetric capacity corresponds to less fuel mass.

First results only show a slight reduction in engine fuel consumption with 100% SAF, which is not sufficient to completely compensate for the mass reduction due to the lower density.

The following chapter gives an overview of the main areas which need to be looked at more in detail.

4. IMPACT ASSESSMENT

The first flights with 100% SAF demonstrated that there is no significant detrimental short-term effect of 100% HEFA fuel on the helicopter or engines.

In the next steps, Airbus Helicopters investigates in detail the mid- and long-term effects of 100% SAF on the helicopter and engine and its performance.

An impact assessment was started to identify the most important areas which need to be looked at. This chapter gives an overview of the main impacted areas. The topics are listed by assessed criticality.

Many of the following impacts will also affect the engine and will have to be investigated by the engine manufacturers in detail. Indeed, the engine design is under their Type Certificate responsibilities. This paper, however, will only give a short view on these engine impacts.

4.1. Fuel Gauging

Most helicopters are using capacitive fuel gauging systems, which rely on the dielectric constant (or relative permittivity) of the fuel to determine the fuel level inside the tank. From this fuel level, the actual fuel volume in the tank is calculated, which then can be converted to a fuel mass in kg using the actual fuel density.

Many fuel gauging systems on legacy and small helicopters are not compensated for difference in dielectric constant. For the calculation of the fuel mass from the volume, often a standard fuel density (e.g. 0.8kg/L) is used on such simple fuel gauging systems.

This was sufficient in the past, as the dielectric constant and density of conventional fuel was within a small band (see figure 19) and the accuracy requirements for helicopters is quite broad (+/- 6% deviation of the actual fuel reading is allowed for the indication on ground).

Figure 19 shows a diagram with data from the ARINC 611 fuel survey [8]. Dielectric constant vs. density of the fuel show a good relationship with relatively small scatter.

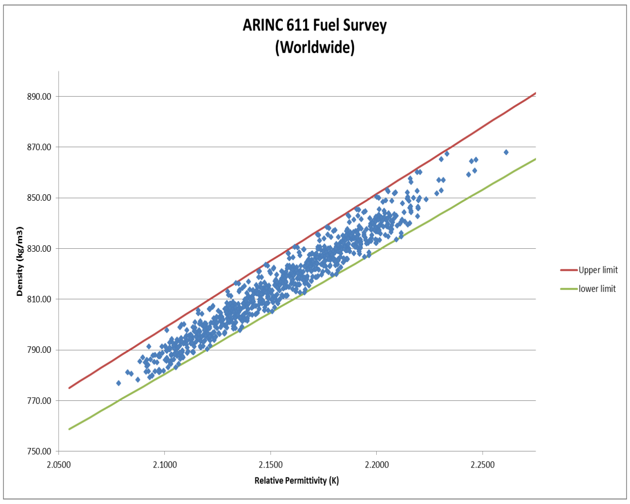

Fig.19 – ARINC 611 Dielectric constant vs. Density

Both, dielectric constant and density, are depending on the fuel type and will be different for a 100% SAF fuel compared to conventional Jet A-1.

Figure 20 presents the evolution of this diagram when SAF fuels are included. The scatter is getting significantly bigger, meaning that the dielectric for a given density can be significantly lower than previously.

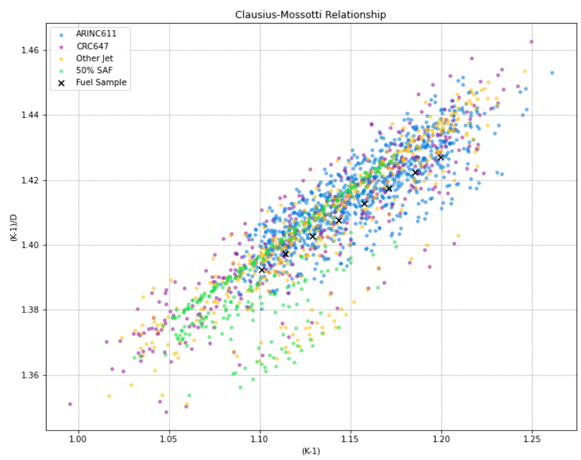

Fig.20 – Dielectric constant vs. Density including SAF fuels

For non-compensated gauging systems, a lower dielectric constant will result in lower fuel readings, as already seen on the H225 flights.

For current approved SAF-blends the deviation is expected to stay within the allowable accuracy, as the dielectric constant vs. density is checked during the approval process in ASTM D7566. For 100% SAF this will no longer be the case and the fuel indication of a non-compensated gauging system may be out of tolerance.

An assessment of the gauging systems for the different helicopters needs to be done to check if they are compatible with 100% SAF.

