European Aviation Safety Agency

Notice of Proposed Amendment 2015-22

Open rotor engine and installation

RMT.0384 (MDM.092) — 21.12.2015

EXECUTIVE SUMMARY

This Notice of Proposed Amendment (NPA) addresses a safety and regulatory coordination issue related to the introduction of open rotor technology into the next generation of engines and aeroplanes.

The specific objective is to establish the certification specifications necessary for the type certification of open rotor engines and their installation.

This NPA proposes changes to both CS-25 and CS-E.

The proposed changes are expected to establish a high level of safety, reduce regulatory burden by pre-defining appropriate type-certification standards and enable a level playing field with harmonised rules.

Applicability		**Process map**	
Affected regulations and decisions:	CS-25, CS-E	Concept paper:	No
		Terms of reference:	14.3.2011
		Rulemaking group:	No (ShG)
Affected stakeholders:	Aircraft and engine manufacturers; regulatory authorities	RIA type:	Light
Driver/origin:	New Technology and Level playing field	Technical consultation during NPA drafting:	No
Reference:		Duration of NPA consultation:	3 months
		Review group:	No
		Focused consultation:	Yes (ShG)
		Publication date of the decision:	2018/Q1

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1. Procedural information

1.1. The rule development procedure

The European Aviation Safety Agency (hereinafter referred to as the 'Agency') developed this NPA in line with Regulation (EC) No 216/2008[1] (hereinafter referred to as the 'Basic Regulation') and the Rulemaking Procedure[2].

This rulemaking activity is included in the Agency's Rulemaking Programme for 2014-2017 under RMT.0384 (MDM.092).

The text of this NPA has been developed by the Agency based on the input of the stakeholder-led group (ShG) RMT.0384 (MDM.092).

The ShG consisted of two subgroups:

Subgroup 1 comprised propulsion and power plant specialists drawn from the Agency, the Federal Aviation Administration (FAA) and airframe and engine manufacturers. The prime task was to address CS-25 issues as well as those CS-E issues that have an impact at aircraft certification level.

Subgroup 2 comprised propulsion specialists drawn from the Agency, the FAA and engine manufacturers. This subgroup addressed all CS-E issues. The members of Subgroup 2 were all members of Subgroup 1.

The NPA is hereby submitted for consultation of all interested parties[3].

The process map on the title page contains the major milestones of this rulemaking activity to date and provides an outlook of the timescale of the next steps.

1.2. The structure of this NPA and related documents

Chapter 1 of this NPA contains the procedural information related to this task. Chapter 2 (Explanatory Note) explains the core technical content. Chapter 3 contains the proposed text for the new requirements. Chapter 4 contains the Regulatory Impact Assessment showing which options were considered and what impacts were identified, thereby providing the detailed justification for this NPA. The appendices include discussions within the ShG on an open rotor engine definition, details regarding rules which were assessed as not requiring change, and a list of issues requiring further consideration.

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[1] Regulation (EC) No 216/2008 of the European Parliament and of the Council of 20 February 2008 on common rules in the field of civil aviation and establishing a European Aviation Safety Agency, and repealing Council Directive 91/670/EEC, Regulation (EC) No 1592/2002 and Directive 2004/36/EC (OJ L 79, 19.3.2008, p. 1).

[2] The Agency is bound to follow a structured rulemaking process as required by Article 52(1) of the Basic Regulation. Such process has been adopted by the Agency's Management Board and is referred to as the 'Rulemaking Procedure'. See Management Board Decision 01-2012 of 13 March 2012 concerning the procedure to be applied by the Agency for the issuing of opinions, certification specifications and guidance material (Rulemaking Procedure).

[3] In accordance with Article 52 of the Basic Regulation and Articles 5(3) and 6 of the Rulemaking Procedure.

1.3. How to comment on this NPA

Please submit your comments using the automated comment-response tool (CRT) available at **http://hub.easa.europa.eu/crt/**[4].

The deadline for submission of comments is **21 March 2016**.

1.4. The next steps in the procedure

Following the closing of the NPA public consultation period, the Agency will review all comments with the aid of the ShG.

The outcome of the NPA public consultation will be reflected in the respective comment-response document (CRD).

The Agency will publish the CRD concurrently with the related decision.

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[4] In case of technical problems, please contact the CRT webmaster (crt@easa.europa.eu).(crt@easa.europa.eu).

2. Explanatory Note

A new engine concept is being proposed to power future large transport aeroplanes as a means of reducing fuel burn and emissions. This concept is known as the 'open rotor engine' concept.

The open rotor engine concept contains a number of features found in traditional turbine engines and in propeller systems. For type-certification, existing turbofan/turboprop engines must comply with the appropriate issue of CS-E, while propellers must comply with CS-P. The Agency and the FAA have recommended that the open rotor engine concept should be certified under CS-E. The reasons for this are that open rotor engine designs may not readily follow the traditional turboprop engine philosophy, where the engine and the propeller are two separate products, certified under two different certification specifications (CS-E and CS-P), and then integrated on the aeroplane. In view of the very high level of integration in open rotor engine designs between the gas generator and the open rotor module (e.g. control system, casings, gearbox), this traditional turboprop approach is not feasible. However, it has been identified that some parts of CS-E are either inadequate or inappropriate due to the novel open rotor engine features (e.g. CS-E 800 Bird Strike and Ingestion, CS-E 810 Compressor and Turbine Blade Failure, CS-E 840 Rotor Integrity, etc.). Therefore, CS-E will need to be amended to address these features.

Furthermore, for type certification, aeroplanes must comply with CS-25. Existing requirements assume that an aeroplane is powered by either a turbofan, a turbojet or a turboprop engine. On the basis that the open rotor engine will be certified as an engine under CS-E, some parts of these requirements are either inadequate or inappropriate due to the novel open rotor engine features — no external blade containment device (e.g. CS 25.903(d)(1)). Therefore, CS-25 will not be directly applicable to an aeroplane powered by an open rotor engine and will need to be amended to address these features.

2.1. Overview of the issues to be addressed

What is an open rotor engine?

Considerable effort was devoted to the search for a definition of an open rotor engine that would distinguish it from a turbofan and a turboprop on purely technical, as opposed to certification route, criteria. The result was the following:

'Open rotor engine — A turbine engine featuring contra-rotating fan stages not enclosed within a casing.'

This definition is not introduced into CS-25, in the same way that there are no definitions of turbofan, turbojet and turboprop engines.

This definition should be considered as a working definition to assist in determining whether these proposed requirements should be applied to a particular project. However, the final determination of the certification basis will be made by the regulatory authority after a detailed review of each application.

It is important to note that in relation to CS-E, where two engine types are referenced, namely turbine and piston engines, this NPA does not introduce a new engine type into CS-E and there is no reference to an open rotor engine. An open rotor engine is simply a new member of the current turbine engine family consisting of turbofans, turbojets, turboprops and turboshafts. For this reason, it is proposed that the definition of an open rotor engine does not appear in CS-E. However, the term 'open rotor' is used extensively in CS-E, so a definition of an open rotor is introduced in CS-E 15.

Open rotor — A turbine engine fan stage that is not enclosed within a casing.

Details of the considerations that went into these definitions are included in Appendix 1.

Open rotor terminology

Open rotor blade	Primary thrust producing component
Open rotor hub	Component to which the open rotor blades are attached
Open rotor module	Assembly of open rotors

Why not certify the open rotor module under CS-P?

The regulatory authorities' representatives on the ShG were unanimous that in view of the anticipated level of integration of the open rotor module into the open rotor engine and the resulting need to perform one system safety assessment for the whole product, the whole of the open rotor engine would need to be certified under CS-E. Only if the open rotor module can be separated from the engine with all control components (excluding electrical, hydraulic and pneumatic supplies) can it be certified separately under CS-P, or CS-P with special conditions, by agreement between the applicant and the regulatory authority.

Review of CS-25 and CS-E

Both CS-25 and CS-E were reviewed to assess the adequacy of the existing requirements for open rotor technology. Where existing requirements were considered inadequate, new requirements were developed to satisfy the safety objective. Impacts between new and existing requirements were considered. In the case of CS-E, since this new technology to a large extent affects the whole product, all the requirements were systematically reviewed. The inadequacies in the existing CS-E requirements for turbine engines were driven by the novel features of open rotor engines relative to turbine engines, namely the lack of fan casing and the introduction of variable pitch open rotor blades. Since these features are similar to propellers, the requirements of CS-P were reviewed and used as the basis in developing CS-E requirements — with appropriate adjustments and subject to the overall safety objectives. CS-25 already contains requirements for the installation of turboprop engines. All CS-25 requirements were reviewed for their continued validity to open rotor engine installations and, where found adequate, were made applicable to open rotor engine installations — with appropriate adjustments and subject to the overall safety objectives.

Open rotor engines will be certified as an engine and they will not feature a propeller. Therefore, unless amended to the contrary by this NPA, when reading CS-25:

— all requirements referring to engines **are** applicable to open rotor engine installations; and

— all requirements referring specifically to propellers, turbojets or turboprop aircraft **are not** applicable to open rotor engine installations.

Previous studies

In the 1980s, there was sufficient interest in open rotor technology that two demonstrators were flight tested. At that time, the FAA and the Joint Aviation Authorities (JAA) launched their own studies into the possible implications for type certification. The ShG reviewed the results of these earlier investigations in order to minimise the risk of overlooking significant issues. The documents available to the ShG were:

- JAR Engine Study Group — Propfan subgroup — Interim report — March 1988; and
- Propfan Type Certification Requirements — FAA Aircraft Certification Office — 9 December 1988.

Issues considered still relevant to open rotor technology and within the terms of reference (ToR) were included in the ShG's work programme.

Equivalent safety

The ToR state that an objective should be to 'ensure that the safety levels of open rotor engine installations are consistent with those of the existing turbofan fleet'. This is in recognition of the expectation that open rotor engines may replace turbofan engines in a large segment of the fleet which is currently not powered by turboprops. The ShG has interpreted 'consistent' as 'equivalent'.

The ShG was advised by the engine manufacturers that at this stage of the technology development, the gas generator of open rotor engines will not introduce any novel features relative to turboprop gas generators. As explained above, the open rotor modules will have many features in common with propellers, but also some important distinguishing features.

Open rotor engine installation

The basic approach for achieving equivalent safety was to make the engine and propeller installation requirements of CS-25 applicable to the open rotor engine installations, amended as necessary to address the open rotor module specificities. This assumed that the safety standards of turboprop installations are equivalent to those of turbofans. A review of service history from 1954 to 1980 conducted as part of evaluating the requirements for unducted fans (another term for open rotor) identified a number of events where propeller system failures resulted in significant aeroplane damage and accidents. Since that time, advancements in propeller designs, including the introduction of new technology composite materials, have significantly improved the safety of turboprop-powered aeroplanes. A review of in-service accidents to turboprop- and turbofan-powered aeroplanes from 2001 to 2010, caused by the power plant, showed similar accident rates for both categories. Events have occurred that resulted in propeller blade and blade fragments penetration of the fuselage. For most of the safety issues addressed in CS-25, the above approach was adopted.

However, this approach was not accepted by the regulatory authorities' representatives on the ShG when applied to two key safety issues, namely open rotor blade release and uncommanded reverse thrust. For these issues, where the turbofan requirements (CS-E 810 and CS 25.933(a) respectively) are higher than the corresponding propeller requirements (CS 25.905(d) and CS 25.933(b)), the regulatory authorities' representatives on the ShG insisted on taking the turbofan safety objectives as the objectives for the open rotor engine. See Section 2.4.1.3 on rotor failure and Section 2.4.1.5 on reverse thrust, for further discussion of the safety objectives for these issues.

Open rotor engine type-certification

For open rotor engine type certification, the starting point was CS-E since, as stated above, the open rotor engine will be certified in its entirety under CS-E, amended as proposed by this NPA. Those existing CS-E requirements which are applicable and adequate for open rotor engines should directly yield safety levels equivalent to turbofans. To address those novel features of open rotor engines that are more similar to propellers than turbofans, for example the open rotor and its variable pitch capability, the CS-P requirements were reviewed and where appropriate incorporated in the proposed amendments to CS-E. In addition, consideration of the effects at aircraft level of open rotor failures resulted in some entirely new requirements being created specifically for open rotor engines. For example, CS-E 845 to require the open rotor hub to be damage tolerant (fail-safe), and CS-E 512 to require engine manufacturers to prepare an open rotor module failure model for mitigation at aircraft level.

Restrict rulemaking to open-rotor-specific issues

In view of the many similarities between propellers and the open rotor module of an open rotor engine, it was to be expected that some issues potentially requiring rulemaking would affect propellers as well as open rotor engines. This ShG was not tasked to propose changes to propeller requirements. Indeed, it specifically ensured that existing turbofan and propeller requirements would not be impacted. As the ShG did not contain representatives of propeller manufacturers, rulemaking was confined to open rotor-specific issues.

2.2. Objectives

The overall objectives of the EASA system are defined in Article 2 of the Basic Regulation. This proposal will contribute to the achievement of the overall objectives by addressing the issues outlined in Chapter 2 of this NPA.

As stated in the ToR, the objective of the task is to identify and propose EASA/FAA harmonised draft requirements and advisory material for respectively engine (14 CFR Part 33/CS-E) and aeroplane (14 CFR Part 25/CS-25) and/or Special Conditions to address the novel features inherent in open rotor engine designs and their integration with the aeroplane.

New requirements and associated acceptable means of compliance (AMC) material have been created to address the unique features of open rotor engines and their installation. These new provisions will ensure that the safety levels of open rotor engine installations are consistent with those of the existing turbofan fleet.

2.3. Summary of the regulatory impact assessment (RIA)

The ShG started with an assumption that some level of regulatory action would be required to meet the objective of ensuring that open rotor engines and their installation in aeroplanes would achieve safety levels consistent with the existing turbofan fleet.

The general conclusion from the assessment of impacts supported this assumption. This option will create minimum standards acceptable to the Agency, ensure a level playing field for all manufacturers, reduce the commercial risks associated with the development and acceptance of this technology and facilitate attainment of the potential environmental and economic benefits (with a potential of 30 % reduction in CO2 emission, as estimated by the ShG).

2.4. Overview of the proposed amendments

2.4.1. CS-25

2.4.1.1. CS 25.107(b) Take-off speeds

CS 25.107(b) defines $V2_{MIN}$ for turboprop-powered and turbojet-powered aeroplanes. In this context, open-rotor-engine-powered aircraft are treated as turboprop-powered aircraft. In CS 25.107(b)(1)(i), for two-engined and three-engined turboprop-powered aircraft, there is a higher factor of $1.13V_{SR}$, since in the event of one engine being inoperative there is no benefit from slip stream effect over the wing. The same factor should apply to aircraft powered by two or three open rotor engines, irrespective of where the open rotor engines are installed.

Only more than three-engined turboprop-powered aircraft benefit from a lower factor on V_{SR} (CS 25.107(b)(2)(i)) due to the slipstream effect. The same factor should apply to aircraft powered by more than three open rotor engines, as they would most likely be installed forward of the main wing, so benefitting from the slipstream effect in the same way as turboprop-powered aircraft. The likelihood of more than three open rotor engines being installed on the rear fuselage is very low. If this did happen, this issue would have to be addressed by a Certification Review Item (CRI).

2.4.1.2. CS 25.145(c) Longitudinal control

It seems illogical that this test should be carried out at less than $V2_{MIN}$, which appears to be the case for two- and three-engined turboprop-powered aircraft ($V2_{MIN}$ from CS 25.107(b)(1)(i) is 1.13 V_{SR}, but CS 25.145(c) test speed is 1.08 V_{SR1}). To avoid this apparent anomaly for open-rotor-engine-powered aircraft, it is proposed to require that the CS 25.145(c) test speed is V_{2MIN}, as determined in CS 25.107(b).

2.4.1.3. CS 25.903(d)(1) Rotor failure

CS 25.903(d)(1) is applicable by default, as a suitable starting point.

The Uncontained Engine Rotor Failure (UERF) requirements in CS 25.903(d)(1) are applicable to turbine engine installations, so the default position is that CS 25.903(d)(1) is applicable to the installation of the whole open rotor engine. It is expected that the gas generator of the open rotor engine is typical of turbofan gas generators, so CS 25.903(d)(1) is adequate to address the rotor failures of that part of the open rotor engine.

The term ‘rotor’ in CS 25.903(d)(1) was agreed to encompass open rotors based on the following existing definitions:

Under AMC E 840, rotor is defined as ‘Individual stage of a fan, compressor or turbine assembly’.

Under AMC 20-128A, section 6a, the definition of rotor includes the following sentence: ‘Typically rotors have included, as a minimum, discs, hubs, drums, seals, impellers, blades and spacers’.

Therefore, with respect to UERF, it was agreed that CS 25.903(d)(1) is an appropriate starting point for the whole open rotor engine, including the open rotor module, from which to develop a requirement to address novel features of open rotor engines. CS 25.903(d)(1) is a requirement to minimise hazards to the aircraft, very similar to the propeller release requirement CS 25.905(d), but with specific residual risk targets in AMC 20-128A.

Industry initially took the position to treat open rotor blade debris in the same way as turbofan UERF debris, i.e. that there is a residual risk of Catastrophic effect which must be minimised in accordance with CS 25.903(d)(1). Industry argued this would achieve equivalence to the turbofan fleet treatment of UERF. However, this position was not accepted by the members of the ShG representing the regulatory authorities. In their view, the appropriate turbofan failure which needed to be compared with the open rotor blade failure was not a turbofan disc burst, but rather a turbofan fan blade release. This failure is required to have no Hazardous Engine Effect, in accordance with CS-E 810. Therefore, for the authorities, the only acceptable objective was to treat the open rotor blade debris in the same way as turbofan fan blade debris, i.e. preclude Catastrophic and Hazardous effects unless this could be demonstrated in the rulemaking process as impractical.

AMC 25.1309 definition of Hazardous failure conditions includes three effects:

(i) A large reduction in safety margins or functional capabilities;

(ii) Physical distress or excessive workload such that the flight crew cannot be relied upon to perform their tasks accurately or completely; or

(iii) Serious or fatal injury to a relatively small number of the occupants other than the flight crew.

It was agreed that it is the fatal injury to a relatively small number of the occupants other than the flight crew that needs to be precluded for open rotor blade release in order to meet the objective of precluding Hazardous effects.

AMC 20-128A describes design precautions to minimise the hazards resulting from UERF. These include:

— location of critical components outside the fragment impact areas;

— separation;

— isolation;

— redundancy; and

— shielding.

Of these techniques, shielding is needed to preclude Catastrophic and Hazardous effects. Therefore, independent studies were initiated by the FAA and industry to investigate the practicality of achieving the safety objective by shielding.

Effects of failure of hub

It was accepted that the effects of the release of a sector of the open rotor hub could not be mitigated at aircraft level. Open rotor concepts presented for consideration include designs with novel hub/blade retention systems including designs with a ring assembly that rotates outside of the engine turbo machinery. Failure of the hub would likely be Catastrophic. Therefore, the regulatory authorities' representatives on the ShG required the hub to have design features such that the engine can be safely shut down if failure of a primary hub feature occurs. No open rotor hub failure will permit separation of the hub, bladed segments of the hub, or more than a single blade. Specific hub design requirements to preclude its failure are introduced in the new CS-E 845. However, hazards associated with failure or release of a single blade must be considered.

CS-E open rotor failure model

At aircraft level, the analysis relies on a failure model established at engine level under the new CS-E 512. Since failure of critical parts may occur, the assumption is that no credit is given for critical parts. The failure modes and associated debris are taken into account in the failure model. It should also be noted that the open rotor blades are exposed to external damage. The debris release to be considered is defined by the engine debris model in CS-E 512.

Shielding studies initiated by the FAA and industry

Industry and the FAA/National Aeronautics and Space Administration (NASA) conducted separate shielding studies. The scope of the studies was limited to single aisle aircraft in the B737/A320 category, this being the envisaged fleet segment where open rotor technology is most likely to be aimed. The FAA/NASA study is contained in the report DOT/FAA/TC-13/34 [Ref 1]. Due to proprietary constraints, this study was based upon a generic wing-mounted engine installation and open rotor diameter of 13.5 ft, as provided in a publicly available NASA/General Electric(GE) report published in 2012. Boeing and Airbus conducted independent studies of various configurations, including rear fuselage and wing-mounted engine installations.

Assumptions of the studies

In order to allow meaningful comparisons between these studies, a generic threat model representing one open rotor aerofoil was used as follows:

— +5° to -5° spread angle;

— kinematic trajectory (cycloid per AC 25.905-1);

— CoG of aerofoil at 1/3 of its length;

— 16 ft diameter front rotor, radius ratio 0.3 — aerofoil energy of 109 000 Joules;

— rear rotor 85 % of front rotor diameter — aerofoil 80 % of front aerofoil energy; and

— 4.5 ft between rotor centre lines

To simplify the studies, secondary blade debris generated either by blade-to-blade or rotor-to-rotor interaction, or by rebound of the failed blade from the shielded fuselage back onto the failed engine, were not taken into account

Development in shielding technology — FAA/NASA research

Significant research into computer modelling of aeroplane shielding and engine debris containment systems has been conducted over the last 15 years, resulting in the ability to accurately model shielding performance and optimise the design. In addition, composite open rotor blades and new technology composite fuselage structures offer the ability to significantly reduce the weight needed to prevent fuselage penetration from blade release. Composite blade tips break up upon impact with the fuselage, reducing the thickness and associated weight needed to provide shielding. Composite fuselage structures can be designed to utilise materials that offer significant shielding capabilities over those of traditional aluminium structures. The FAA has completed the research into possible mitigation of the blade hazard to the aeroplane by providing shielding of the fuselage to prevent penetration into the passenger cabin. NASA and China Lake Naval Weapons Center completed analytical studies to determine the weight of fuselage shielding systems for wing-mounted open rotor. FAA report DOT/FAA/TC-13/34 includes a blade impact area study that shows the size of the fuselage shield for a wing-mounted twin-engined configuration can be limited to +/-3 degrees fore and aft. The trajectory analysis is supported by in-service blade release events.

NASA shielding weights

The NASA study includes estimated total weight for fuselage shields in the range of 230 to 430 lbs. The FAA sponsored blade impact testing that was completed at China Lake Naval Weapons Center in February of 2014. This testing validated the analytical shielding models. The results of the testing have been included in a revision to the report noted earlier.

Weight of engine fan case and ice shield used as a guide

The position of the authorities' representatives is that the baseline safety level provided by today's turbofan aeroplanes include fan blade containment systems. Removing the fan blade containment system from turbofan engines results in a significant weight saving and this weight could be used in an open rotor design to protect the passenger cabin from blade hazards. However, the authorities have not been able to gather specific data on the weight needed to comply with existing fan blade containment requirements. Industry members of the ShG have not provided detailed weight estimates due to the complexity in determining the portion of the fan case weight that is allocated specifically to containment, as well as proprietary information concerns. In addition, many turboprop aeroplanes have fuselage ice shields that are needed to prevent damage from ice shed by the propellers as required for compliance with CS 25.875. The weight to protect the aeroplane from ice shedding was also not available. Fuselage blade shielding designs could include integration of the ice protection features.

Regulatory assessment of industry studies

The total net weight change of an open rotor aircraft design compared to an existing turbofan aircraft design is highly dependent upon the aeroplane and engine configuration. While an open rotor engine benefits from the lack of an open rotor blade containment system, incorporating shielding in the aeroplane, as well as mitigating possible cross-engine damage will have a detrimental impact on weight. Two of the industry members of the ShG conducted separate uncontained open rotor blade studies. Due to the numerous variables as well as uncertainties associated with the introduction of new technology shielding, industry shielding studies included numerous conservative assumptions. These included: utilising large shields to account for engines being located much further from the fuselage than traditional turboprop designs and to protect against other engine debris, assuming the use of older technology composite materials, technology risk factors that doubled the weight, cycling factors for aft fuselage configurations, and the fore and aft blade trajectory was assumed to be +/-5 degrees, etc. In addition, designs used in the industry analysis were based upon existing configurations that had not been developed considering the need to mitigate blade hazards, including the threat to the other engine. It should be noted that if pusher type open rotor engines are located on the aft fuselage, cross engine debris can be addressed by taking advantage of fuselage and vertical tail structure. For wing-mounted configurations, the fuselage height for a 737/A320 sized aeroplane is 13'–2". The largest diameter of the open rotor engine that is publicly available is 13'–8". When blades are released, the fragments rotate about the centroid of the fragment as described in AC 25.905, therefore if the fuselage provided blade penetration protection, the threat from the other engine could be mitigated.

Synergies can reduce shielding weight penalty

As with today's turbofan fan blade containment capabilities, significant synergies exist when shielding is integrated into the initial aeroplane design. For example, engines can be located so that cross-engine debris is eliminated or significantly reduced without adding weight. New, high-performance composite materials can be used as secondary shields or part of the fuselage structure for load carrying, ice shed damage protection and blade damage mitigation in areas subject to blade impact. It should be noted that the NASA shield weight of 430 lbs is based upon installing a separate shield for each rotor that is independent of the aeroplane structure. Therefore, there is no credit for possible design synergies. When synergy factors are taken into consideration, it appears that the net weight increase, if any, for mitigating the uncontained blade threat through fuselage shielding is relatively small and therefore mitigating the uncontained blade hazard is practical.

Conclusions from shielding studies

Both manufacturers used proprietary design and aeroplane configuration factors that were used to generate their weight estimates. In assessing practicality, industry used their own criteria relating to technical feasibility and economic aspects, covering such parameters as fuel burn and operating costs. The conclusions from the shielding studies were as follows:

- **Shielding of the fuselage to preclude Catastrophic effects is practical.** Precluding catastrophic effects from impacts on the airframe of a full aerofoil, that is excluding direct engine to engine impacts, would be practical, based on the above assumptions (Assumptions of the studies) and simplifications.
- **It is not practical to preclude Catastrophic effects for cross-engine debris.** To preclude Catastrophic effects for direct engine to engine trajectories over the top of the fuselage would require installing a dorsal shield on the top of the fuselage. The practicality of such a solution depends on the size of the shield, primarily related to the vertical positioning of the engines, and the axial position on the fuselage. Two airframe manufacturers made individual presentations to the authorities' members to show what the residual risk of Catastrophic effects would be from cross-engine debris without installing any dorsal shield and the practicality of installing dorsal shields. There were two main conclusions. The specific risk associated with differing aeroplane engine installations such as mid-fuselage, high wing or pusher configurations was shown to vary substantially. Also, it was shown that dorsal shielding can range from practical and effective to impractical and not effective. It was concluded that precluding Catastrophic effects was not practical for all installation configurations, in particular wing-mounted configurations. The exposure to direct engine-to-engine trajectories would be minimised depending on other design and performance considerations, by positioning the engines to gain the most protection from the shielded fuselage and other available surfaces. The residual risk of Catastrophic effects for each stage of open rotor would then be assessed against a specific residual risk target. This minimising objective is already covered by the existing wording of CS 25.903(d)(1); therefore, it does not need to be explicitly included in the proposed revision of that requirement.
- **It was not considered practical to preclude occupants being within the range of structural deflections for all possible occupant postures**. The threat to individual occupants arises either from penetration of the cabin or from deflection of the cabin structure. It was concluded that

the objective for mitigating the threats to individual occupants should be a minimising rather than precluding objective.

Based on the above conclusions, CS 25.903(d)(1) is amended to require that Catastrophic effects from impacts of the proposed CS-E 512 open rotor failure model debris on the airframe are precluded and the threat to cabin occupants is minimised. The requirement to minimise the risk of Catastrophic effects for other trajectories, in particular direct engine to engine impacts, is covered by the existing wording of CS 25.903(d)(1) and is addressed in the proposed AMC No 2 to CS 25.903(d)(1).

AMC 20-128A is applicable for gas generator

AMC 20-128A provides advisory material which is applicable and adequate for UERF in the gas generator of an open rotor engine. However, the open rotor module is different from the fan module of a turbofan engine. Open rotor module will have some features similar to propellers, and the failure model in AMC 20-128A may not be appropriate.

New advisory material required for open rotor module

New advisory material is required for uncontained rotor failures in the open rotor module. Rather than amend AMC 20-128A, it was decided to create a new AMC which would mostly deal with the open rotor module, cross-referring to AMC 20-128A where appropriate, but also explaining how rotor failures for the whole open rotor engine should be addressed.

New AMC defines detailed safety objectives

The new AMC defines the safety objectives for the effectiveness of the shielding, the unbalance loads, the residual risk from direct engine-to-engine impacts, the high power condition, as well as the protection of cabin occupants.

In view of the two objectives related to Catastrophic effects one precluding, the other minimising, debris trajectories need to be separated into those that impact the airframe and those that could directly impact the other engine. It was agreed the trajectory of the fragment Centre of Gravity (CoG) should be used as the criterion, rather than whether the fragment impacts the airframe. This is because the tumbling motion of the blade where the CoG would not impact the airframe could nevertheless result in impact on the airframe. Fragments on such a trajectory should be subject to the minimising Catastrophic effects objective and not to the precluding objective.

New open rotor module failure model required from CS-E 512. Consideration of partial aerofoil release rejected.

The key input for the safety assessment is the failure model of the engine, which characterises the fragments released by the engine which have to be addressed at the aircraft level. The failure model defined in AMC 20-128A defines generic failure models for turbojet engines, based on many engine rig, test bench and in-service events. The design of open rotor modules is expected to be such that the generic failure models in AMC 20-128A will not be applicable. In order to include all potential debris to be addressed at aircraft level, the engine manufacturers would need to provide a project-specific failure model. This is covered by a new CS-E requirement — CS-E 512. Consideration of partial aerofoil release was rejected by the authorities' representatives for first generation open-rotor-powered aircraft.

Spread angle

The definition of spread angle is adapted from the definition in FAA AC 25.905-1, paragraph 4b. The +25° spread angle in AC 25.905-1 was discounted, since that was based on one event during a wind tunnel model test. The vertex of the spread angle was moved from the engine centre line in AC 25.905-1 to the hub rim to account for the large range of open rotor hub diameters expected. Puller configurations are likely to have much smaller hubs than pusher configurations. Consideration had been given to placing the vertex at the outermost retention feature of the blade, in order to be consistent with the blade release position to be used in the CS-E 810 blade failure test. However, it was concluded that in view of the need to finalise the impact zone on the airframe early in the programme, the hub rim would be a clearer position to identify sufficiently early. Any difference between the hub rim and the outermost retention feature would have a small effect on the size of the impact zone.

The 6° range of the spread angle is based on a review of turboprop in-service events where a propeller blade was released and there was some evidence of the impact position and on an analysis of the aerodynamic loads on a released blade, but did not take into account the effects of propeller pitch. Both these were reported in FAA/NASA report DOT/FAA/TC-13/34. The conclusion from the propeller events was that the impact zone is in the plane of rotation of the propeller. The conclusion from the analysis was that the dispersion would be less than 1° for the blade considered. It is considered that the proposed 6° dispersion includes sufficient margin to cover uncertainties and future blade designs.

A project-specific mean trajectory (θ^{o} angle to the plane of rotation) has been introduced in the AMC to account for the parameters that will drive the trajectory of the blade fragment in the engine vicinity, e.g. fragment initial velocity, fragment's CoG position at release. θ^{o} angle is providing the nominal trajectory when the fragment is leaving the sphere of influence of the engine (i.e. open rotor envelope).

Without usable in-service experience on open rotor engines, a 6° spread angle range (θ +/-3°) has been deemed acceptable to cover uncertainties on blade trajectory outside the engine vicinity — that depends on parameters like e.g. aerodynamic forces applying on the fragment along its trajectory, inertia forces, drag effects and trajectory length.

It was recognised that the spread angle has a significant effect on the design of the airframe and as such needs to be confirmed early in the development program, certainly well before significant engine certification tests. For example, the open rotor blade release test in the proposed revision to CS-E 810 would very likely occur after the fuselage design was frozen. Following current engine and aircraft certification practices, the authorities and applicants will resolve certification issues when certification test results or other information arises that conflicts with earlier certification assumptions, as needed.

Unbalance loads

Unbalance loads need to be taken into account as an integral part of the open rotor blade release failure analysis. This is in marked contrast to the turbofan situation, where the UERF (CS 25.903(d)(1)) and sustained engine imbalance (AMC 25-24) analyses relate to separate failure events, i.e. disc failure (UERF) vs fan blade failure (SEI). For open rotor blade failures, the impact and unbalance effects result from the same event. The unbalance and flight loads to be taken into account are set out in detail. The unbalance loads are provided by the engine manufacturer, in accordance with CS-E 520(c)(2).

Minimising Catastrophic effects for cross-engine debris

Engine installation can significantly affect the residual risk of impacts from cross-engine debris. In addition to cross-engine debris exposure, other considerations need to be taken into account to ensure a safe and economically viable product. These considerations include but are not limited to ground clearance, fuel burn optimisation, range, payload, drag, stability and control, community noise, cabin noise, airframe–propulsor integration and optimisation, structural optimisation to minimise weight, passenger and cargo loading, and maintenance considerations.

The potential geometric residual risks for various configurations under consideration were reviewed. The lowest residual risk that would allow configurations to go forward was considered acceptable, taking account of the potential practicality for installing dorsal shields.

The finally agreed specific residual risk targets are (1) geometric and (2) take account of flight phase reduction factors.

The reduction factors used for setting the target were those proposed by AMC 20-128A for 'total loss of thrust causing catastrophic consequences' — with margin, taking into account UERF event distribution per flight phase for turboprop engines.

A reference fragment is required for residual risk assessment (risk measure and comparison to target), in line with risk assessments performed today on turbofan A/C for gas generator 1/3 discs. The specific residual risk for cross-engine impact is calculated assuming one blade from the outermost retention feature to the tip rather than the debris from the CS-512 failure model.

Industry position

The industry position included consideration of exposure assessments of a limited number of concepts in the overall aeroplane design trade space. It must be recognised that these assessments in no way cover the complete range of potential configurations.

The geometric residual risks for the concepts considered ranged from zero to 1/20, but it should be understood that aeroplane optimisation trade space extends beyond 1/20. The industry position is that an 1/20 geometric residual risk level (and 1/35 taking account of reduction factors) provides a reasonable target that could be achieved considering future design space exploration and optimisation work, without onerous aeroplane-level penalties. Taking account of the other safety standards proposed, this ensures turbofan safety standards are maintained. See 'How the ToR objective is met' below.

In contrast, the Authority position is that an 1/35 (geometric) probability allows significant design latitude for development of a practical wing-mounted engine configuration. Industry views that maintaining the viability of this type of configuration is vital, and as previously stated that an 1/20 (geometric) probability is appropriate. The engine on wing design is the most dominant configuration type in commercial transports today. With regard to turboprop class engines, it is virtually the only regional or transport category configuration that has been successfully employed for multi-engine aircraft. Although wing positioning may differ as being high wing or low wing (relative to body), in either case this design arrangement has predominated for good reason. There are no mainstream commercial or military transport turboprops that have engines that were/are aft body mounted.

The Authority position rests heavily on simple geometry assumptions provided by China Lake and NASA consultants. These assumptions are overly simplistic and fail to take into consideration practical airplane design practices. Focusing on a single aspect (the use of the fuselage to block cross engine blade travel) fails to reflect the realities of other, competing design consideration and requirements. These can be both of practicality, and of safety. The practical economic considerations are that engines cannot be simply positioned in an engine-to-engine/fuselage blocking arrangement without significant and likely impractical design compromises. Relative to the sketches provided by China Lake and NASA, engines could not be put into such locations relative to the body without either very low-slung engines relative to the wing or wing to body positioning that intrudes into the cabin. Low-slung engine installations will carry attendant large strut support weight and drag. Any significant movement of the wing carry-through structure into the fuselage of a 737 class transport would quickly become unviable from interior airline and passenger arrangement perspective. In addition to the design efficiency/practicality considerations, there is likely a detriment to overall safety for the occupants rather than an improvement with the Authority position. One of the many considerations in a complete airplane design layout is that of minimising the consequences of a landing with any or all of the landing gear collapsed or stowed. In past discussions, Industry presented historical data that shows that current generation of technology fan blades have uncontained releases that are approaching the magnitude of 1 × 10-8 events. Future developments, plus increased design requirements agreed to by Industry in this proposed rule, would further diminish the probability of these events. Current industry fleet experience is that landing with any or all of the landing gear collapsed or stowed is roughly an order of magnitude more likely to occur (for example, the combined fleet average through 2008 for Boeing 737, 747, 757,767, DC9/MD80, and DC10/MD11 is approximately 1.4 × 10-7 for a landing with one Main Landing Gear collapsed or stowed). Minimising the consequences of these events is seriously considered by Industry in the design and layout of transport category airplanes. For this rulemaking activity, assuming a 737 fuselage to ground clearance (as required for airplane rotation angle to achieve acceptable take-off and landing performance), and adjusting position for a body-mounted gear typical of most high wings configurations, both of the China Lake/NASA figure’s engine size and engine to body position scenarios would have large incursion into the ground by the rotors for a single side gear collapse case. With contra-rotating stages of engine rotors, ground contact would result in release of many blades and associated debris in the direction of the fuselage. Ground contact is a far more unpredictable release case; blade debris would likely release in a wider dispersion pattern forward and aft than assumed for the current single blade release in flight (trajectory analysis referenced in Section 2.4.1.3 supporting +3/-3 degree spread). No amount of fuselage shielding is likely practical for covering this increase in blade debris dispersion angles. Due to the unpredictability of causes for collapsed gear cases, the design practice by commercial industry is minimising risk. Raising the engines higher relative to the ground, not lowering them (as shown by the China Lake/NASA figures) is the primary means for minimising this particular risk.

In summary, the Authority position on cross-engine debris does not recognise highly constrained airplane design and safety considerations and does not provide significant design latitude. The Authority recommendation of lowering the engine relative to the fuselage would drive costly (low-slung engine) or impractical (wing carry through intrusion into cabin) design solutions. The Authority recommendation would also drive a reduction in safety for landing gear failure events, which are expected to be significantly more probable than blade release events. In the Industry’s view, the proposed geometric residual risk level of 1/20 provides a reasonable and practical target that balances these competing factors.

Industry agrees with the impracticality of large protective 'dorsals'. As engines are typically mounted off the front of wings, that puts the dorsal typically well ahead of the aerodynamic centre and CoG of a typical airplane. This is a highly destabilising position, to varying degrees in all three airplane axes. Control surface and empennage sizing would be increased to compensate, depending on the degree of the dorsal sizing. A level of impracticality of this unprecedented design feature would be achieved quickly. Hence, the reasonably balanced minimisation level of 1/20 (geometric) is most likely to allow development of a practical Open Rotor configuration that does not preclude the most dominant and prevalent class of transport (engine on wing vs aft body-mounted).

Authority position

The tasking for the ShG was based upon providing equivalent safety to that of a turbofan engine. Turbofan engines have no cross-engine debris exposure for fan blades because of the containment system.

The open rotor engine design concepts include two counter-rotating blade hubs with, for example 11 blades on each hub. This results in adding 44 safety-critical components, that are exposed to birds and Foreign Object Damage (FOD), whose failure could be Catastrophic. In addition, to the increased potential for hazardous debris, the opposite engine may present a large target since the opposite engine blades are not protected by a cowling. While the Authorities agree with the industry position that it is impractical to preclude all cross-engine debris exposure by the addition of dorsal shields, no agreement was reached as to the geometric exposure that was proposed. Geometric cross-engine debris exposure presentations by Boeing and Airbus, as well as generic drawings developed by China Lake Weapons Center show significant shielding between the two engines is provided for both aft fuselage and wing-mounted engine configurations. The two figures below, provided to the ShG by China Lake Weapons Center, show significant design latitude with a geometric full-blade exposure of 1/40.