For new helicopters, compensated fuel gauging systems will be installed, as already done on the latest developments. A dedicated capacitor which is always immersed in fuel measures the actual dielectric constant so that the fuel level can be compensated for differences in the dielectric constant. This significantly reduces the indication error.

The compensator will also be used for the calculation of the actual fuel density based on the actual dielectric constant and the relationship shown in figure 19. The bigger scatter in this relationship due to 100% SAF (see figure 20) can introduce some additional error and has to be taken into account for the assessment of the gauging accuracy.

Different fuel gauging technologies will also be analyzed if they are better suited for 100% SAF.

4.2. Fuel Flammability and Volatility

There are indications that 100% SAF fuels may be more volatile than conventional Jet A-1. The vapor pressure may be higher, which means that the fuel will evaporate earlier. This can have an impact on the suction feed capability of the helicopter fuel system and can cause cavitation inside the fuel pumps of the engine.

Also the flammability of 100% SAF seems to be different from conventional Jet A-1. Especially the autoignition temperature of the fuel may be lower than what is currently taken into consideration in aircraft design. Historically, approx. 200°C (400°F) were accepted by the authorities as a safe maximum surface temperature inside fuel tanks for normal kerosene (see AC 25.981-1D [9]), based on a safe margin to the minimum autoignition temperature of 224-232°C (435-450°F) for Jet A-1 kerosene.

Flammability data of some 100% SAF fuels show that the autoignition temperature can be even below 200°C, which would jeopardize the current design guidelines of the AC.

The maximum allowable surface temperature for equipment inside fuel tanks will have to be lowered and existing equipment be reassessed in this case.

4.3. Engine Operation

Fuel lubricity capability is key for some engine components such as fuel pumps or actuators using fuel as a working fluid (e.g. IGV actuators). It will be important to clearly understand the long term effects on these components. Failure to clearly assess this could lead to engine reliability issues or even operability issues.

Depending on the engine design, the fuel control system may contain elastomeric components that could suffer from the lack of aromatics in SAF. Considering the potential consequences of the failure of such elements, this will also be an area of concern to be investigated in great detail when applicable.

Of course fuel inlet interface conditions currently applicable need to be revalidated with SAF within the complete engine operating range. This could lead to more stringent requirements potentially impacting the helicopter fuel system. This aspect needs to be worked in close collaboration between the engine and the helicopter manufacturers.

The engine operability as well as flame out capabilities need to be further investigated to cover the complete flight domain. Indeed, the limited number of flight conditions encountered during the tests performed by Airbus Helicopters is indeed encouraging but is neither, in no way, a complete demonstration for this specific application and nor could it be extended to other designs. This most probably will require extensive engine bench testing (including altitude testing) and analysis.

As seen previously, the engine behavior during starting phases needs to be further investigated to understand the root causes of the differences highlighted in this paper. Similarly, the potential long term effects of this specificity on the engine has to be addressed. It is clear at this stage that there are no detrimental short term effects, but it seems yet too early to provide a final conclusion.

Finally, as far as the engine integration into the helicopter is concerned, complementary investigations shall be performed to check that no undesired effects are to be expected. For example, extreme hot and cold temperatures conditions were not covered during this first work.

4.4. Material Compatibility

The compatibility of the different materials used in helicopter fuel systems has to be assessed to enable the use of 100% SAF without detrimental effects.

Tests already performed by Airbus on different materials with synthetic fuels with low or no aromatic content indicate an impact on the performance of some of the tested materials. Elastomeric material, especially Nitrile, has shown unsatisfactory results and needs to be further investigated in detail. For other materials like Polyamide, Polyurethane, Epoxy Varnish and Primers, etc. there is only a low risk expected for a performance impact. Still this has to be proven by further testing.

Material testing with different 100% SAF fuels is ongoing and needed to get the full view of potential material performance impacts.

On helicopter side, a deeper assessment will be performed for the flexible fuel tank bladders, as they are made of liners using elastomeric materials, some of them being Nitrile or Polyurethane.

Material testing of the different fuel tank bladder materials shall be performed together with the fuel tank manufacturers to identify any potential mid or long term impacts on important material properties like mechanical strength, fuel tightness and flexibility.

4.5. Fluid Mechanical Equipment

For fluid mechanical equipment like fuel pumps and valves, the viscosity and lubricity of the fuel are of importance. Both characteristics have shown to be different for certain 100% SAF fuels.

Sulfur is contributing to the lubricity of the fuel, therefore a low sulfur content of a 100% SAF can have a negative effect on lubrication of fluid mechanical equipment. Conventional Jet A-1 allows up to 0.3% of total sulfur content in the fuel (=3000ppm), whereas a 100% HEFA or FT fuel only contains up to 15ppm sulfur acc. to ASTM D7566 [1]. Although there was no detrimental effect noticed during the flights performed on H225, the long-term effects of missing sulfur still need to be assessed in detail.