Figure 1: 13.5 ft diameter rotor allows locating engine 41 inches above fuselage centreline, with a 1/40 geometric risk

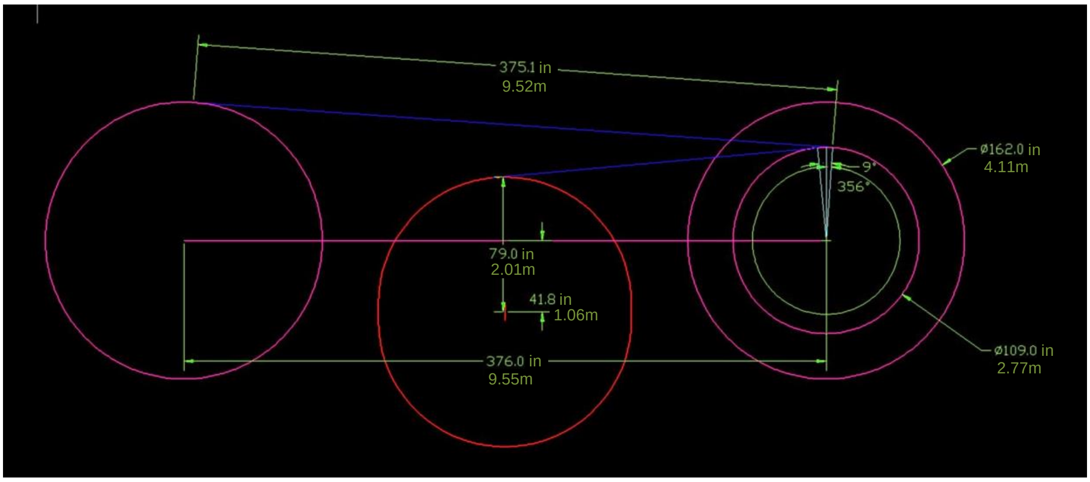
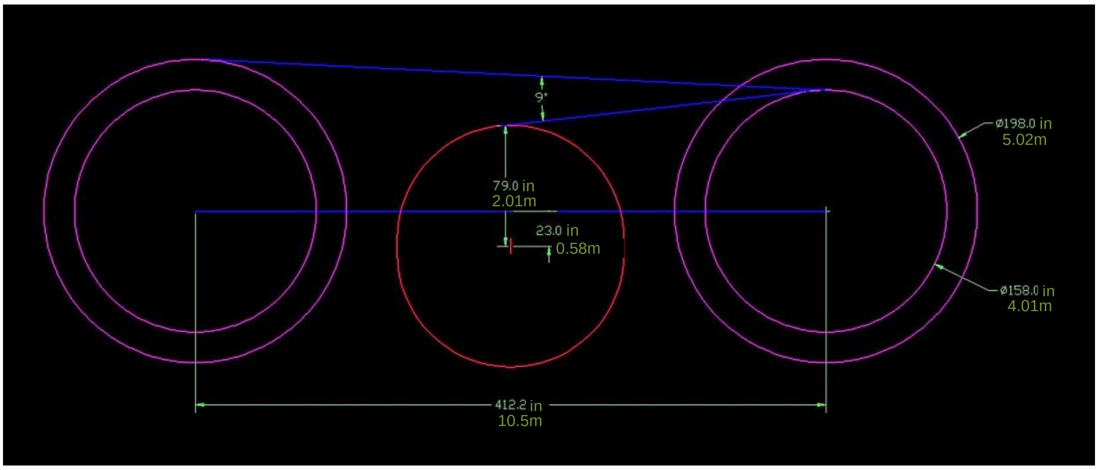


Figure 2: 16.5 ft diameter rotor allows locating engine 23 inches above fuselage centreline, with a 1/40 geometric risk



The authorities’ position is that opposite engine exposure should be limited so that designs are not developed with unacceptable exposure to cross-engine debris. The 1/35 geometric exposure for wing-mounted configurations would allow significant design latitude for locating the engines, and provides an acceptable cross-engine debris exposure. Where possible, the engine should be installed to minimise the debris exposure.

Minimising risk to occupants

Two threats to occupants were considered, namely impact from deflections of the airframe structure and impact from debris entering the cabin.

To minimise the risk from airframe defections, a standard value for the allowable deflection was initially considered. This was rejected since the allowable deflection should be based on where the occupants are seated relative to the fuselage wall. So a keep-out zone representing the head of a 95 % male fully seated against the back rest was defined in Figure 3 of AMC No2. The deflection of the airframe structure outer mould line should not enter this keep-out zone. The dimensions in Figure 3 were derived from ‘The Measure of Man and Woman, Human Factors in Design’ revised edition 2002 [Ref 2]. This gives a 95 % adult male sitting height erect of 96.5 cm above the seat. Allowing for a 5 cm reduction from sitting against the back rest and a seat height of 38 cm gives a height above the floor of 129.5 cm. A 95 % head width of 16 cm is assumed.

Regarding penetration criteria, rather than to preclude any penetration, it has been agreed to leave open the possibility of having debris puncturing the fuselage/fuselage shielding, as long as it is demonstrated that debris energy will be absorbed before impact on the occupant.

Industry position

Industry considered that it has not been shown to be practical to preclude impact on occupants when the windows are impacted, for the following reasons.

Industry has considered the use of impact-resistant materials that can mitigate window penetration. While it is true that such materials exist, there are no examples of windows made from these materials on an existing passenger airplane. Furthermore, there are currently no proposed designs for such windows. Industry is willing to investigate this concept further; however, a summary conclusion of precluding any penetration through the windows on the basis of unproven potential technology is premature.

The justification for the authority position suggests several means of eliminating passenger windows from the impact zone. One suggestion is to place a door in the impact zone. However, the doors must be located where best suited for safe and successful evacuation of passengers from the airplane. Constraining this location may likely result in a sub-optimum cabin configuration, meaning fewer passengers for a given airplane size (or conversely a significant increase in the airplane size to achieve the targeted passenger capacity). In addition, a door placed intentionally in line with a wing-mounted engine's open rotor blades would be hazardous in any emergency scenario requiring evacuation of the passengers. Deployment of the door's emergency slide would be highly impractical due to engine proximity. The door design would be made more complicated in an effort to maintain its function as an emergency exit after a blade impact. In summary, Industry considers doors in close proximity to an open rotor engine to be highly impractical.

Industry has considered placing galleys and lavatories in the impact zones in order to eliminate the need for windows in the impact zone. For a wing-mounted engine configuration, this would be in the centre of the fuselage, just forward of the wing. In Section 4.1.3 of this NPA, the 737/A320 (single aisle) category is specifically identified as a significant potential fleet of airplanes that may be replaced by open-rotor-powered airplanes. These single aisle airplanes have the galleys and lavatories located exclusively at the forward and aft ends of the fuselage. This configuration maximises passenger count for a given size airplane, leverages synergies with evacuation exit requirements (servicing, galleys and lavatories all take advantage of safety dictated assist space and evacuation path clear zone requirements). The current practice is volumetrically efficient, and shortens the time required to service galleys and clean the airplane. Non-evacuation-rated service only doors are rare, and in this case would be impractical due to deliberate placement of the doors where service vehicles could not readily access the airplane (due to interference with engines and rotor blades). Maximising interior payload efficiencies and quick airplane servicing are critical to airline profitability and productivity in the competitive low-cost marketplace. Therefore, it is not clear that a configuration with interior furnishings in the middle of the fuselage is either feasible or acceptable to airline customers.

Industry also considered eliminating the windows where passengers are in the impact zone. It is true that some window locations are blocked on existing airplanes to accommodate air conditioning ducts, etc. However, these locations are singular, so that passengers in adjacent seat rows may still see outside the airplane. Blocking three or more rows of windows would create a zone where outside visibility would be impossible, and may result in a zone of reduced-fare seating. Further to that, this location typically corresponds to the premium class cabin, and the economic burden to the airlines could be significant. Industry is willing to investigate synthetic vision systems to replace windows. However, this has not yet proven practical to satisfy the passenger's desire to see outside of the airplane on demand. Industry believes that requiring this unproven technology as a mitigation is premature.

The overarching objective of the open rotor blade release proposal is to achieve the same safety as an equivalent turbofan aeroplane. In a turbofan, the fan containment case precludes the impacting of full blades on the fuselage. To prevent Catastrophic effects and minimise passenger fatality from blade release, the fuselage of the open rotor aeroplane requires structural reinforcement beyond what is required for a turbofan. This reinforcement acts not only to protect against open rotor blades, but also protects against a number of other potential threats to passengers. Examples include but are not limited to: small fragments released during rotorburst events; external impacts by ground service equipment or during emergency landing; and post-crash fire events. The level of protection provided by this reinforcement is enhanced when compared to equivalent turbofan-powered aeroplanes. The area of vulnerability associated with a window is small compared to the area of increased protection. Overall, this increased protection against other threats offsets the small reduction in protection by specifically excluding windows from open rotor blade release. Hence, the Industry position is that the objective of equivalent safety is preserved.

Authority position

Protection of the windows is essential due to the proximity of passengers. Creating an aperture where blades and fragments could impact the passengers would not meet the safety objective. Several design options exist to prevent passengers from being exposed to debris:

(1) Provide penetration-resistant windows;

(2) Eliminate windows in the blade impact zone, possibly provide alternative features that simulate windows; and

(3) Locate passengers outside the impact area, e.g. by installing lavatories, emergency exit doors and galleys in the impact zone, so no windows are required.

Provide penetration-resistant windows

Impact-resistant materials exist that can mitigate penetration of the windows. Other options include layered window designs. The number of windows that would typically be located within the open rotor blade impact zone is relatively small, 3 on each side of the fuselage.

The window frames offer significant structural capability so the weight increase would likely result from the window material and beefing up of the retention features. The industry position is that preventing penetration of the windows is impractical. However, no data, including weight calculations, were provided by the industry members. Therefore, excluding the windows is not justified.

Eliminating windows in the impact zone

On many flights, passengers are requested to keep the window shades closed to assist sleeping, watching entertainment and controlling heating of the passenger compartment while on the ground. Technology is available to provide for video images of the external aeroplane view. Windows are not provided in a number of locations on other aeroplane models. No windows are located where passenger exit doors, frame bays where environmental control system ducting, and lavatories are located. These features could be located in the impact zone so no passenger windows would be needed.

How the ToR objective is met

Global interpretation of equivalent safety

The finally agreed revision to CS 25.903(d)(1) does not strictly meet the turbofan safety standard for fan blade release, in that Catastrophic effects of open rotor blade release have not been precluded for all trajectories. However, the ShG concluded that equivalence to turbofan safety standards would be achieved when taking into account the increased open rotor safety standards relating to other threats. This is a global interpretation of equivalent safety.

'Pairs' of threats, each has one fail-safe, the other is Catastrophic (CAT)

Consider the turbofan and open rotor pairs of threats in the table below.

	Turbo fan engine		Open rotor engine	
Threat	Fan blade release	Fan disc burst	Open rotor blade release	Open rotor hub burst
Safety standard at aircraft level	Preclude HAZ and CAT* (CS-E 810)	Minimise CAT	Minimise CAT	Preclude HAZ and CAT** (CS-E 845)

* Derived from 'No Hazardous engine effect' requirement at engine level.

** Derived from the new fail-safe requirement at engine level for hub.

So comparing these pairs of threats , each pair has one threat that is fail-safe and the other threat has a residual risk of catastrophic effect.

Furthermore, the following proposed changes to CS-E impose higher standards than turbofan and turboshaft engines. Open rotor hubs and blades will be required to meet higher overload standards than turbofan discs and blades, as required by the new CS-E 842 (Open rotor centrifugal load tests). The proposed CS-E 520(c)(3) will require that there is no Hazardous effect on the gas generator of an open rotor engine following open rotor blade failure. There is no equivalent requirement for a turboprop engine.

The following table compares the turbofan and open rotor engine safety standards for various criteria.

COMPARISON OF TURBOFAN FAN STAGE AND OPEN ROTOR SAFETY STANDARDS

Criteria	**Turbofan standard***	**Open rotor safety standard**	**Comment**
Disk/hub Design	Safe life (critical part)	Fail-safe or damage-Tolerant	Open rotor higher standard
Disk/hub testing	Tested to 120 % of max permissible speed as a minimum	Tested to 200 % of max load	Open rotor higher standard
Disk/hub failure effect at A/C level	Potential for CAT hazards (1/3 disk debris & 1/10 specific residual risk)	No potential for CAT hazards. Failure of internal disks can impact open rotor hub, potentially reducing safety	Open rotor similar standard
Blade Design	Not classified as critical part	Critical part (Safe life)	Open rotor higher standard, but open rotor module significantly increases the critical part count
Blade retention system Testing	Tested to 120 % of max permissible speed as a minimum	Tested to 200 % of max load	Open rotor higher standard
Effect of blade release at A/C level	Part 25 design precautions against 1/3 aerofoil. No HAZ engine effect (containment required by CS-E 810)	Prevent CAT effects for impact on airframe Residual risk of CAT effects from impact on other engine	Turbofan higher standard Neither standard accounts for off field landings, impact with snow banks, FOD, impact with ground handling equipment, wheels up landing. Today's turbofan engines have been shown to safely shutdown with birds exceeding 8 lbs. This was not addressed by the ShG.
Imbalance following blade release	No CAT effect	No CAT effect	Same standard

* For certain engines, turbofan standards have been modified by special conditions. For example, some composite turbofan blades required testing to 200 % max load, lightning strike on the blade and a retention reliability of extremely improbable.

The ShG concluded, based on respective positions for open rotor blade failure residual risk, that taking account of open rotor blade and hub failure risks, and those safety standards that are higher than turbofan safety standards, a safety standard at an aircraft level equivalent to that of turbofan fan disc and fan blades will be achieved.

2.4.1.4. CS 25.925 Ground clearance

CS 25.925(a) requires adequate propeller clearance with the ground during ground operations. The 'pusher' configuration of the open rotor installation, when mounted on the airframe empennage (tail-mounted), may present unique installation conditions that were not envisioned when the rule was promulgated.

Specifically, paragraph 'a' of the requirement is written for tricycle or tail dragger gear, with propellers mounted forward of the line of aircraft pitch rotation. As such, there are some specific conditions called out in the requirement for ground clearance considerations that should be expanded to ensure proper evaluation of a rear fuselage-mounted 'pusher' configuration at the critical case which is take-off rotation.

2.4.1.5. CS 25.933 Reversing systems

CS 25.933 on *Reversing Systems* currently prescribes different requirements for turbojet reversing systems in CS 25.933(a) versus propeller reversing systems in CS 25.933(b). Due to the evolution of the turbojet requirements based on in service experience, including accidents and significant events, they currently require demonstration of compliance with a higher safety standard.

Revision to the CS 25.933 requirement is needed to require open rotor reverser systems to comply with the extremely improbable requirement of 25.933(a), with the reliability methods described in AMC 25.933(a)(1), to ensure an equivalent level of safety between turbojet and open rotor reverser systems. Likewise, AMC 25.933(a)(1) is made applicable to open rotor engine reversing systems.

2.4.1.6. CS 25.1305 Power plant instruments

CS 25.1305(d) and (e) both list power plant instrumentation or indications required to be displayed to the flight crew. The intent of both sub-paragraphs is similar but, owing to the different design configuration and characteristics of the turbojet/turbofan and turboprop, the required indications are different. Given that the open rotor engine has similarities to both a turboprop and a turbofan neither sub-paragraph completely captures adequately the requirements for indication for an open rotor power plant.

Examination and comparison of the sub-paragraphs shows that three indications are mandated:

(1) An indication of the power plant thrust production at a point in time whether through the direct measurement of thrust or a parameter related to thrust. In the case of the turboprop, the engine provides a power or torque input to the propeller which then produces thrust.

(2) An indication of the power plant being in a configuration which could produce reverse thrust or drag/negative thrust.

(3) Only in CS 25.1305(d), an indication of rotor unbalance.

Therefore, wording is required to achieve the indication of the above parameters/conditions in a manner most appropriate for an open rotor engine.

For open-rotor-powered aeroplanes, a new sub-paragraph CS 25.1305 (g) is required to be added to CS 25.1305 in order to reflect the specific indication requirements of an open rotor installation.

2.4.1.7. CS-25 propeller requirements applicable to open rotor engine installations

Most of the CS-25 requirements which reference propellers or turboprops were judged to be appropriate and adequate for open rotor engine installations. Therefore, the extent of rulemaking required is to add '... and open rotor engines' or '... and aircraft powered by open rotor engines' respectively to these requirements.

2.4.2. CS-E

2.4.2.1. CS-E 10 Applicability

Background and rationale for the proposed changes:

Requirement (reflects the majority position):

An engine with an open rotor will receive a type certificate when compliance with CS-E Subparts A, D, E and F has been demonstrated. The corresponding ETCDS will include a note stating the installed aeroplane requirements of subpart G must be completed prior to aircraft certification. The ETCDS note will then be removed when compliance with Subpart G has been accepted by the engine certification team, based on flight-test results. This approach is entirely consistent with CS-P.

AMC material (reflects the majority position):

The AMC provides the precise wording to be entered in the ETCDS until compliance with Subpart G has been demonstrated. This approach is entirely consistent with CS-P.

The ShG members were unable to reach full consensus on this point. The two alternative positions are stated below:

Minority position: Regulations which address the safe installation of the engine in the aeroplane are typically located in CS-25; regulations which address the safety of the engine as a stand-alone system are typically addressed in CS-E (Part 33). CS-E 650 addresses the effect of the aeroplane on the engine, and therefore seems to align better with CS-25 requirements, such as CS 25.907. Treating this as a CS-25 requirement would preserve the capability of certifying an engine independently of the aeroplane.

Majority position: The two-step approach, initially requiring an engine type certificate data sheet (ETCDS) note (stating the installed aeroplane requirements of subpart G must be completed prior to aircraft certification) is consistent with CS-P. The later removal of the ETCDS note will require only a re-issue of the engine ETCDS, not the engine type certificate. This approach ensures the finding of compliance for the installation effects on the open rotor, is determined by the engine certification team, whereas the minority position would require the aircraft certification team to approve compliance of an engine level issue.

2.4.2.2. CS-E 15 Terminology

Background and rationale for the proposed changes:

Requirement:

Appropriate definitions from CS-P 15 Terminology have been transferred, with some wording changes as appropriate.

AMC material:

There is no existing AMC material and none is proposed.

2.4.2.3. CS-E 30 Assumptions

Background and rationale for the proposed changes:

Requirement:

No change proposed to the existing requirement.

AMC material:

Include additional guidance regarding definition of high energy debris, specific to an engine with an open rotor.

2.4.2.4. CS-E 40 Ratings

Background and rationale for the proposed changes:

Requirement:

No change proposed to the existing requirement.

AMC material:

Include specific reference to an open rotor.

2.4.2.5. CS-E 50 Engine Control System

Background and rationale for the proposed changes:

Requirement:

The requirements of CS-P 230 Propeller Control System were reviewed to ensure they were adequately covered by CS-E 50 Engine Control System.

Whilst CS-E 50(c)(3) covers single failures of the control system resulting in a hazardous engine condition, the requirement has been amended to also include loss of normal open rotor pitch control, not limited to just a single failure that may not result in a hazardous engine condition — a read-across from CS-P 230(b)(3).

AMC material:

Additional AMC specifically addressing the loss of primary open rotor pitch control requirement is introduced by requirement (c)(5).

2.4.2.6. CS-E 52 Open Rotor Feathering

Background and rationale for the proposed changes:

Requirement:

New requirement read-across from CS-P 220 Feathering Propellers, whilst combining CS-P 220(d) into (a) and making it specific to an engine with an open rotor.

AMC material:

New AMC material read-across from AMC to CS-P 220 Feathering Propellers, combining section (d) into (a) and making it specific to an engine with an open rotor.

2.4.2.7. CS-E 54 Variable and Reversible Pitch Open Rotor

Background and rationale for the proposed changes:

Requirement:

New requirement read-across from CS-P 210 Variable and Reversible Pitch Propellers, whilst making it specific to an engine with an open rotor.

AMC material:

New AMC material read-across from AMC to CS-P 210 Variable and Reversible Pitch Propellers, whilst making it specific to an engine with an open rotor.

2.4.2.8. CS-E 185 Open Rotor Functional Test

Background and rationale for the proposed changes:

Requirement:

New requirement read-across from CS-P 400 Functional Test, whilst making it specific to an engine with an open rotor. The reference to 'manual control' has been removed as the open rotor will be automatically controlled by the control system. The option to show compliance by similarity has also been removed since the open rotor will be unique and an integral part of the engine, rather than a separate bolt-on module.

AMC material:

New AMC material read-across from AMC to CS-P 400 Functional Test, whilst making it specific to an engine with an open rotor.

2.4.2.9. CS-E 510 Safety Analysis

It confirms excessive drag as a Hazardous Engine Effect and adds specific reference to an engine with an open rotor.

AMC material:

It provides guidance prompts when completing the safety analysis for an engine with an open rotor. Also provides a definition of excessive drag.

2.4.2.10. CS-E 512 Open Rotor Debris Model

Background and rationale for the proposed changes:

Requirement:

New requirement derived (not read-across from CS-P). It recognises that CS-E 810 has been amended to allow the release of a single open rotor blade as well as the additional material associated with consequential damage following the blade release. The debris model provides the aeroplane constructor with the necessary information to complete an aircraft level assessment of the released engine material.

AMC material:

New AMC material to support the new requirement.

2.4.2.11. CS-E 520 Strength

Background and rationale for the proposed changes:

Requirement:

The existing rule has been amended to be consistent with CS-E 810 Compressor and Turbine Blade Failure, in allowing the release of an open rotor blade and consequential damage.

AMC material:

Existing AMC material has been noted to also apply to the additional requirement paragraph added.

2.4.2.12. CS-E 570 Oil System

Background and rationale for the proposed changes:

Requirement:

The existing rule has been amended to generalise the feathering system: all references to ‘Propeller feathering system’ have been changed to ‘feathering system’.

AMC material:

No change proposed to the existing AMC material.

2.4.2.13. CS-E 640 Pressure Loads

Background and rationale for the proposed changes:

Requirement:

Read-across from CS-P 430 Propeller Hydraulic Components, included as an additional section within the existing CS-E 640.

AMC material:

Minor changes to the existing AMC material to reflect the additional paragraph in the requirement and add specific reference to open rotor components.

2.4.2.14. CS-E 650 Vibration Surveys

Background and rationale for the proposed changes:

Requirement:

It confirms that the existing CS-E 650 requirements apply to open rotor components as well as accepting that the open rotor, like a propeller, is subject to vibration effects due to the installation, requiring compliance with Subpart G.

AMC material:

It confirms that the existing CS-E 650 requirements equally apply to open rotor components. In addition, it states the need to comply with Subpart G.

2.4.2.15. CS-E 655 Open Rotor Fatigue Characteristics

Background and rationale for the proposed changes:

Requirement:

New requirement, essentially a copy of CS-P 370 Fatigue Characteristics, with the appropriate changes to apply to an engine with an open rotor. The resultant fatigue characteristics for the open rotor will then be used as an input to show compliance with Subpart G.

AMC material:

New AMC material, essentially a copy of AMC to CS-P 370 Fatigue Characteristics, with removal of the references to solid aluminium alloy blades and wooden fixed pitch propellers.

2.4.2.16. CS-E 742 Components of the Open Rotor Control System

Background and rationale for the proposed changes:

Requirement:

New requirement read-across from CS-P 420 Components of Propeller Control System, whilst making it specific to an engine with an open rotor.

AMC material:

AMC material read-across from AMC P 420 Components of Propeller Control System, whilst making it specific to an engine with an open rotor.

2.4.2.17. CS-E 780 Icing Conditions

Background and rationale for the proposed changes:

Requirement:

Whilst it was noted that the lower tip speed and variable pitch control of Open Rotors(s) will affect ice accretion/shedding, it was concluded the current CS-E 780 requirement did not require any amendment.

AMC material:

AMC 25.929(a) contains guidance on propeller de-icing which is appropriate to be applied to Open Rotor de-icing. Therefore, reference to AMC 25.929(a) is added to AMC E 780.

2.4.2.18. CS-E 790 Ingestion of Rain and Hail

Background and rationale for the proposed changes:

Requirement:

It introduces a reference to an open rotor and the corresponding large hailstone concentration, independent of core inlet area.

AMC material:

It defines the open rotor inlet area in order to allow the required large hailstone concentration. It also introduces the large hailstone rig test option. Finally, it clarifies that open rotor and the corresponding core engine can separately be shown to comply with the rain and hail ingestion requirements.

2.4.2.19. CS-E 795 Open Rotor Lightning Strike

Background and rationale for the proposed changes:

Requirement:

CS-E explicitly addresses the effects of lightning strike on both the engine control system and engine equipment. The open rotor is exposed to the possibility of a direct lightning strike, therefore CS-P 380 Lightning Strike, has been read-across, whilst making it specific to an engine with an open rotor. CS-P 380 states ‘without causing a Major or Hazardous effect’, however, since CS-E 510 does not define major engine effects directly applicable to the open rotor, they have been included in the requirement.

AMC material:

Read-across from CS-P 380 Lightning Strike, whilst making it specific to an engine with an open rotor.

2.4.2.20. CS-E 800 Bird Strike and Ingestion

Background and rationale for the proposed changes:

Requirement:

There were protracted ShG discussions on Bird Strike and Ingestion requirements for an engine with an open rotor.

It should be noted that the engine regulator representatives on the ShG stipulated that given there was no containment casing for the open rotor, then the open rotor blades must be subject to an 8 lb single large bird, irrespective of the open rotor inlet area. It is noted that the equivalent for a propeller is a 4 lb bird.

The core inlet area of an engine with an open rotor would continue to be based on the existing inlet area tables; however, given the inevitably smaller core inlet area of an engine with an open rotor, relative to that of a bypass engine in the same thrust class, it will inevitably result in a smaller bird requirement for the core section. It is recognised that based on expected multi-engine rates of birds heavier than the medium bird demonstration, there is a significant potential for Multi Engine Power Loss (MEPL) to be higher than current turbofans in a similar thrust class. However, the option to defer judgement to the Aviation Advisory Rulemaking Committee (ARAC), and in particular the

Transport Airplane and Engine (TAE) subcommittee's bird working group was proposed in order to consider the required number and weight of birds to be ingested.

A notable discussion point centred on the potential for an open rotor, due to it having variable pitch and low rotational speed, of encountering increased bird impact energies below the 200 knots required by CS-E single large and large flocking bird requirements. Unlike a traditional turbofan therefore, any potential open rotor material loss as a result of increased impact energies below 200 knots cannot rely on a containment case to prevent any subsequent debris release. Additionally, it was noted that the CS-P 360 Bird Impact requirement for a propeller is based on a critical point analysis, albeit with a smaller 4 lb bird. In the end, however, the ShG agreed that the current CS-E requirement does not require a critical point analysis and this approach should be retained for an engine with an open rotor.

Based on the issues considered by the ShG, it is recommended that open rotor bird ingestion requirements be considered by a dedicated specialist rulemaking group. It is therefore recommended that this topic be added to the current TAE bird working group task list.

AMC material:

The existing AMC material has been updated to include a definition of the open rotor inlet area from which to determine the bird requirements.

Recognising the difficulty of carrying out successful bird tests due to blade count and therefore gaps between open rotor blades (referred to as 'low solidity'), the AMC introduces the option to demonstrate compliance through a combination of rig testing and validated analysis.

2.4.2.21. CS-E 810 Compressor and Turbine Blade Failure

Background and rationale for the proposed changes:

Requirement:

The open rotor engine by definition does not have a fan containment case. It is necessary therefore to allow non-containment of a failed open rotor blade. The changes have been incorporated into the existing CS-E 810 requirement rather than by introducing a new regulation specific to an engine with an open rotor.

Whilst allowing a hazardous engine condition following an open rotor blade release, in terms of the potential for high energy debris release, including consequential secondary damage, the requirement does not allow any further hazardous engine condition prior to engine shutdown.

AMC material:

Run-on requirements following open rotor blade failure have been added. The assumed position of the failure of the open rotor (default being the top of the retention member) is required to be consistent with the assumption made in CS-E 512 Open Rotor Debris Model.

2.4.2.22. CS-E 840 Rotor Integrity

Background and rationale for the proposed changes:

Requirement:

No proposed change to the existing requirement.

AMC material:

Open rotor Integrity is addressed by the new requirements:

— CS-E 842 Open Rotor Centrifugal Load Test; and

— CS-E 845 Open Rotor Integrity.

On the basis that the CS-E 842 Open Rotor Centrifugal Load Test requirement is always more arduous than the current CS-E 840 Rotor Integrity test requirement, the AMC has been amended to confirm that open rotor integrity is addressed by CS-E 842 and CS-E 845, not CS-E 840. The intention is either CS-E 840 or CS-E 842/845 to apply to an engine rotor, not both.

2.4.2.23. CS-E 842 Open Rotor Hub Centrifugal Load Tests

Background and rationale for the proposed changes:

Requirement:

Proof test has been read-across from CS-P 350 Centrifugal Load Tests to read-across good integrity experience demonstrated by the turboprop fleet, with minimal change to make it specific to an engine with an open rotor.

AMC material:

Read-across from CS-P 350 Centrifugal Load Tests, with minimal change to make it specific to an engine with an Open Rotor.

2.4.2.24. CS-E 845 Open Rotor Hub Integrity

Background and rationale for the proposed changes:

Requirement:

CS-E 840 Rotor Integrity/CS-E 842 Open Rotor centrifugal Load Tests, whilst demonstrating open rotor hub margin to burst, do not preclude open rotor hub failure.

The regulators' representatives on the ShG stipulated:

(1) Failure of the open rotor hub must be precluded, given the potential for sufficient energy to hazard the aircraft.

(2) Requirement for damage tolerant and fail-safe open rotor hub design — a damage-tolerant design without detection of impending failure or a fail-safe (multiple load path) design without detection of dormant failure, is not sufficient.

AMC material:

New guidance material has been produced to support the new requirement.

2.4.2.25. CS-E 900 Propeller Parking Brake

Background and rationale for the proposed changes:

Requirement:

Include reference to an Open Rotor.

AMC material:

There is no existing AMC material and none is proposed.

2.4.2.26. CS-E SUBPART G - ENGINE WITH AN OPEN ROTOR: VIBRATION AND FATIGUE EVALUATION TESTS

Background and rationale for the proposed changes:

Requirement:

CS-E subpart G is effectively a copy of CS-P subpart D, with references to propeller changed to open rotor. It addresses airframe interaction effects on both open rotor vibration and fatigue. See CS-E 10 Applicability for further discussion on this requirement and the ShG minority position.

The one exception to the read-across of CS-P Subpart D is CS-P 560 (Flight Functional Tests). This is based on CS-25 certification test requirements adequately covering the content of CS-P 560 and additionally makes it consistent with FAA Part 35 (Airworthiness Standards: Propellers).

The CS-P Subpart D requirements that have been copied over to CS-E Subpart G are the following:

— CS-P 510 Applicability becomes CS-E 1110

— CS-P 530 Vibration and Aeroelastic Effects becomes CS-E 1120

— CS-P 550 Fatigue Evaluation becomes CS-E 1130

AMC material:

The corresponding AMC material has also been copied over, with references to propeller changed to open rotor.

2.5. The Agency’s position on contentious issues raised by the ShG

Full consensus has not been reached in four areas. Both positions in each of the contentious issues are documented and fully reproduced in this NPA.

The four areas of contention, and the proposed way forward, are as follows:

Minimising catastrophic consequences for cross-engine debris

The issue relates to the installation of open rotor engines and the potential risk due to cross-engine debris exposure. This is when a failure of one engine results in separation of an open rotor blade or other high energy debris, which then impinges on and damages a second engine. This failure scenario would constitute a potentially Catastrophic failure condition in a twin engine configuration and must therefore be minimised to the lowest practical value. While accepting that zero risk is probably unachievable due to the restrictions on design configurations or on the level of shielding that would be required, a residual risk level based on a geometric probability of occurrence is proposed, similar to that used for discs.

The industry position is that a value needs to be chosen that provides the necessary flexibility to allow optimisation of design configurations that balance safety concerns with commercial, environmental and other factors. Industry studies concluded that a geometric residual risk level of 1/20 provided a reasonable and practical target that balanced these factors. Industry further contests that enhancements in other safety standards beyond current turbofan standards will compensate for any increased residual risk due to this failure scenario.

The view of authority members of the regulatory authorities' representatives on the ShG is that a residual risk level of 1/40 constitutes a realistic target, which has parallels with the existing accepted design requirement for an average intermediate-size rotor disc fragment. A study on the feasibility of meeting the 1/40 for a typical configuration was subsequently undertaken by the FAA and illustrated a level of flexibility. As a compromise position, a value of 1/35 was offered.

Agency position

The Agency is of the opinion that each failure condition must be addressed separately and mitigated to achieve at least the minimum safety objective. The fact that safety may have been enhanced in other areas bears no significance to this issue. The Agency should not show undue bias to any specific technological solution or sector of industry, but adopt objective rules that meet the safety intent. In comparison to turbofan engines, for which the containment system offers a high level of protection, moving to a probabilistic approach is already a change in philosophy that will introduce additional risk and could be seen as favouring open rotor engines. This level of risk must however remain within the bounds of acceptability and the 1/35 residual risk value offered by the authorities is a further attempt to reach a compromise. The Agency takes the view that any further increase in risk would be unacceptable.

Minimising risk to occupants

Turbofan-powered aircraft and their occupants are afforded a high level of protection against uncontained blade hazards on account of the engines' containment structure. As open rotor engines are aimed at replacing turbofan engines in the next generation of aircraft, there is a need to show at least an equivalent level of safety. Without such a structure for open rotor engines, protection must be provided by alternative means, including fuselage shielding.

The industry position is that shielding would be a practical means of protecting occupants, except for windows. Removing the windows or removing passenger seats from the blade impact zone would constrain cabin design and/or passenger acceptance and without this flexibility may be an economic burden to the airlines.

The view of the regulatory authorities' representatives on the ShG is that without taking into account the windows, their capability to shield occupants, and their location close to passengers, the safety objective will not be met.

Agency position

The Agency is of the opinion that the aircraft and occupants must be afforded a level of protection against uncontained engine debris in an open rotor configuration equivalent to that provided by a turbofan engine. If the design of conventional windows to protect against this hazard is impractical, then restricting the potential design configuration would be the only acceptable alternative. It is anticipated that an application for certification of an aircraft incorporating open rotor engines will not be received before 2020, so there is still time for industry to invest in technology that would resolve this issue.

Airframe interaction effects for vibration and fatigue

Majority position

An engine with an open rotor will receive a type certificate when compliance with CS-E Subparts A, D, E, and F has been demonstrated. The corresponding Engine type certificate data sheet (ETCDS) will include a note stating that the installation requirements of Subpart G must be completed prior to aircraft certification. The ETCDS note will then be removed when compliance with Subpart G has been accepted by the engine certification team, based on flight-test results.

Minority position

Regulations which address the safe installation of the engine in the aeroplane are typically located in CS-25 and regulations which address the safety of the engine as a stand-alone system are typically addressed in CS-E. CS-E-650 addresses the effect of the aeroplane on the engine, and therefore seems to align better with CS-25 requirements, such as 25.907. Treating this as CS-25 requirement would preserve the capability of certifying an engine independent of the aeroplane.

Agency position

The Agency supports the majority position. The two-step approach, initially requiring an ETCDS note (stating that the installed aeroplane requirements of Subpart G must be completed prior to aircraft certification) is consistent with CS-P. The later removal of the ETCDS note will require only a reissue of the engine ETCDS, not the engine type certificate. This approach ensures that the finding of compliance for the installation effects on an open rotor engine is determined by the engine certification team, whereas the minority position would require the aircraft certification team to approve compliance of an engine-level issue.

Open rotor engines cannot be distinguished from turboprops

The ShG struggled to establish a definition of an ‘open rotor engine’ to the satisfaction of all. This was partly due to the variety of possible configurations that were envisaged and the need to encapsulate all. There appears to be no unique identifying feature for open rotor engines that distinguish them from turboprops.

The minority position noted that turboprop aircraft are equivalently safe to turbofan aircraft with regard to engine-related causes, and that there was no safety basis for broad changes to either the turboprop engine or aeroplane installation regulations. The minority view was that the difference between turboprop and open rotor engines lies only in the certification strategy, not in any specific technical aspect. Therefore, an open rotor engine should be considered as a turboprop, and held to the same regulations as the existing turboprops.

Agency position

The Agency’s principal objective is to establish and maintain a high uniform level of civil aviation safety in Europe. As a minimum, therefore, the Agency needs to ensure that the established level of safety is not adversely impacted by the introduction of new technologies. As the foreseen market for open rotor technologies is in the class of aircraft currently powered by turbofan engines, it is the established level of safety for turbofan engines, and the associated airworthiness requirements dictating their design and installation, that must form the basis for open rotor requirements.

Adhering to this principle will ensure that overall safety levels are maintained as open rotor aeroplanes take a larger portion of the aeroplane fleet.

Where it can be shown that this is not the case, and if the open rotor module is physically separated from the engine to be considered as a separate product, then the open rotor module could be certified under CS-P. However, as CS-P does not currently address contra-rotating propellers, the Agency may prescribe a special condition to establish a level of safety for this novel feature that is equivalent to that established in CS-P.

Stakeholders' views on these specific points are explicitly requested.

3. Proposed amendments

The text of the amendment is arranged to show deleted text, new or amended text as shown below:

(a) deleted text is marked with ~~strike through~~;

(b) new or amended text is highlighted in grey;

(c) an ellipsis (…) indicates that the remaining text is unchanged in front of or following the reflected amendment.

3.1. Draft certification specifications (Draft EASA Decision) — CS-25

BOOK 1
SUBPART B — FLIGHT

CS 25.33 Propeller and open rotor speed and pitch limits

(a) The propeller and open rotor speed and pitch must be limited to values that will ensure–

(1) Safe operation under normal operating conditions; and

(2) Compliance with the performance requirements in CS 25.101 to 25.125.

...

CS 25.103 Stall speed

...

(b) V_{CLMAX} is determined with:

(1) Engines idling, or, if that resultant thrust causes an appreciable decrease in stall speed, not more than zero thrust at the stall speed;

(2) Propeller and open rotor pitch controls (if applicable) in the take-off position;

...

CS 25.107 Take-off speeds

…

(b) V_{2MIN}, in terms of calibrated airspeed, may not be less than:

(1) 1·13 V_{SR} for –

(i) Two-engined, ~~and~~ three-engined turbo-propeller- and open-rotor-engine-powered aeroplanes; and

(ii) Turbojet-powered aeroplanes without provisions for obtaining a significant reduction in the one-engine-inoperative power-on stall speed;

(2) 1·08 V_{SR} for –

(i) Turbo-propeller- and open-rotor-engine-powered aeroplanes with more than three engines; and

(ii) Turbojet-powered aeroplanes with provisions for obtaining a significant reduction in the one-engine-inoperative power-on stall speed: and

(3) 1·10 times V_{MC} established under CS 25.149.

…

CS 25.111 Take off path

...

(c) During the take-off path determination in accordance with sub-paragraphs (a) and (b) of this paragraph –

...

(4) The aeroplane configuration may not be changed, except for gear retraction and automatic propeller and open rotor feathering, and no change in power or thrust that requires action by the pilot may be made, until the aeroplane is 122 m (400 ft) above the take-off surface;

...

CS 25.143 General

...

(c) The aeroplane must be shown to be safely controllable and manoeuvrable with the most critical of the ice accretion(s) appropriate to the phase of flight as defined in Appendices C and O, as applicable, in accordance with CS 25.21(g), and with the critical engine inoperative and either its propeller (if applicable) in the minimum drag position or its open rotor (if applicable) in its approved shutdown position:

(1) At the minimum V_2 for take-off;

(2) During an approach and go-around; and

(3) During an approach and landing.

...

CS 25.145 Longitudinal control

…

(c) It must be possible, without exceptional piloting skill, to prevent loss of altitude when complete retraction of the high lift devices from any position is begun during steady, straight, level flight at 1·08 V_{SR1}, for propeller-powered aeroplanes or 1·13 V_{SR1}, for turbo-jet powered aeroplanes or V_{2MIN}, as defined in CS 25.107(b), for open-rotor-engine-powered aeroplanes, with –

(1) Simultaneous movement of the power or thrust controls to the go-around power or thrust setting;

(2) The landing gear extended; and

(3) The critical combinations of landing weights and altitudes.

…

CS 25.147 Directional and lateral control

(a) *Directional control; general.* (See AMC 25.147(a).) It must be possible, with the wings level, to yaw into the operative engine and to safely make a reasonably sudden change in heading of up to 15°

in the direction of the critical inoperative engine. This must be shown at 1·3 V_{SR1}, for heading changes up to 15° (except that the heading change at which the rudder pedal force is 667 N (150 lbf) need not be exceeded), and with –

(1) The critical engine inoperative and either its propeller in the minimum drag position or its open rotor in its approved shutdown position;

...

(b) *Directional control; aeroplanes with four or more engines.* Aeroplanes with four or more engines must meet the requirements of sub-paragraph (a) of this paragraph except that –

(1) The two critical engines must be inoperative with either their propellers (if applicable) in the minimum drag position or their open rotors (if applicable) in the approved shutdown position;

...

(c) *Lateral control; general.* It must be possible to make 20° banked turns, with and against the inoperative engine, from steady flight at a speed equal to 1·3 V_{SR1}, with –

(1) The critical engine inoperative and either its propeller (if applicable) in the minimum drag position or its open rotor (if applicable) in its approved shutdown position;

...

CS 25.149 Minimum control speed

...

(c) V_{MC} may not exceed 1·13 V_{SR} with –

...

(7) If applicable, the propeller or open rotor of the inoperative engine –

(i) Windmilling;

(ii) In the most probable position for the specific design of the propeller or open rotor control; or

(iii) Feathered, if the aeroplane has an automatic feathering device acceptable for showing compliance with the climb requirements of CS 25.121.

...