There are indications that the viscosity of some 100% SAF is higher at very low temperatures than expected. This can increase friction losses in the fluid mechanical equipment as well as in fuel lines and reduce the performance of the fuel distribution and fuel feed system. Even though the impact may be relatively small, it needs to be assessed in detail as it can have an impact on the available fuel pressure at the engine fuel inlet, which may introduce limitations at cold fuel temperatures.

4.6. Flame Characteristics

The use of SAF raises an additional question regarding the validity of the fire proofness demonstration performed up to now using a burner fed with conventional JET A-1. Indeed, the flame characteristics could be modified due to the SAF characteristics, thus leading, potentially, to invalidate current certified designs. Complementary activities will be required to assess this risk.

4.7. Other Characteristics

Finally there are other characteristics of the fuel which can have an impact on the fuel system performance.

Water solubility and ice formation should be looked at in more detail if the behavior is different for 100% SAF fuels compared to conventional Jet A-1.

Microbiological contamination may be different for 100% SAF with the absence of aromatics and sulfur. This can be particularly interesting for helicopters, due to the much lower fuel usage compared to large transport aircraft, which results in longer storage time of the fuel either inside the helicopter fuel tanks or at the refueling station of the operator.

100% SAF fuels can be less conductive due to the cleanliness and missing contaminants. Static dissipater additives may have to be added already at the refinery to keep the conductivity within the specified limit. However, due to the relatively low refueling rates for helicopters compared to transport aircraft, fuel conductivity is less of an issue for helicopters.

4.8. Summary

The impact assessment has identified several areas of the helicopter fuel system and engine which need to be looked at in detail for a 100% SAF compatibility. The main topics are fuel gauging, flammability and volatility of the fuel, detailed engine behavior and material compatibility, especially with the flexible fuel tank bladder material.

Additional areas were identified which should also be checked, but where the impact is considered of less importance and lower risk.

5. NEXT STEPS

All the above discussions call for a dedicated roadmap to keep the momentum on what has been initiated. Considering the fact that today, it is not possible to anticipate what will be tomorrow's 100% SAF definition, Airbus Helicopters intends to investigate both, drop-in and non drop-in pathways.

The 100% drop-in solution is currently being handled by an ASTM task force. Airbus Helicopters will therefore closely follow the on-going discussion from this group and will, when required, perform the necessary complementary analysis and tests to ensure the 100% SAF drop-in specification is validated on our product ranges as a baseline. This logic will remain true for any new drop-in pathway the ASTM may decide to validate. The first 100% drop-in pathway is currently scheduled for ASTM approval in 2023.

On the non drop-in pathways, synergies within Airbus Group are currently being consolidated to further investigate the main topics identified in the previous section, as well as any new ones that may appear in the future. Regarding future helicopter developments, Airbus Helicopters anticipates compatibility with 100% SAF without aromatics (non drop-in) as an option. Suppliers of fuel system equipment and engines should be asked to analyze and assess the compatibility with such fuel. This should allow to simplify the validation activities whenever a non drop-in 100% SAF specification will be finally released.

The non drop-in 100% SAF specification has recently been kicked-off by Airbus in ASTM and the approval process is expected to take at least 3 years.

6. REFERENCES

[1] ASTM D7566 - Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons

[2] ASTM D1655 - Standard Specification for Aviation Turbine Fuels

[3] DEF-STAN 91-091 - Turbine Fuel, Kerosene Type Jet A-1; NATO Code: F-35; Joint Service Designation: AVTUR

[4] CRC Report 647 - World Fuel Sampling Program - Coordinating Research Council, Inc.

[5] CS27 - Certification Specifications for Small Rotorcraft

[6] CS29 - Certification Specifications for Large Rotorcraft

[7] Airbus website - This chase aircraft is tracking 100% SAF's emissions performance

[8] ARINC 611 - Guidance for the Design and Installation of Fuel Quantity Systems

[9] AC 25.981-1D - Fuel Tank Ignition Source Prevention Guidelines

7. SYMBOLS AND ABBREVIATIONS

AC	Advisory Circular
ARINC	Aeronautical Radio, Inc.
ASTM	American Society of Testing and Materials
ATJ	Alcohol To Jet
CRC	Coordinating Research Council, Inc.
EPC	Engine Power Check
FT	Fischer-Tropsch
H/C	Helicopter
HEFA	Hydroprocessed Esters and Fatty Acids
HIGE	Hover In Ground Effect
MGB	Main Gear Box
N1	Engine Gas Generator Speed
N2	Engine Power Turbine Speed
OEM	Original Equipment Manufacturer
SAF	Sustainable Aviation Fuel
TAS	True Air Speed
T4	Engine Turbine Gas Temperature
TQ	Engine Output Shaft Delivered Torque
XPC	Collective Pitch Position