(f) (See AMC 25.149 (f)) V_{MCL}, …

(5) For propeller and open rotor aeroplanes, the propeller or open rotor of the inoperative engine in the position it achieves without pilot action, assuming the engine fails while at the power or thrust necessary to maintain a 3 degree approach path angle; and

...

(g) (See AMC 25.149(g)) For aeroplanes with three or more engines, V_{MCL-2},

...

(5) For propeller and open rotor aeroplanes, the propeller or open rotor of the more critical engine in the position it achieves without pilot action, assuming the engine fails while at the power or thrust necessary to maintain a 3 degree approach path angle, and the propeller or open rotor of the other inoperative engine feathered

...

(h) In demonstrations of VMCL and VMCL-2 –

...

(4) For propeller and open rotor aeroplanes, hazardous flight characteristics must not be exhibited due to any propeller or open rotor position achieved when the engine fails or during any likely subsequent movements of the engine, open rotor or propeller controls (see AMC 25.149(h)(4)).

SUBPART C — STRUCTURE

CS 25.345 High lift devices

...

(b) The aeroplane must be designed for the conditions prescribed in sub-paragraph (a) of this paragraph except that the aeroplane load factor need not exceed 1·0, taking into account, as separate conditions, the effects of –

(1) Propeller or open rotor slipstream corresponding to maximum continuous power at the design flap speeds VF, and with take-off power at not less than 1·4 times the stalling speed for the particular flap position and associated maximum weight;

...

CS 25.361 Engine and auxiliary power unit torque

(a) For engine installations:

(1) Each engine mount, pylon and adjacent supporting airframe structures must be designed for the effects of:–

(i) a limit engine torque corresponding to take-off power/thrust and, if applicable, corresponding propeller or open rotor speed, acting simultaneously with 75% of the limit loads from flight condition A of CS 25.333 (b);

(ii) a limit engine torque corresponding to the maximum continuous power/thrust and, if applicable, corresponding propeller or open rotor speed, acting simultaneously with the limit loads from flight condition A of CS 25.333 (b); and

(iii) for turbo-propeller and open rotor engine installations only, in addition to the conditions specified in sub-paragraphs (a) (1) (i) and (ii), a limit engine torque corresponding to take-off power and propeller or open rotor speed, multiplied by a factor accounting for propeller or open rotor control system malfunction, including quick feathering, acting simultaneously with 1 g level flight loads. In the absence of a rational analysis, a factor of 1·6 must be used.

(2) The limit engine torque to be considered under sub-paragraph (1) must be obtained by:

(i) for turbo-propeller or open rotor engine installations, multiplying mean engine torque for the specified power/thrust and speed by a factor of 1·25

...

CS 25.367 Unsymmetrical loads due to engine failure

(a) The aeroplane must be designed for the unsymmetrical loads resulting from the failure of the critical engine. Turbo-propeller and open-rotor-engine-powered aeroplanes must be designed for the following conditions in combination with a single malfunction of the propeller or open rotor drag limiting system, considering the probable pilot corrective action on the flight controls:

...

(3) The time history of the thrust decay and drag build-up occurring as a result of the prescribed engine failures must be substantiated by test or other data applicable to the particular engine-propeller combination or open rotor engine.

(4) The timing and magnitude of the probable pilot corrective action must be conservatively estimated, considering the characteristics of the particular engine-propeller-aeroplane or open rotor engine aeroplane combination.

...

SUBPART D — DESIGN AND CONSTRUCTION

CS 25.629 Aeroelastic stability requirements.

(a) General. The aeroelastic stability evaluations required under this paragraph include flutter, divergence, control reversal and any undue loss of stability and control as a result of structural deformation. The aeroelastic evaluation must include whirl modes associated with any propeller, open rotor or rotating device that contributes significant dynamic forces.

...

(d) Failures, malfunctions, and adverse conditions

...

(5) For aeroplanes with engines that have propellers, open rotors or large rotating devices capable of significant dynamic forces, any single failure of the engine structure that would reduce the rigidity of the rotational axis.

(6) The absence of aerodynamic or gyroscopic forces resulting from the most adverse combination of feathered propellers, open rotors or other rotating devices capable of significant dynamic forces. In addition, the effect of a single feathered propeller, open rotor or rotating device must be coupled with the failures of sub-paragraphs (d)(4) and (d)(5) of this paragraph.

(7) Any single propeller, open rotor or rotating device capable of significant dynamic forces rotating at the highest likely overspeed.

...

CS 25.771 Pilot compartment

...

(b) The primary controls listed in CS 25.779 (a), excluding cables and control rods, must be located with respect to the propellers and open rotors so that no member of the minimum flight crew (established under CS 25.1523), or part of the controls, lies in the region between the plane of rotation of any inboard propeller or open rotor and the surface generated by a line passing through the centre of the propeller or open rotor hub making an angle of 5^{o} forward or aft of the plane of rotation of the propeller or open rotor.

...

CS 25.809 Emergency exit arrangement

...

(f) Each door must be located where persons using them will not be endangered by the propellers or open rotors when appropriate operating procedures are used.

...

CS 25.875 Reinforcement near Propellers and open rotors

(a) Each part of the aeroplane near the propeller or open rotor tips must be strong and stiff enough to withstand the effects of the induced vibration and of ice thrown from the propeller or open rotor.

(b) No window may be near the propeller or open rotor tips unless it can withstand the most severe ice impact likely to occur.

SUBPART E — POWER PLANT

CS 25.903 Engines

...

(c) *Control of engine rotation*.

...

If hydraulic propeller or open rotor feathering systems are used for this purpose, the feathering lines must be at least fire-resistant under the operating conditions that may be expected to exist during feathering.

(d) *Turbine engine installations*. For turbine engine installations –

(1) Design precautions must be taken to minimise the hazards to the aeroplane in the event of an engine rotor failure or of a fire originating within the engine which burns through the engine case. (See AMC 25.903(d)(1) and AMC 20-128A.)

In addition, for any open rotor debris in the failure model from CS-E 512 which impacts the airframe,

— Catastrophic effects must be precluded; and

— the risk of fatalities to aeroplane occupants must be minimised.

(See AMCs No 1 and 2 to CS 25.903(d)(1) and AMC 20-128A)

CS 25.907 Propeller and open rotor vibration

(See CS-P 530, ~~and~~ CS-P 550, CS-E 1120 and CS-E 1130.)

(a) The magnitude of the propeller and open rotor blade vibration stresses under any normal condition of operation must be determined by actual measurement or by comparison with similar installations for which these measurements have been made.

...

CS 25.925 Propeller and open rotor clearance

Unless smaller clearances are substantiated, propeller and open rotor clearances with the aeroplane at maximum weight, with the most adverse centre of gravity, and with the propeller and open rotor in the most adverse pitch position, may not be less than the following:

(a) *Ground clearance*. There must be a clearance of at least 18 cm (7 inches) (for each aeroplane with nose wheel landing gear) or ~~(~~23 cm (9 inches) (for each aeroplane with tail-wheel landing gear) between each propeller or open rotor and the ground with the landing gear statically deflected and in the level take-off, or taxying attitude, whichever is most critical. In addition, there must be positive clearance between the propeller or open rotor and the ground when in the level take-off attitude with the critical tyre(s) completely deflated and the corresponding landing gear strut bottomed. For open rotor engines only, the maximum rotated take-off attitude must be assessed in addition to the above attitudes.

(b) *Reserved*.

(c) *Structural clearance*. There must be –

(1) At least 25 mm (1·0 inch) radial clearance between the blade tips and the aeroplane structure, plus any additional radial clearance necessary to prevent harmful vibration;

(2) At least 13 mm (0·5 inches) longitudinal clearance between propeller blades or cuffs, or open rotor blades and stationary parts of the aeroplane; and

(3) Positive clearance between other rotating parts of the propeller, ~~or~~ spinner or open rotor and stationary parts of the aeroplane.

CS 25.933 Reversing systems

(a) For turbojet and open rotor engine reversing systems:

...

CS 25.937 Turbo-propeller and open rotor engine drag limiting systems

Turbo-propeller-powered aeroplane propeller drag limiting systems and open-rotor-engine-powered aeroplane open rotor drag limiting systems must be designed so that no single failure or malfunction of any of the systems during normal or emergency operation results in propeller or open rotor drag in excess of that for which the aeroplane was designed under CS 25.367.

CS 25.1025 Oil valves

…

(b) The closing of oil shut-off means may not prevent propeller or open rotor feathering.

…

CS 25.1027 Propeller and open rotor feathering system

(See AMC 25.1027.)

(a) If the propeller or open rotor feathering system depends on engine oil, there must be means to trap an amount of oil in the tank if the supply becomes depleted due to failure of any part of the lubricating system other than the tank itself.

…

(d) Provision must be made to prevent sludge or other foreign matter from affecting the safe operation of the propeller or open rotor feathering system.

CS 25.1153 Propeller and open rotor feathering controls

(a) There must be a separate propeller feathering control for each propeller and a separate open rotor feathering control for each open rotor engine. The control must have means to prevent its inadvertent operation.

(b) If feathering is accomplished by movement of the propeller or open rotor engine pitch or speed control lever, there must be means to prevent the inadvertent movement of this lever to the feathering position during normal operation.

CS 25.1155 Reverse thrust and propeller and open rotor pitch settings below the flight regime

Each control for selecting propeller or open rotor pitch settings below the flight regime (reverse thrust for turbo-jet powered aeroplanes) must have the following:

...

(b) A means to prevent both inadvertent and intentional selection or activation of propeller or open rotor pitch settings below the flight regime (reverse thrust for turbo-jet-powered aeroplanes) when out of the approved in-flight operating envelope for that function, and override of that means is prohibited.

...

(e) A caution provided to the flight crew when a cockpit control is displaced from the flight regime (forward thrust regime for turbojet-powered aeroplanes) into a position to select propeller or open rotor pitch settings below the flight regime …

CS 25.1189 Shut-off means

(c) Operation of any shut-off means may not interfere with the later emergency operation of other equipment, such as the means for feathering the propeller or open rotor.

SUBPART F — EQUIPMENT

CS 25.1305 Power plant instruments

…

(g) *For open-rotor-engine-powered aeroplanes.* In addition to the power plant instruments required by sub-paragraphs (a) and (c) of this paragraph, the following power plant instruments are required:

(1) An indicator to indicate power or thrust, or a parameter that is directly related to power or thrust, to the pilot. The indication must be based on the direct measurement of power or thrust or of the parameters that are directly related to power or thrust. The indicator must indicate a change in power or thrust resulting from any engine malfunction, damage or deterioration. (See AMC 25.1305 (g)(1).)

(2) An indicator to indicate to the flight crew when open rotor blade angle is below the in-flight low-pitch position, for each engine.

(3) An indicator to indicate rotor system unbalance.

SUBPART G — OPERATING LIMITATIONS AND INFORMATION

CS 25.1549 Power plant instruments

…

(d) Each engine, ~~or~~ propeller or open rotor speed range that is restricted because of excessive vibration stresses must be marked with red arcs or red lines.

CS-25 BOOK 2

AMC 25.903(b)

Engine isolation

In order to comply with this requirement, aircraft manufacturers intending to install open rotor engines will need to take note of the following. In complying with the strike and ingestion of foreign matter requirements of CS-E 540, open rotor engine manufacturers will declare a level of open rotor blade debris that could be released, if any, as a result of the strike/ingestion. Aircraft manufacturers will need to assess the risk of this debris impacting the other engine(s) and nacelle(s). When such impacts are possible, the engine manufacturer will have to provide evidence that the damage to the other engine(s) and nacelle(s) will not preclude continued safe flight and landing.

AMC 25.903(d)(1)

Amend the title of this AMC to read AMC No 1 25.903(d)(1)

AMC No 2 to 25.903(d)(1)

1 Uncontained engine rotor failures for open rotor engines

For an open rotor engine, the engine rotor failure requirements of CS 25.903(d)(1) are applicable to the whole engine, including the open rotor module. For rotor failures in the gas generator, the advisory material AMC 20-128A is applicable. This AMC provides advisory material to address rotor failures in the open rotor module, including the safety assessment required.

2 Safety objectives for uncontained rotor failures in the open rotor module

CS 25.903(d)(1) requires that ‘design precautions must be taken to minimize the hazards to the aeroplane in the event of an engine rotor failure. In addition, for any open rotor debris in the failure model from CS-E 512 which impacts the airframe,

— Catastrophic effects must be precluded and

— the risk of fatalities to aeroplane occupants must be minimised.’

The safety objectives are

1 Preclude Catastrophic effects for impact on airframe;

2 Minimise risk of Catastrophic effects for impact on other engine; and

3 Minimise risk of occupant fatalities.

The applicant needs to show for open rotor debris impact:

- the effectiveness of airframe shielding — safety objective to preclude Catastrophic effects;
- that damaged airframe can sustain unbalance loads — safety objective to preclude Catastrophic effects;
- that fuselage deflections do not enter a keep-out zone representing a seated occupant;
- that there is occupant protection from blade fragments penetrating the passenger cabin;

— the residual risk assessment for trajectories that impact the other engine — safety objective to minimise Catastrophic effects; and

— high power condition — safety objective preclude Catastrophic effects.

3 Terminology

Catastrophic effect. In addition to the definition of Catastrophic effect in AMC 25.1309, the impact of open rotor debris on the other engine is considered a Catastrophic effect unless it can be demonstrated that the impact of the released debris will not prevent continued safe flight and landing.

Airframe. The airframe is the whole aircraft excluding the engines and their nacelles.

Other engine. The use of this term is interpreted to mean other engine(s) and nacelle(s)

4 Means of compliance applicable to all safety objectives

4.1 Open rotor module failure model

a. General

The open rotor module failure model will define the fragment characteristics, for example, sizes, number, spread angles, trajectories and energies. In addition to this information, the unbalance loads will be required. Both are required to show that the open rotor module complies with the requirements of CS 25.903(d)(1). In view of the anticipated novel features in open rotor module designs, all the characteristics of the failure model to be used may need to be project-specific.

b. Responsibilities for creating and substantiating the failure model

The fragment numbers, sizes and energies, being entirely dependent on the engine design, are the responsibility of the engine manufacturer to define and substantiate to their authority, in accordance with CS-E 512. The engine manufacturer will need to provide the aircraft manufacturer with some level of detail of the blade design to allow the aircraft manufacturer to carry out impact simulations. In addition, the engine manufacturer will provide unbalance loads in accordance with CS-E 520(c)(2).

The minimum open rotor blade fragment is defined by the engine manufacturer in compliance with CS-E 512.

c. Debris trajectory (front view)

When assessing the impact location and conditions on the airframe or the other engine, the following alternative assumptions are acceptable. Kinematic motion of debris about its centre of gravity, as illustrated below for a generic blade debris, may be considered.

Such a kinematic debris trajectory model should be project-specific, not a general model.

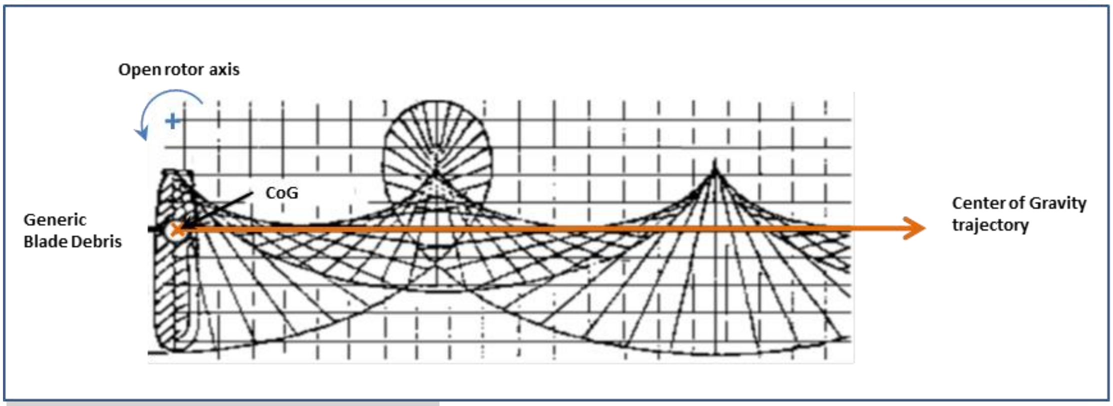


Figure 1 Kinematic debris trajectory

Alternatively, the size of the largest CS-E 512 fragment dimension can be used, without any kinematic effect, that is, the full length of the debris in the above example.

Whichever assumption is used, the trajectory of the fragment CoG should be used to distinguish between those trajectories that impact the airframe and therefore need to comply with the preclude Catastrophic effects safety objective and those trajectories that do not impact the airframe.

d. Blade spread angle

The fragment spread angle for open rotor blade fragments is the angle measured fore and aft from the plane of rotation of an individual open rotor stage, initiating at the outer rim of the hub.

The plane of rotation is defined by the blade pitch change axis.

To allow for novel blade designs which could bias the fragment trajectory either fore of aft of the plane of rotation, a project specific nominal (or mean) trajectory is defined at Θ^o to the plane of rotation.

The range of the spread angle is 6^o, symmetrically placed relative to the nominal trajectory unless an alternative spread angle can be substantiated.

Thus the spread angle is Θ^o+/-3^o. See Figure 2 below.

An analytical method for determining Theta should be used (through airframe/engine manufacturers interchange) in time to determine airframe primary structural design, and meet the requirements of this Subpart. Any anomaly between this analytical method and the CS-E512 model and/or results should be reconciled by the airframe and engine manufacturers.

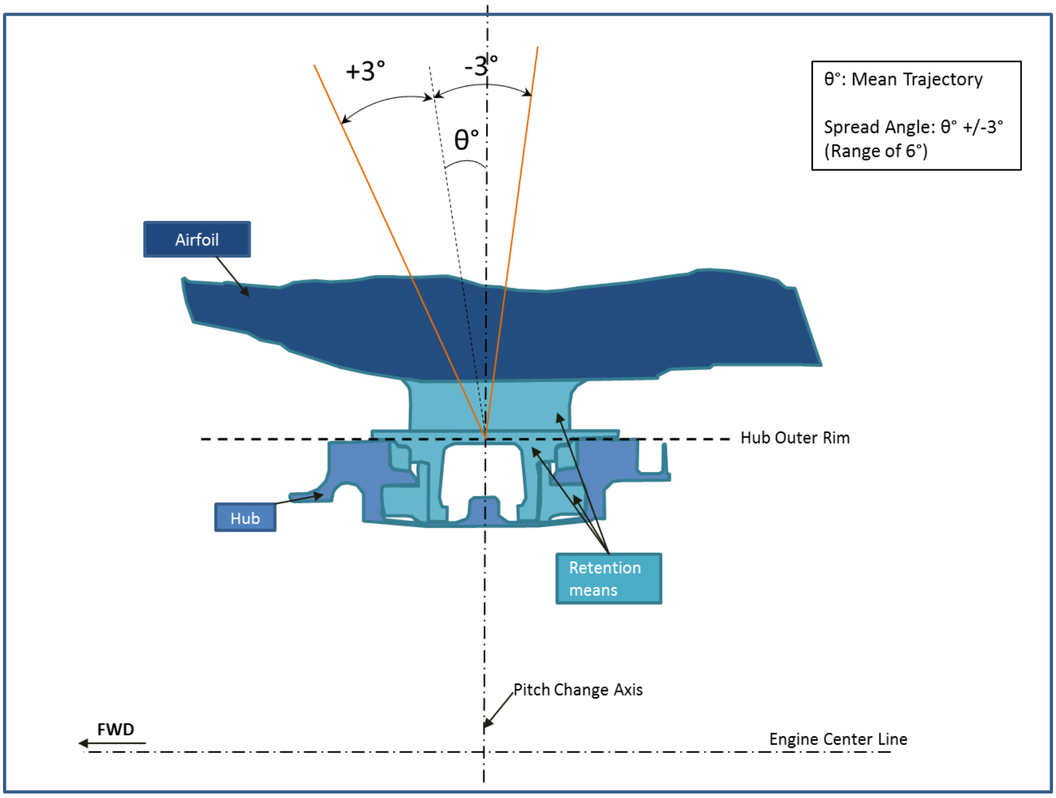


Figure 2 Spread angle and mean trajectory

e. Fragment energy

The fragment energy is the energy when the event occurs assuming a rotor speed of 100 % redline.

4.2 Safety analysis

A safety analysis should be made using the failure model provided by the engine manufacturer in accordance with CS-E 512 to determine the critical areas of the aeroplane likely to be damaged by open rotor debris, to evaluate the consequences of this damage and unbalance loads, and drive the design of the shielding and other appropriate design precautions. This analysis should be conducted in relation to all normal phases of flight, or portions thereof. Drawings should be provided to define the open rotor impact threat by showing the trajectory paths of open rotor debris relative to critical areas. See AMC 20-128A, paragraph 10(a) and (b), for further guidance, which is applicable to this safety analysis.

5 Precluding Catastrophic effects for impacts on the airframe

5.1 Effectiveness of shielding

In order to preclude Catastrophic effects for those trajectories of debris that impact the airframe, it may be necessary to provide shielding. The effectiveness of this shielding will need to be demonstrated by test and/or analysis. Any analysis tool will need to be validated by test. The effects of structural deflections on systems need to be taken into account.

5.2 Residual strength and unbalance loads

Should the airframe sustain any damage, the ability of the aircraft to ensure continued safe flight and landing in this damaged condition will need to be shown, taking account of the unbalance loads. However, it should be noted that the compliance with CS 25.903(c) Control of Engine Rotation will contribute significantly to minimising the unbalance loads. This objective will be met by complying with CS 25.362 and AMC 25-24 criteria for the damaged airframe. As well as effects on structure, this will address effects on essential systems including effects on other engine, pilotability due to sustained windmilling and the high power condition.

Any structural damage resulting from open rotor debris should be considered catastrophic unless the residual strength criteria below and the flutter criteria of AMC 25.571(a) sub-paragraph 2.7.2 can be met without failure of any part of the structure essential for completion of the flight.

Static loads

The static loading cases to be considered are based on the UERF loads specified in AMC 20-128A paragraph 10(b)(1), the Sustained Engine Imbalance static loads specified in AMC 25-24, paragraph 5c(3)(a) and CS 25.362(b) criteria.

<u>Time of occurrence</u>:

— 1g+(ΔP+ΔPaero)*1.1

— ‘Over swing’ condition loads

— transient loads + 1g (*1.0 for mounts and pylon, *1.25 for adjacent structure) + (when appropriate) 1.0ΔP and 1.0ΔP aero

<u>Continued flight</u>:

— initial descent, cruise, descent, approach (phases of diversion mission): peak windmill loads + get home loads (1g + 0.7 limit flight manoeuvre loads, 1g + 0.4 limit gust loads) + (when appropriate) 1.0 ΔPcabin and 1.0ΔPaero

— initial descent, cruise, descent, (phases of diversion mission): 1.375 * (peak windmill+1g + when appropriate 1.0 ΔPcabin and 1.0ΔPaero).

— approach: 1.375 * (peak windmill + 1.15g manoeuver+ when appropriate 1.0 ΔPcabin and 1.0ΔPaero)

Fatigue and damage tolerance

Fatigue and damage tolerance analysis as specified in AMC 25-24, paragraph 5c(4) should be carried out.

Note:

The pressurised compartment loads of CS 25.365(e)(1) and (g) must be met.

5.3 Systems

Design precautions should be used to preclude the risk of catastrophic system effects from impacts on the airframe. These precautions may include location of critical components outside the fragment impact areas or separation, isolation, redundancy, or shielding of critical aeroplane components and/or systems. AMC 20-128A, paragraphs 7 and 8, contain details of acceptable design precautions and specific risks.

5.4 High power condition

The high power imbalance condition occurs immediately after blade failure but before the engine is shut down or otherwise spools down. This condition addresses losing less than a full blade which may not be sufficient to cause the engine to spool down on its own. This condition may last from several seconds to a few minutes. In some cases, it could hamper the crew's ability to read instruments that may have aided in determining which engine was damaged. An imbalance condition equivalent to XX percent of one blade at cruise rotor speed considered to last for 20 seconds may be assumed unless it is shown that the engine will respond automatically and spool down in a shorter period. The imbalance loads possible at the high power condition should be provided by the engine manufacturer. The assessment of vibration frequency, amplitude, structural coupling/resonances and pilot reaction time must be analysed to determine if additional study of this condition is necessary, beyond that contained in AMC 25-24, section 9. It should be shown that attitude, airspeed and altimeter indications will withstand the vibratory environment of the high power condition and operate accurately in that environment. Adequate cues should be available to determine which engine is damaged.

6 Minimising risk for open rotor blade fragments that could impact the other engine

Where possible, the engines should be installed to minimise the exposure to cross-engine debris by maximising the protection provided by the airframe. The cross-engine debris trajectories will be included in the residual risk calculations.

Compliance with the requirement to minimise the risk of CAT effects from cross-engine debris will be met if there is not more than 1/35 geometric (1/60 with reduction factors) specific risk of a Catastrophic effect from release of one blade from the outermost retention feature to the tip from each open rotor stage considered separately for engine to engine trajectories. The probability assessment methodology of AMC 20-128A, Appendix 1, Section 6 can be used. The flight phase risk reduction factors proposed in that AMC are considered applicable to open rotor engines until data is accumulated to suggest a change is needed, or unless others can be substantiated.

In determining the specific risk, any impact on the other engine affecting continued safe flight and landing will need to be evaluated taking account of:

- the ability of the other engine to provide useful thrust; and
- the loads from unbalance in all engines.

7 Minimising risk of occupant fatalities

7.1 Deflection of airframe

Where a seated occupant is located anywhere in the applicable spread angle cones (in 4.1 d above) associated with each rotor, an analysis is required. This analysis will show that the Outer Mould Line (OML) of the aeroplane fuselage shall not deflect inwards any more than that required to prevent impact of aircraft structural elements with the head of the 95 % male, fully seated against the backrest (see figure 3), when impacted by debris from the open rotor failure model.

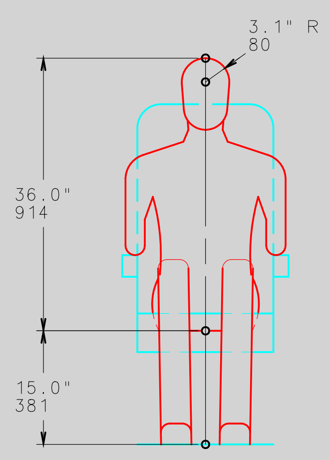


Figure 3. 95 % male, adapted from 'The Measure of Man and Woman, Human Factors in Design' revised edition 2002.

7.2 Fragments penetrating the passenger compartment

Impact on occupants from debris which could penetrate the passenger compartment should be precluded.

Acceptable precautions are the preclusion of passenger compartment penetration or debris energy absorption before impact on the occupant.

8 Final assessment at aircraft level

It will be considered that compliance with CS 25.903(d)(1) will have been met if:

a. For the gas generator and power turbine (if applicable), the safety analyses for the rotor stages are carried out and the acceptable residual risk levels have been achieved, in accordance with AMC 20-128A, Section 10.

b. For the open rotor module:

   i. The safety analysis of Section 4.2 has been carried out.

   ii. The effectiveness of the means to preclude Catastrophic effects from impacts of open rotor debris on the airframe has been demonstrated in accordance with Section 5.

   iii. The safety analyses for the open rotor stages are carried out and the acceptable residual risk levels in Section 6 have been achieved.

   iv. The risk of occupant fatalities has been minimised in accordance with Section 7.

AMC 25.933(a)(1)

Unwanted inflight thrust reversal of turbojet and open rotor engine thrust reversing~~ers~~ systems

AMC 25.1305(g)(1) Power plant Instruments

The following are examples of parameters which are considered to be directly related to power or thrust; engine torque, open rotor angle, speed (rpm), Integrated Engine Pressure Ratio (IEPR) and Engine Pressure Ratio (EPR), depending on engine type.

3.2. Draft certification specifications (Draft EASA Decision) — CS-E

Book 1

CS-E 10 Applicability

...

(e) An engine with an Open Rotor is eligible for a type certificate when compliance with Subparts A, D, E and F has been demonstrated. For an engine with an Open Rotor, if the additional compliance with Subpart G has not also been shown, this must be stated in the engine type certificate data sheet (ETCDS). (See AMC E 10 (e))

CS-E 15 Terminology

…

(f) Engines with an Open Rotor

Open Rotor:	means a Turbine Engine fan stage that is not enclosed within a casing.
Feather:	means moving the Open Rotor blade angle to Feathered Pitch.
Feathered Pitch:	means the Pitch setting, which in flight corresponds to an Open Rotor with a windmilling torque of approximately zero and approximately zero rotational speed.
Flight Idle:	typically means the power associated with the minimum Open Rotor blade Pitch position permitted in flight (In-Flight Low-Pitch Position).
In-Flight Low-Pitch Position:	means the minimum Open Rotor Pitch permitted in flight.
Pitch:	means the Open Rotor blade angle, measured in a manner and at a radius declared by the manufacturer and specified in the appropriate Engine Manual.
Pitch Control System:	means the components of the Engine System that functions to control Pitch position, including but not limited to governors, Pitch change assemblies, Pitch locks, mechanical stops and Feathering system components.
Reverse Pitch:	means the Open Rotor blade angle used for producing reverse thrust with an Engine. Typically this is any Open Rotor blade angle below ground idle Open Rotor blade angle.

CS-E 50 Engine Control System

(See AMC E 50)

...

(c) *Engine Control System Failures.* The Engine Control System must be designed and constructed so that:

(1) The rate for Loss of Thrust (or Power) Control (LOTC/LOPC) events, consistent with the safety objective associated with the intended aircraft application, can be achieved,

(2) In the Full-up Configuration, the system is essentially single Fault tolerant for electrical and electronic Failures with respect to LOTC/LOPC events.

(3) Single Failures of Engine Control System components do not result in a Hazardous Engine Effect,

(4) Foreseeable Failures or malfunctions leading to local events in the intended aircraft installation, such as fire, overheat, or Failures leading to damage to Engine Control System components, must not result in a Hazardous Engine Effect due to Engine Control System Failures or malfunctions.

(5) No loss of primary Open Rotor pitch control may cause a Hazardous Engine Effect under the intended operating conditions.

...

CS-E 52 Open Rotor Feathering

(See AMC E 52)

(a) Feathering Open Rotors must be designed to Feather from all conditions in flight, while taking into account likely system degradation (wear, leakage, etc.). Feathering and unfeathering limitations must be documented in the appropriate manual(s) and where appropriate the engine type certificate data sheet (ETCDS).

(b) Open Rotor Pitch Control Systems must incorporate a means to Feather that is independent of primary pitch control actuation motive force failure.

(c) Feathering Open Rotor must be designed to be capable of unfeathering after being feathered for the maximum expected diversion time at the minimum declared steady state outside air temperature.

CS-E 54 Variable and Reversible Pitch Open Rotor

(See AMC E 54)

(a) No single failure or malfunction in the Open Rotor will result in unwanted travel of the Open Rotor blades to a position below the In-Flight Low-Pitch Position. The extent of any intended travel below the normal In-Flight Low-Pitch Position must be documented in the appropriate manuals. Failure of structural elements need not be considered if the occurrence of such a failure is shown to be Extremely Remote under CS-E 510.

(b) For an engine with an Open Rotor incorporating a method to select blade Pitch below the In-Flight Low-Pitch Position, provision must be made to sense and indicate to the flight crew that the Open Rotor blades are below that position by an amount defined in the Engine Operating Instructions. The method for sensing and indicating the Open Rotor blade Pitch position must be such that its failure does not affect the control of the Open Rotor.

CS-E 185 Open Rotor Functional Test

(See AMC E 185)

(a) For an engine with an Open Rotor, the following functional tests must be completed either combined with, or in addition to, the endurance test of CS-E 740 to demonstrate that the integrated Open Rotor will function satisfactorily without evidence of failure or malfunction. The same Engine used for the test of CS-E 740 must also be used for the Open Rotor Functional Tests:

(b) The following functional tests must be carried out:

(1) For a variable pitch Open Rotor, 1500 complete cycles must be made across the range of pitch and rotational speed.

(2) For a feathering Open Rotor, 50 cycles of feathering and unfeathering operation.

(3) For a reversible pitch Open Rotor, 200 cycles must be made from minimum Flight Idle Pitch to maximum Reverse Pitch. For each cycle, while at maximum Reverse Pitch, the Open Rotor must be run for at least 30 seconds at the maximum power and rotational speed to be approved.

…

CS-E 510 Safety Analysis

(See AMC E 510)

…

(g) For compliance with CS-E, the following Failure definitions apply to the Engine:

(1) An Engine Failure in which the only consequence is partial or complete loss of thrust or power (and associated Engine services) from the Engine must be regarded as a Minor Engine Effect.

(2) The following effects must be regarded as Hazardous Engine Effects:

(i) Non-containment of high energy debris,

(ii) Concentration of toxic products in the Engine bleed air for the cabin sufficient to incapacitate crew or passengers,

(iii) Excessive drag or ~~S~~significant thrust in the opposite direction to that commanded by the pilot,

(iv) Uncontrolled fire,

(v) Failure of the Engine mount system leading to inadvertent Engine separation,

(vi) Release of the propeller or Open Rotor by the Engine, if applicable,

(vii) Complete inability to shut the Engine down.

…

CS-E 512 Open Rotor Debris Model

(See AMC E 512)

For Engines with an Open Rotor, a debris model must be prepared identifying the debris which would be released by the Open Rotor as a result of any failure reasonably expected to occur. The debris model must include estimates of fragment masses, geometries, numbers, energy levels and initial trajectory range from the plane of the rotor.

CS-E 520 Strength

...

(c) (1) The strength of the Engine must be such that the shedding of compressor or turbine blades, either singly or in likely combinations, will not result in a Hazardous Engine Effect (e.g. as a long term effect in respect of those Failures which would not be detected by the declared instrumentation, such as vibration detectors and within the likely shutdown time for those which would be detected, and during any continued rotation after shutdown). (See AMC E 520 (c)(1))

(2) Validated data (from analysis or test or both) must be established and provided for the purpose of enabling each aircraft constructor to ascertain the forces that could be imposed on the aircraft structure and systems as a consequence of out-of-balance running and during any continued rotation with rotor unbalance after shutdown of the Engine following the occurrence of blade Failure as demonstrated in compliance with CS-E 810. If the Failure of a shaft, bearing or bearing support or bird strike event, as required under CS-E 800, result in higher forces being developed, such Failures must also be considered, except for bird strike in relation to continued out-of balance running. (See AMC E 520 (c)(2)&(c)(3)).

(3) Following the shedding of Open Rotor blades, either singly or in likely combinations, the strength of the Engine must be such that no Hazardous Engine Effect can arise as a result of other Engine damage likely to occur except for non-containment of high energy debris originating from the Open Rotor blades themselves. (See AMC E 520 (c)(2)&(c)(3)).

...

CS-E 570 Oil System

(See AMC E 570)

…

(e) (1) Except where the tank, its supports and all oil system components external to the Engine casing are Fireproof, a means must be provided to shut off the oil supply to the Engine. The means must be such that in the event of Failure of any oil system pipe, it will, when operated, prevent the discharge of hazardous quantities of oil.

(2) When applicable, operation of the shut-off means must not prevent the utilisation of any oil supply intended for the ~~Propeller~~ feathering operation.

(f) (1) Each un-pressurised oil tank must not leak when subjected to the maximum operating temperature and a differential pressure of 35 kPa.

(2) Each oil tank must have, or have provision for, an oil quantity indicator.

(3) If a ~~Propeller~~ feathering system depends on Engine oil:

(i) There must be means to trap an amount of oil in the tank if the supply becomes depleted due to Failure of any part of the lubricating system other than the tank itself. The amount of trapped oil must be enough to accomplish one feathering operation taking into account deterioration in service, and must be available only to the feathering pump.

(ii) Provision must be made to prevent sludge or foreign matter from entering the ~~Propeller~~ feathering system.

(iii) The design of the Engine oil system must be such that it is possible to complete the feathering and unfeathering operation under all normal operating conditions.

…

CS-E 640 Pressure Loads

(See AMC E 640)

…

(b) It must be established by test, validated analysis or combination thereof that Open Rotor components which are subject to significant gas or liquid pressure loads can withstand, for a stabilised period of one minute:

(1) A Proof Pressure equal to 1.5 times the maximum working pressure without permanent deformation or leakage that would prevent performance of the intended function.

(2) A Burst Pressure equal to 2.0 times the maximum working pressure without failure. Leakage is permitted and seals may be excluded from tests.

(c)~~(b)~~ Compliance with CS-E 640 (a) or (b) must take account of:

(1) The operating temperature of the part,

(2) Any other significant ~~static~~ loads in addition to pressure loads,

(3) Minimum properties representative of both the material and the processes used in the construction of the part, and

(4) Any adverse geometry conditions allowed by the type design.

CS-E 650 Vibration Surveys

(See AMC E 650)

…

(b) The vibration surveys must cover the ranges of power or thrust and rotational speed for each rotor module, including open rotor modules, corresponding to operations throughout the range of ambient conditions in the declared flight envelope, from the minimum rotational speed up to at least the maximum of:

(1) 103 % of the maximum rotational speed permitted for rating periods of two minutes or longer;

(2) 100 % of the maximum rotational speed permitted for rating periods of less than two minutes;

(3) 100 % of any Maximum Engine Over-speeds declared under CS-E 830.

...

(h) Compliance with this CS-E 650 must be substantiated for each specific installation configuration that can affect the vibration characteristics of the Engine. If these vibration effects cannot be fully investigated during Engine certification, the methods by which they can be evaluated and compliance shown must be substantiated and defined in the Engine instructions for installation required under CS-E 20 (d). For an Engine with an Open Rotor, those instructions must state that this substantiation is shown by compliance with CS-E Subpart G.

CS-E 655 Open Rotor Fatigue Characteristics

(See AMC E 655)

(a) Fatigue characteristics, to support CS-E 650 and Subpart G, must be established by tests, or analysis based either on tests or previous experience, for:

(i) Hubs,

(ii) Blades,

(iii) Blade retention components, and

(iv) Other Open Rotor components, which are affected by fatigue loads and which are shown under CS-E 510 as having a fatigue Failure Mode leading to Hazardous Engine Effects.

(b) The fatigue characteristics must take into account:

(i) All known and reasonably foreseeable vibration and cyclic load patterns that are expected in service, and

(ii) Expected service deterioration, variations in material properties, material fatigue scatter, manufacturing variations and environmental effects.

CS-E 742 Components of the Open Rotor Control System

(See AMC E 742)

By tests or analysis based on tests or service experience on similar components, it must be demonstrated that each component of the Pitch Control System can withstand cyclic operation that simulates the normal load and pitch change travel to which the component would be subjected during not less than 1000 hours of typical operation in service.

CS-E 790 Ingestion of Rain and Hail

(See AMC E 790)

(a) *All Engines*

(1) The ingestion of large hailstones (0.8 to 0.9 specific gravity) at the maximum true air speed, for altitudes up to 4500 metres, associated with a representative aircraft operating

in rough air, with the Engine at Maximum Continuous power/thrust, must not cause unacceptable mechanical damage or unacceptable power or thrust loss after the ingestion, or require the Engine to be shut down. One-half the number of hailstones must be aimed randomly over the inlet face area and the other half aimed at the critical inlet face area. The hailstones must be ingested in a rapid sequence to simulate a hailstone encounter and the number and size of the hailstones must be determined as follows:

(i) One 25-millimetre~~s~~ diameter hailstone for Engines with inlet throat areas of not more than 0.0645 m^2.

(ii) One 25-millimetre~~s~~ diameter and one 50-millimetre~~s~~ diameter hailstone for each 0.0968 m^2 of inlet throat area, or fraction thereof, for Engines with inlet throat areas of more than 0.0645 m^2.

(iii) For an Engine with an Open Rotor: One 25-millimetre diameter and one 50-millimetre diameter hailstone for each 0.0968 m^2 of Open Rotor inlet area, or fraction thereof.

…

CS-E 795 Open Rotor Lightning Strike
(See AMC E 795)

It must be demonstrated, by tests or analysis based on tests or experience on similar designs, that the Open Rotor is capable of withstanding a lightning strike without causing a Hazardous Engine Effect or any of the following:

(a) An inability to feather the Open Rotor,

(b) An inability to change Open Rotor pitch when commanded,

(c) An uncommanded change in Open Rotor pitch,

(d) An uncontrollable torque or speed fluctuation.

The limits to which the Open Rotor has been qualified must be documented in the appropriate manual(s)

CS-E 800 Bird Strike and Ingestion
(See AMC E 800)

…

(b) *Single large bird ingestion test.*

…

(1) *Test conditions.*

…

(ii) The bird to be used must be of a minimum mass of:

(A) 1·85 kg for Engine inlet throat areas of less than 1·35 m^2, including the core (primary flow path) of an Engine with an Open Rotor, unless a smaller bird is determined to be a more severe demonstration.

(B) 2·75 kg for Engine inlet throat areas of less than 3·90 m^2 but equal to or greater than 1·35 m^2.

(C) 3·65 kg for Engine inlet throat areas equal to or greater than 3·90 m^2, or the fan blades of any size Open Rotor.

(iii) The bird must be aimed at the most critical exposed location on the ~~first stage~~ fan rotor blades.

…

(c) *Large flocking bird.* An Engine test using a single bird must be carried out at the conditions specified below for Engines with an inlet throat area equal to or greater than 2.5 m^2. Alternative evidence may be acceptable as provided under CS-E 800 (f)(1).

…

(iv) The bird must be targeted on the first exposed rotating fan stage(s) at a blade aerofoil height of not less than 50 %, measured at the leading edge.

…

(d) *Medium and small birds ingestion tests. …*

(1) *Test Conditions.*

…

(v) (A) *Medium birds*. Masses and quantities of birds will be determined from column 2 of Table A. When only one bird is specified, it must be aimed at the Engine core primary flow path; the other critical locations on the Engine face area must be addressed by appropriate tests or analysis or both.

When two or more birds are specified, the largest must be aimed at the Engine core primary flow path and a second bird must be aimed at the most critical exposed location on the first stage rotor blades. Any remaining birds must be evenly distributed over the Engine face area.

For an engine with an Open Rotor:

— the core inlet throat area shall be used to define the core ingestion number and mass of birds from column 2 of Table A.

— the inlet area defined in CS-E 800(f)(9), shall be used to define a total bird number and their masses from column 2 of Table A. This total quantity shall be reduced by one (the lightest bird to be eliminated); the remainder will be aimed at the Open Rotor blades. The heaviest bird must be aimed at the most critical exposed location on the Open Rotor blades and the remaining birds must be evenly distributed over the Open Rotor blade face area.

…

(f) *General*

…

(9) For an Engine with an Open Rotor, the inlet throat area should be taken to be the frontal projected area described by the tip diameter of the largest Open Rotor stage.

CS-E 810 Compressor, Open Rotor and Turbine Blade Failure (See AMC E 810)

(a) It must be demonstrated that:

(1) ~~a~~Any single compressor or turbine blade will be contained after Failure and that no Hazardous Engine Effect can arise as a result of other Engine damage likely to occur before Engine shut down following a blade Failure.

(2) Following a failure leading to the release of a single Open Rotor blade and any consequential secondary Open Rotor blade debris release, no additional Hazardous Engine Effect can arise as a result of other Engine damage likely to occur before Engine shut down.

...

CS-E 842 Open Rotor Hub Centrifugal Load Tests (See AMC E 842)

It must be demonstrated that the Open Rotor hub complies with CS-E 842(a), (b) and (c) without evidence of failure, malfunction or permanent deformation that would result in a Hazardous Engine Effect. When the Open Rotor could be sensitive to environmental degradation, this must be taken into account.

(a) The Open Rotor hub, blade retention system, and the counterweights must be tested for a period of one hour to a load equivalent to twice the maximum centrifugal load to which the Open Rotor would be subjected at the Maximum Permissible Rotational Speed.

(b) If appropriate, Open Rotor blade features associated with transitions to the retention system must be considered in showing compliance with CS-E 842(a).

(c) Components used with or attached to the Open Rotor such as spinners, de-icing equipment, and blade shields, must be capable of withstanding for a period of 30 minutes a load equivalent to 159 % of the maximum centrifugal load to which the component would be subjected at the Maximum Permissible Rotational Speed. This may be performed by either:

(i) Testing at the required load for a period of 30 minutes, or

(ii) A validated analysis based on test.

CS-E 845 Open Rotor Hub Integrity
(See AMC E 845)

(a) No Open Rotor hub failure will permit separation of the hub, bladed segments of the hub, or more than a single blade.

(b) The blade from the top of the retention member, including retention components that are not precluded from release, must be demonstrated as defined in CS-E 810 (See AMC E 810) and included in the debris model of CS-E 512.

CS-E 900 Propeller or Open Rotor Parking Brake
(See AMC E 900)

If a Propeller or Open Rotor parking brake is provided it must be operated 100 times during the endurance test. It must be applied at the maximum Propeller or Open Rotor speed recommended by the Engine constructor.

SUBPART G — ENGINE WITH AN OPEN ROTOR: VIBRATION AND FATIGUE EVALUATION TESTS

CS-E 1110 Applicability

This Subpart prescribes the tests and evaluations to be performed on an engine with an Open Rotor and airframe combination for which approval is sought.

CS-E 1120 Vibration and Aeroelastic Effects
(See AMC E 1120)

(a) It must be demonstrated by tests, analysis based upon tests or previous experience on similar designs that the Open Rotor does not experience harmful aeroelastic effects (including flutter) or harmful effects of vibration throughout the operational envelope of the aircraft with suitable stress margins.

(b) When necessary for complying with the safety objective of CS-E 1120 (a), the magnitude of the Open Rotor vibration stresses or loads, including any stress peaks and resonant conditions, must be determined throughout the declared operational envelope of the intended aircraft by either:

  (1) Measurement of stresses or loads through direct testing or analysis based on direct testing of the Open Rotor on the aircraft and engine installation for which approval is sought, or

  (2) Comparison of this engine with an Open Rotor to similar engines with an Open Rotor installed on similar aircraft installations for which these measurements have been made.

CS-E 1130 Fatigue Evaluation
(See AMC E 1130)

(a) An evaluation of the Open Rotor must be conducted to show that failure due to fatigue will be avoided throughout the intended operational life of the Open Rotor, using the fatigue and structural data obtained in compliance with CS-E 655 and vibration data obtained in compliance with CS-E 1120. This evaluation must include:

(1) A determination of operating limitations, service life, mandatory replacement times and inspection intervals for the Open Rotor.

(2) The intended loading spectra, including all reasonably foreseeable vibration and cyclic load patterns, considering identified emergency, over-speed or over-torque conditions.

(3) The effects of temperature, humidity and likely deterioration expected in service.

(b) Each determined mandatory replacement period and inspection interval must be included in the airworthiness limitation section of the instructions for continued airworthiness required by CS-E 25.

(c) Any operating conditions or speed ranges shown by the fatigue evaluation and vibration survey to require limitation must be clearly stated in the Engine certification documentation.

Book 2

AMC E 10 (e) Engine with an Open Rotor

If approval is granted for an Engine with an Open Rotor after compliance has been shown with Subparts A, D, E and F of CS-E, the engine type certificate data sheet (TCDS) will include the following statement:

‘This Engine has been certified in accordance with CS-E Subparts A, D, E and F. Compliance with the requirements of Subpart G, which is specific to each aircraft installation, has not yet been demonstrated.’

AMC E 30 Assumptions

…
Addition to the existing TABLE 1 (Specifications/References and Assumptions):
…

Specifications/References	*Assumptions*
ENGINE WITH AN OPEN ROTOR	
Open Rotor High Energy Debris CS-E 510, E 512, E 810	Early coordination with the aeroplane constructor is advised to agree the definition of high energy debris for an Open Rotor (likely to penetrate and pass through an assumed/actual fuselage pressure skin of the intended airframe installation).
Open Rotor Excessive Drag CS-E 52, CS-E 510	Early coordination with the aeroplane constructor is advised to agree the definition of excessive drag for an engine with an Open Rotor (sufficient drag such that the aeroplane is uncontrollable at any point in the flight envelope or which would make an aeroplane with an engine out unable to climb, continue flight or land safely.

AMC E 40(d) Operating Limitations

The Operating limitations established under CS-40 (d) should normally include those items listed below.

(1) General

  (a) Environmental conditions. (Flight envelope)

  (b) Maximum declared Engine conditions for Reversible Pitch Propeller or Open Rotor operations. (If applicable)

  (c) Types of Propellers approved. (If applicable)

  (d) Equipment approved for use on the Engine.

…

(3) Turbine Engines

  …

  (u) Maximum rpm for application of Propeller or Open Rotor brake (if applicable~~.~~).

AMC E 50 (c)(5) Engine Control System

A secondary system (protection or backup, generally a feathering system) is required where the loss of the primary Open Rotor pitch control results in a Hazardous Engine Effect.

Primary Open Rotor pitch control: the part of the control system normally used for controlling Open Rotor pitch operation.

Whereas (c)(3) specifically addresses single failures, the loss of primary Open Rotor Pitch control in (c)(5) is not limited to single failures.

AMC E 52 Feathering Open Rotor

Early coordination with the aeroplane constructor is required to determine the need for Open Rotor feathering capability.

(1) Emergency conditions in flight are those flight conditions outside of normal operation but not beyond the operational envelope of the aeroplane. Flights speeds above Vne and below the stall warning speed are outside of the range of emergency conditions.

(2) The Feathering and unfeathering characteristics and limitations may include parameters such as and not limited to: Feather angle, rate of Pitch change, and airspeed limits above which the Open Rotor may not Feather completely or Feather at a slower rate. Such data should be made available to airframe TC holders, as necessary.

(3) Evaluation at the minimum declared outside temperature may be verified in a cold chamber or by flight test. If a maximum diversion time has been established for the aeroplane installation, this would be appropriate to use as the time for stabilisation to a steady state temperature.

The following term is defined for the purposes of interpreting CS-E 52 and this AMC.

Motive force:	The means by which actuation of the Open Rotor pitch mechanism is achieved. Examples might include but are not limited to pressurised oil or electrical power.

AMC E 54 Variable and Reversible Pitch Open Rotor

The extent of any intended travel should account for backlash, tolerances, secondary stops, etc. For example, a hydraulic failure of a dual acting Open Rotor System with Pitch lock operating at the In-Flight Low-Pitch Position could permit a small decrease in blade angle due to system backlash. The Pitch lock may require a small blade angle change before it engages. This value is to be documented in the Engine Installation Manual.

AMC E 185 Open Rotor Functional Test

The functional tests are intended to substantiate the control function of an Engine with an Open Rotor and may be performed in conjunction with the CS-E 740 Endurance Test.

…

AMC E 510 Safety ~~a~~Analysis

…

(4) Analytical techniques.

…

Various methods for assessing the causes, severity levels, and likelihood of potential Failure conditions are available to support experienced engineering judgement. The various types of analyses are based on either inductive or deductive approaches. Brief descriptions of typical methods are provided below. More detailed descriptions of analytical techniques may be found in the documents referenced in paragraph (6) of this AMC.

(5) Engine with an Open Rotor

The safety analysis of an Engine with an Open Rotor should consider the potential for:

(a) High unbalance loads after Open Rotor blade failure leading to mount failure,

(b) Failures in the pitch change mechanism resulting in:

  (i) High drag;

  (ii) Open Rotor overspeed;

  (iii) Uncommanded reverse thrust;

  (iv) Inability to feather the Open Rotor blades;

  (v) Uncommanded pitch change;

  (vi) Uncontrollable torque or speed fluctuation; and

  (vii) Uncommanded blade movement out of feather.

(6) Related documents.

…

(7) Definitions.

The following definitions are applicable. They should not be assumed to apply to the same or similar terms used in other specifications or AMCs.

…

Excessive Drag (Open Rotor):	Sufficient drag such that the aeroplane is uncontrollable at any point in the flight envelope or which would make an aeroplane with an engine out unable to climb, continue flight or land safely. Early coordination with the aeroplane constructor, to quantify excessive drag, is advised (see also CS-E 30 Assumptions).

High Energy Debris (Open Rotor):	The energy level of Open Rotor debris that would be likely to penetrate and pass through an assumed/actual fuselage pressure skin of the intended airframe installation (see also CS-E 30 Assumptions).

AMC E 512 Open Rotor Debris Model

The objective of preparing the debris model is to provide a rational representation, for use by the aeroplane manufacturer, of the debris that would be generated by the Open Rotor in the unlikely event of failure within the Open Rotor or affecting the Open Rotor. This will enable the aeroplane manufacturer to mitigate the effects of the debris at the aeroplane level.

Engine manufacturers and modifiers may base the CS-E-512 debris model on the results of the CS-E 510 safety analysis, augmented with estimates of the physical parameters defined in the rule. Depending on the circumstances of the application or modification, the debris model may use one or more of the following:

— A report describing details associated with a failure condition;

— An interpretation of test results;

— A comparison of two similar components or assemblies;

— Other qualitative information; or

— A detailed analysis.

The debris model must consider failure of each individual component unless it can be excluded as described below. It must consider consequential secondary failures caused by the initial failure.

The parameters provided in the debris model should include: fragment maximum dimension, to the nearest cm, fragment mass(es), axial trajectories in the immediate vicinity of the engine (as the fragment passes through the near-field envelope defined by the open rotor blade tip radius), fragment energy, the radius from engine centre line at which the fragment was released, the direction of rotation of that stage, and numbers of significant fragments.

This will result in a very large candidate list of debris models. The engine manufacturer must prepare summary debris models, for the failure progressions releasing:

— The largest fragment;

— Hazardous (high energy) fragments;

— The highest energy fragment.

In dealing with events with such very low probabilities, where absolute proof of the progression of each failure is not possible, extensive use may be made of engineering judgment, similarity and/or previous experience combined with sound design and test philosophies. If the validity of such engineering judgment is in question to the extent that the conclusions of the analysis could be invalid, additional substantiation may be required. Additional substantiation may consist of reference to previous relevant service experience, engineering analysis, material, component, rig or engine test or a combination of these. If doubt of the validity of the substantiation exists, additional testing or other validation may be required.

AMC E 520 (c)(2) and (c)(3) Engine Model Validation

Change limited to AMC title above to additionally cover new paragraph (c)(3) — no change to the AMC material

AMC E 640 Pressure Loads

(1) Definitions. For the purpose of CS-E 640 (a) and (b), the following definitions apply and should be related to the Engine when installed in a typical installation.

Normal Working Pressure:	the maximum pressure differential likely to occur on most flights including any pressure fluctuations as a result of the normal operation of valves, cocks, etc., where these could produce significant surge pressures.
Maximum Working Pressure:	the maximum pressure differential which could occur under the most adverse operational conditions (e.g. forward speed, altitude, ambient temperature, Engine speed, use of OEI ratings) likely to be encountered in service, including any pressure fluctuations as a result of the normal operation of valves, cocks, etc., where these could produce significant surge pressures.
Maximum Possible Pressure:	the maximum pressure differential which could occur under the most adverse combination of operational conditions (e.g. forward speed, altitude, ambient temperature, Engine Speed, use of OEI ratings) likely to be experienced in service, together with Failure of any relevant parts of the Engine or control system, or combinations of Failures which are more likely than Extremely Remote. Consideration should be given to any pressure fluctuations as a result of normal or emergency use of valves, cocks, etc., where these could produce significant surge pressures.
~~Static~~ Parts subject to significant gas or liquid pressure loads:	the components subject to high-pressure loads or whose design is influenced by the gas or liquid pressure loads to be contained. Examples might include the compressor, combustor and turbine casings, heat exchangers, bleed valve solenoids, fan pitch control mechanism, starter motors or fuel, oil and hydraulic system components. Special attention should be given to any filler cap.

(2) Static Pressure Tests (see CS-E 640 (a) and (b))

The anticipated Engine manual serviceable limits may be used as the criteria to judge the acceptability of any permanent distortion. When a test is performed on a part which is subjected in service to a varying pressure throughout its length, it is permissible to simulate the pressure conditions by suitably dividing the part into zones and applying the maximum pressure for each zone including the appropriate factors of CS-E 640 (a) and (b).

(3) Tests. General

If the part is subject to loads in addition to those resulting from differential pressure (e.g. flight manoeuvre loads, Engine mounting loads, rotational loads, etc.), an analysis should be made of these additional loads and their effect examined. If the effect of these loads is small it may be possible to simulate them by an addition to the test pressure differential. However, if the loads are of significant magnitude or cannot adequately be represented by a pressure increment the test should be carried out with such loads acting in addition to the pressure loads.

…

AMC E 650 Vibration Surveys

...

(1) Definitions

...

Module:
A module is either a compressor ~~or,~~ a turbine or an open rotor module which may be single or multi-stage, or a gear box. If multi-stage, the rotating elements are mechanically joined and rotate at the same speed. The gas path entry and exit points are clearly defined and are frequently nodal points in a performance model.

…

(13) Installation Compatibility.

(a) The intent of CS-E 650 (h) is to ensure vibratory compatibility between the Engine and each intended installation configuration when the Engine is installed and operated in accordance with the manufacturers approved instructions. The applicant will normally be expected to provide sufficient information in the Engine instructions for installation to enable the aircraft manufacturer(s) to establish that the installation does not unacceptably affect the Engine’s vibration characteristics. In establishing vibratory compatibility between the Engine and the installation, consideration should be given to the need to declare operating limitations and procedures. Where appropriate, at least the following aspects and installation features should be considered:

— each Propeller approved for use on the Engine;

— each thrust reverser approved for use on the Engine;

— installation influences on inlet and exhaust conditions;

— mount stiffness; ~~and~~

— rotor drive systems; and

— Open Rotor components.

(b) For Engines with an Open Rotor, installation compatibility is shown by compliance with CS-E Subpart G.

...

AMC E 655 Open Rotor Fatigue Characteristics

(1) Vibratory Loads — Acceptable Levels

The acceptable levels for vibratory loads are expressed in terms of minimum factors for the resultant vibratory stress levels when related to the working fatigue limit for the component.

(a) The mean fatigue limit should be established from an S/N Curve constructed from representative tests and other data on the material concerned. Normally, a fatigue limit established at 10^8 cycles would be acceptable.

(b) The working fatigue limit should be derived from the mean fatigue limit suitably factored to ensure, with a high degree of confidence, that all components produced to the same drawings and specifications as those tested to produce the S/N Curve of (a) will sustain no unacceptable fatigue damage.

(2) Verification of Fatigue Limits

The procedures and factors presented by this AMC are intended to produce components with unlimited fatigue lives, but the variables introduced by operation of the Engine may require special procedures to ensure that the fatigue properties of the components are adequately maintained throughout the life of the Engine. It will therefore be necessary to declare and institute methods to achieve this purpose. Such methods will usually take the form of:

(a) Adequate maintenance procedures (inspections, surface refurbishment, overhaul, etc.); and

(b) Specimen fatigue testing of components withdrawn from service at periodic intervals.

Damage Tolerance methodology can be used as an alternative to the establishment of an Approved Life, if agreed by the Agency.

AMC E 742 Components of the Open Rotor Control System

This requirement is intended to identify functionality and wear of the Open Rotor Pitch Control System's components for the purpose of establishing appropriate instructions for continued airworthiness. This may be performed in conjunction with CS-E 185 Open Rotor Functional Test.

AMC E 780
Icing Conditions

….

(1.8) Compliance of Open Rotor IPS with icing conditions

The guidance of AMC 25.929(a) for Propeller IPS should be applied to Open Rotor IPS.

…

AMC E 790 Ingestion of Rain and Hail ~~Ingestion~~

…

(6) For an Engine with an Open Rotor:

- (a) For the purposes of interpreting the 'Open Rotor inlet area' requirements of CS-E 790(a)(1)(iii), see paragraphs (1) and (5)(e) in AMC CS-E 790(a)(2).
- (b) For the purposes of interpreting the requirements of CS-E 790 (a)(2) see paragraph (5)(e) in AMC CS-E 790 (a)(2).

AMC E 790 (a)(2)
Rain and Hail Ingestion – Turbine Engine Power/Thrust Loss and Instability in Extreme Conditions of Rain and Hail

(1) Definitions

The following terms are defined for the purpose of this AMC:

…

Open Rotor inlet area	the frontal projected area between the Open Rotor blade leading edge tip and root diameters.

…

(5) Compliance Methods

…

(e) For engines with an Open Rotor:

Since the majority of Large Hailstones defined in CS-E 790(a)(1)(iii) may not strike the Open Rotor blades due to low blade solidity, rig testing to demonstrate that the Open Rotor blades will not incur unacceptable mechanical damage if impacted at critical locations under the impact conditions defined for the largest hailstone is acceptable for compliance.

Equivalent soft-body impact testing (birds, ice) which is shown to be more severe in terms of localised impact energy can be used to show compliance in place of large hailstones.

The core inlet flow field will not be significantly affected by the Open Rotor blades, thus for the requirements of CS-E 790(a)(2), the core flow can be considered in isolation from the Open Rotor. It is not necessary to subject the Open Rotor blades to the defined Appendix A rain/hail environments since mechanical integrity is assessed under CS-E 790(a)(1).

AMC E 795 Open Rotor Lightning Strike

This guidance provides a description of test methodology used to determine the effect of a lightning strike on an Open Rotor. Detailed methods, test set-up information on voltage waveforms, current waveforms, or data collection are provided in the reference documents.

(1) Consideration should be given to all components of the Open Rotor assembly that could be in the lightning path. These include but are not limited to the spinner, blade, hub, blade bearings, and possibly the Pitch change mechanism. Additional consideration should be given to electrical/electronic components that could be influenced by the indirect effects. These include Open Rotor blade and spinner de-icing system components as well as any other Open Rotor mounted electrical or electronic components.

(2) The damage caused by lightning is characterised into two categories: direct and indirect. The direct effects associated with lightning depend on the structural component involved, the attachment point and current path through the structure. The indirect effects are classified as damage to electrical equipment by the current or voltages either by the associated electromagnetic field, surges, or by current directly injected into the electrical wires. Indirect effects testing determines the conducted currents, surge voltages, and induced voltages entering the aircraft electrical system through systems such as the Open Rotor de-icing system. Testing involves measurement of voltages at the terminals of the de-icing system or other electrical/electronic systems where they connect to the aircraft electrical system.

(3) The references below provide information regarding test set-up, simulated lightning wave forms and other general procedures to conduct a lightning strike test:

(a) EUROCAE ED-81, ‘Protection of Aircraft Electrical and Electronic Systems Against the Indirect Effects of Lightning’;

(b) EUROCAE ED-14D, ‘Environmental Conditions and Test Procedures for Airborne Equipment’;

(c) EUROCAE ED-91, ‘Aircraft Lightning Zoning Standard’; and

(d) EUROCAE ED-84, ‘Aircraft Lightning Environment and Related Test Waveforms Standard’.

AMC E 800
Bird Strike and Ingestion

(1) Ingestion Tests

…

(b) Large Flocking Bird

…

The use of ‘stage(s)’ is intended to allow for alternative designs such as rear mounted fans where each exposed stage will be evaluated independently, see section (3)(c).

…

(3) Impact

…

(c) The term 'first stage rotor blades' when used in CS-E 800 includes the first stage of any fan or compressor rotor which ~~is~~ susceptible to bird strike or bird ingestion. These first stage rotor blades are considered to be part of the front of the Engine. This definition encompasses ducted, unducted and aft fan designs. In this latter case, blades on two different rotors (in primary and secondary flows) would probably need to be considered, also contra-rotating fan stages would need to assess impact effects on both blade rows.

(4) General

…

(c) CS-E 800 (f)(1) is intended to allow certification of design changes or derivative engines without conducting a full engine test. It is not intended~~, considering the present state of the art,~~ to be used for certification of new engines. However, ~~it offers the possibility of future advancement~~ new technology such as an Engine with an Open Rotor with low-solidity, variable pitch contra-rotating fans challenges the assumptions that an engine test can fully demonstrate compliance to the spirit of the regulations. It may be difficult to strike the widely spaced blades with a 'full slice' of the bird; appropriate rig testing and validated analyses may be necessary instead. Similarly, the effects of bird debris propelled from the 1st stage to a trailing stage may only be amenable to validated analyses. If the applicant has insufficient experience from prior certifications or operations, it may be necessary for compliance to be demonstrated using analyses supported by rig and/or engine testing.

(d) Any parametric analysis used to substantiate derivative engines as allowed under CS-E 800 (f)(1) should fall within a 10 % variation in the critical impact parameter used to substantiate the original base engine. The critical impact parameter(s) is often associated with impact load at the point of bird and rotor blade contact. This is generally a function of bird speed, rotor speed, and blade twist angle. This 10 % variation on the critical impact parameter should not be assumed to be a direct tolerance on the applicants proposed changes to take-off power or thrust ratings themselves.

(e) Any analytical means used in place of a test demonstration (where analysis is permitted) should be validated by evidence based on representative tests and should have demonstrated its capability to predict engine test results.

(f) When reference is made to 'exposed location' this should be understood to be any part of the engine which is not shielded.

(g) When the CS-E 810 test is proposed as an alternative to the single large bird test (see CS-E 800 (f)(2)), the demonstration should include consideration of unbalance as well as effects of the axial loading from the bird strike on bearings or other structures.

(h) Artificial birds may be used in the tests if they are internationally standardised and are acceptable to the Agency.

AMC E 810 Compressor, Open Rotor and Turbine Blade Failure

(1) General

(a) Compliance with the specifications of CS-E 810 (a)(1) may be shown in accordance with either (i), (ii) or (iii):

...

(c) Compliance with the specifications of CS-E 810 (a)(2) may be shown in accordance with either (i), (ii) or (iii):

(i) By compliance with the tests detailed in (4);

(ii) By presentation of adequate evidence substantiating the strength of the Engine either by blade Failure experience on Engines agreed by the Agency to be of comparable size, design and construction, or by blade Failures which have occurred during the development of the Engine, provided that the conditions of Engine speed, shut down period, etc., are sufficiently representative; or

(iii) By other evidence acceptable to the Agency.

...

(4) Running following Open Rotor Blade Failure

(a) The test should be conducted on a complete Engine, mounted in such a manner that the reactions induced by the out-of-balance on the Engine carcass and mounts will be representative of those which would occur in the installed condition. Alternatively, the test may be carried out on a rig, but consideration should be given to the effects of shaft power input, further subsequent damage, heavy out-of-balance forces on other parts of the Engine, possible shaft Failure, etc., when interpreting the test results as being indicative that no hazardous damage would occur in a complete Engine.

(b) Test Conditions. The test should be carried out on the Open Rotor stage adjudged to be most critical from the point of view of Engine damage subsequent to Open Rotor blade Failure as a result of out-of-balance forces existing during the period prior to Engine shutdown.

(i) The Engine should be run, with an out-of-balance representative of the loss of Open Rotor blade and retention components as defined by CS-E 845(b) and any consequential secondary damage, at the maximum rotational speed to be approved (other than the Maximum Engine Over-speed) until either the Engine stops of its own accord, or a period of at least 15 seconds has elapsed. Definition of the top of the blade retention member and the assumed consequential secondary damage should be consistent with the blade debris failure model produced in compliance with CS-E 512.

(ii) During the run, the power setting should not be altered.

(c) Condition after Test. On completion of the test, the result should be such that there is no hazard to the aircraft, except for the release of the Open Rotor blade debris. Complete power Failure is permitted.

AMC E 840 Rotor Integrity

…

(2) General:

…

(m) CS-E 840 does not apply to an Open Rotor. Open Rotor integrity is addressed by CS-E 842 and CS-E 845

AMC E 842 Open Rotor Hub Centrifugal Load Tests

(1) The pass/fail criteria for these tests is that the Open Rotor completes the tests without evidence of:

(a) Failure

A failure would consist of the release of any component or debris. The fracture of a component without release would be a failure. Specifically, the separation of a composite blade bonded to a metallic retention would be a failure, even when the design has a backup system to prevent release of the blade.

(b) Malfunction

Elastic deformation of a hub that would prevent the blades from changing Pitch would be a malfunction.

(c) Permanent deformation is not acceptable.

(2) Open Rotor hub, retention system and counterweight

(a) The maximum centrifugal load is based on the maximum permissible rotational speed declared in the type certificate data sheet (TCDS). Transient overspeed events are not considered normal and do not constitute the maximum rpm to be used for establishing test conditions.

(b) The test may be conducted on an assembly, either by whirl testing or static testing, by applying the load to the assembled components to simulate the centrifugal load, as appropriate.

(c) This test does not have to include the complete blade. Stub blades, with weights to establish the correct centrifugal load during whirl tests, can be used. The stub blades should have the same blade retention as the full blade, to maintain similarity to the full blade retention.

(3) Blade Features

Blade features such as those associated with transitions from composite blade to the metallic retention can be tested during the hub and retention system test required by CS-E 842(a) or with a separate component test. There may be other applicable configurations, such as the transition associated with a configuration in which the blade of any material construction is bonded or otherwise attached to the portion of the blade that is retained in the hub.

(4) Open Rotor Components

Open Rotor components not requiring twice centrifugal load tests should be subjected to test or analysis equivalent to the centrifugal load resulting from 126 % rotational speed (equivalent to 159 % load at 100 % speed) for a period of 30 minutes. These components may also be shown to be acceptable by similarity to existing components with applicable service history. Testing can involve whirl testing, static testing with the assembly or on a component or sub-component level. Analysis methods used to demonstrate compliance for these components should be accepted by the Agency.

AMC E 845 Open Rotor Hub Integrity

(1) The following terms are defined for the purposes of interpreting CS-E 845 and this AMC.

Hub failure: The loss of function of the hub resulting in the release of high energy debris with the exception of the release of a single Open Rotor blade as defined in CS-E 810 (a) (2)

(2) Reasonably expected to occur failures of components separate from the hub that could damage the hub must be identified. It must be shown that failure of these components will not result in the consequences defined in CS-E 845 (a).

(3) Hub failure does not result from a single failure and no combination of failures resulting in hub failure shall occur at a rate greater than 10-9 per Engine flight hour.

(4) In showing compliance with CS-E 845 (a) and (b), a damage-tolerant (‘fail-safe’) design concept should be applied. Design features which should be considered in attaining a damage-tolerant structure include the following:

- (i) Designed Integrity and Quality, including Life Limits (Critical Part), to ensure intended function and prevent failure;
- (ii) Redundancy or Multiple Load Path to enable continued function after any single and likely combination of failure;
- (iii) low probability of multiple concurrent damage which could contribute to common fracture path;
- (iv) Design features that allow failure detection before loss of residual load carrying capability;
- (v) Inspectability and appropriate Mandatory Maintenance instructions contained in the Airworthiness Limitations Section (ALS) of the instructions for continued airworthiness;
- (vi) Damage Tolerance tests in order to assess the effects of fatigue, corrosion (if applicable) and accidental damage.

(5) A single Open Rotor blade includes the blade retention features.

(6) If it can be shown to the satisfaction of the Agency that using the ‘fail-safe’ damage-tolerant design principles of AMC E 845 (4), the design releases less than a single Open Rotor blade, then this will accordingly be reflected in CS-E 810 blade failure test and CS-E 512 debris model. As a minimum, the debris model of CS-E 512 will include at least a full aerofoil and any consequential damage material released with the aerofoil.

SUBPART G — ENGINE WITH AN OPEN ROTOR: VIBRATION AND FATIGUE EVALUATION TESTS

AMC E 1120 Vibration and Aeroelastic Effects

If a test is to be conducted for compliance with CS-E 1120, then:

(a) The disposition and number of measuring points should be such as to give adequate indication of vibratory stresses in all significant flapping, edgewise and torsional modes of the blade.

(b) The survey should provide for at least the following:

   (i) Ground Engine. The survey should cover all the operating combinations of speed and torque from Ground Idle to Maximum Governed Rotational Speed;

   (ii) Aircraft Engine ground and flight tests.

   The results of (b)(i) should show that the stresses likely to be present in conducting the flight tests of (b)(ii) are not excessive.

   The results of (b)(ii) should be used in conjunction with the fatigue data generated in CS-E 655 to carry out the Fatigue Evaluation of CS-E 1130.

   (iii) In conducting the tests of (b)(ii), the complete range of aircraft and operating conditions should be covered over the range of aircraft weights. The testing should also cover all ground operations, including Reverse Pitch if applicable, over the range of wind speed and directions for which approval is sought.

AMC E 1130 Fatigue Evaluation

(1) From the fatigue data generated in CS-E 655 (S/N curve), a mean line is established together with a low probability of failure line. The low probability of failure line should take account of statistical variation due to scatter of results and due to the number of test specimens.

(2) The fatigue evaluation on the Open Rotor, using data generated to show compliance with CS-E 655 and CS-E 1120, should use suitable factors to allow for manufacturing and material variations, deterioration during service and the permitted range of aircraft loading. In the absence of any other data, the combined effect of these factors should be taken as 1.5. The low probability of failure line should be reduced by this combined factor to produce a working line to be used in the fatigue evaluation.

(3) If the fatigue data on full size components is for full reversal tests with no steady load, then the effect of the steady loads should be taken into account in the evaluation. Coupon tests may be used to establish the effect of steady loads.

(4) The fatigue evaluation can be carried out using safe life methods where the damage sustained during each vibratory cycle in the Open Rotor's life can be summed using methods such as Miner's rule using a working line on the S/N curve as established in (1) above.

(5) Damage Tolerance methodology can be used as an alternative to the establishment of an Approved Life, if agreed by the Agency.

(6) It is recognised that operation of the Open Rotor may result in changes to the fatigue properties of the Open Rotor. Therefore, in addition to adequate maintenance procedures (inspections,

surface refurbishment, overhaul, etc.), specimen fatigue testing of components withdrawn from service at periodic intervals may be required.

4. Regulatory impact assessment (RIA)

4.1. Issues to be addressed

A new engine concept is being proposed to power future large transport aircraft as a means of reducing aircraft fuel burn and emissions. This concept is known as the 'open rotor engine' concept.

Designs of open rotor engines are being considered by a number of engine design organisations. In conjunction, over the past 3 years, industry stakeholder efforts (airframe manufacturers, engine manufacturers, and research partners) have led to significant achievements (NACRE, DREAM). These efforts confirm the viability of an open rotor-driven aircraft. These efforts will be continued into the future at both the sub-scale level and in product scale engine demonstrator programmes. The culmination of these efforts will be an associated engine demo flying test bed.

The open rotor engine concept contains some features of traditional turbine engines and some propeller system features. For certification, existing turbofan/turboprop engines must comply with the appropriate issue of CS-E, while propellers must comply with CS-P. The Agency and the FAA have recommended that the open rotor engine concept should be certified under CS-E. The reasons for this are as follows:

In the case of a traditional turbo prop engine, the Engine and Propeller are two separate products, certified under two different certification specifications (CS-E and CS-P), and then integrated on the aircraft. In view of the very high level of integration (e.g. control system, casings, gearbox) in open rotor engine designs between the gas generator and the open rotor module, this traditional turboprop approach is not feasible. It has been identified that some parts of these requirements are either inadequate or inappropriate due to the novel open rotor engine features (e.g. CS-E 800 Bird Strike and Ingestion, CS-E 810 Compressor and Turbine Blade Failure CS-E 840 Rotor Integrity). Therefore, CS-E will need to be amended to address these features.

Furthermore, for type certification, aircraft must comply with the appropriate issue of CS-25. Existing requirements assume that an aircraft is powered by either a turbofan or a turboprop engine. It has been identified that some parts of these requirements are either inadequate or inappropriate due to the novel open rotor engine features, for example CS 25.901(c), CS 25.903(d)(1). Therefore, CS-25 may not be directly applicable to an aircraft powered by an open rotor engine and will need to be amended to address these features.

One particular issue of note is the consequences of Uncontained Engine Rotor Failure (UERF). Since CS 25.903(d)(1) is applicable to engine installations, the issue arises as to whether and to what extent CS 25.903(d)(1) can be applied to the installation of the whole open rotor engine. The failure model defined in AMC 20-128A as acceptable means of compliance with CS 25.903(d)(1) does not appear to be applicable to the open rotor novel features. Since the open rotor failure model to be considered will heavily depend on the open rotor engine failure analysis, engine manufacturers will need to be involved in the compliance demonstration of the CS-25, by providing the interface data (e.g. open rotor debris and initial trajectory) for this installation issue.

4.1.1. *Safety risk assessment*

This task relates to the possible introduction of new technology and is not addressing a safety issue for the existing turbofan/propeller fleet. An objective of this task is to ensure that a fleet of aircraft using the open rotor engine concept should maintain the safety level consistent with that of the existing turbofan fleet. Since the introduction of new technology always involves addressing risk, the open rotor technology is no exception. Relative to turbofans, open rotor engines do not feature a fan containment casing, so that the threat from open rotor blade failure is one of the risks that has been addressed in the rulemaking process. Therefore, stakeholders views, especially on the NPA's contentious issues, are explicitly requested (e.g. Section 2.5).

4.1.2. *Who is affected?*

This issue affects aircraft and engine manufacturers, and regulatory authorities.

4.1.3. *How could the issue/problem evolve?*

Introduction of new technology is not facilitated

If the introduction of such technology is not facilitated, one sector of the large commercial aircraft fleet that could be affected, is single-aisle aircraft of the 737/A320 category. The ShG estimated that in 2012 there were approximately 12 400 of this category of aircraft in service, and this number is expected to double by 2031. Some of these aircraft could be fitted with open rotor engines, which would result in increased efficiency.

Manufacturers will not be benefitting from the use of the certification specifications for the new open rotor engine concept (thus delays in certification may be possible), and the operators may delay benefitting from using a more efficient engine (based on this technology).

Environmental benefits are prevented

By not facilitating this new technology, the environment benefits in terms of fuel emissions may also be prevented.

4.2. Objectives

The overall objectives of the Agency are defined in Article 2 of the Basic Regulation. This proposal will contribute to the overall objectives by addressing the issues outlined in Chapter 2 of this NPA.

The specific objectives of this proposal are to:

- ensure that the safety levels of open rotor engine installations are consistent with those of the existing turbofan fleet;
- identify and recommend EASA cost-efficient requirements and advisory material for respectively engine CS-E and aircraft CS-25 to address the novel features inherent in open rotor engine designs and their integration with the aircraft; and
- ensure these requirements are acceptable to the FAA so that they could be included in 14 CFR parts 25 and 33.

4.3. Policy options

Table 1: Selected policy options

Option No	*Short title*	**Description**
0		Baseline option (no change in the certification specifications; risks remain as outlined in the issue analysis).
1		Revise the certification specifications as appropriate.

The current CS-E and CS-25 have been reviewed to determine their applicability to and adequacy for open rotor technology. Those that have been found to be applicable but not adequate have been assessed on a case-by-case basis. For example, if the inadequacy is related to very specific, detailed design features of an open rotor engine, it may be more appropriate to address this by project-specific special condition after an application. See Appendix 4.

An alternate position was proposed by one member, that Option 0 should be adopted for all Certification Specifications. That position is as follows:

‘There appears to be no single identifiable distinguishing feature for ‘open rotor’ engines distinguishing them from turboprops. Past turboprops have included various numbers of blades, in some cases with multiple contra-rotating stages; electronic propeller controls (propeller controls are even addressed in FAA Part 33 certification standards) and various blade geometries. There is a perception that turboprops are those engines which permit removal of the ‘propeller module’ from the engine; this is equally the case with some turbofans. The difference between turboprop and open rotor engines appears to lie only in the certification strategy, not in any specific technical aspect.

The accident record shows that current turboprops are safe, factoring out the unstructured operational environment to which the turboprop fleet is exposed. There appears no safety basis for broad changes to the turboprop regulations which were used for the design of the legacy fleet. This is the case for both engine/propeller Certification Specifications and aeroplane installation Certification Specifications. Open rotor engines should be considered as turboprops, and held to the same Certification Specifications as existing turboprops, with the opportunity to incorporate more advanced technologies conferring safety benefits. Recognition and full credit should be provided for the use of advanced technology to improve safety.’

However, the Agency’s position on this issue was already provided in the Explanatory Note (in particular, in section 2.5), and section 4.1 of the RIA.

4.4. Analysis of impacts

4.4.1. Safety impact

Option 0 would leave the current situation unchanged. It is assumed that any future special conditions would seek to achieve safety levels consistent with turbofan levels.

Option 1 would also have a neutral safety impact, as the objective is to maintain the safety level of the turbofan fleet.

4.4.2. Environmental impact

All open-rotor-powered aircraft will be required to comply with the applicable noise and emissions requirements.

The motivation for introducing open rotor technology is to achieve a significant reduction in fuel burn. Since Option 1 reduces the open rotor development risks (providing the regulatory framework to facilitate the manufacturers to develop this technology), it is more likely to allow the estimated 30 % reduction in CO2 emission to be achieved between aircraft equipped with open rotor engines and aircraft equipped with current turbofan engines, equivalent to an average of 8.8x10E8 tons of CO2 over a 20-year period.

The ShG estimate is based on:

- 30 % reduction in fuel burn;
- 40 t CO2 per turbofan aircraft flight;
- 10 000 open-rotor-powered aircraft in 20 years; and
- 30 000 flights per aircraft in 20 years.

4.4.3. Social impact

Both Options 0 and 1 are neutral with respect to social impacts.

4.4.4. Economic impact

Option 1, by revising the certification specifications including open rotor technology, would affect:

- Manufacturers: Manufacturers would be benefitting from the use of Certification Specifications thus reducing certification costs and risks of delays.
- Operators: the ShG estimates 30% reduction in fuel burn, therefore this may represent an important reduction in operator costs of ownership with increased fuel efficiency. Option 1 would ensure that this benefit is achieved earlier and with lower development risks.
- Passengers: the reduced costs for fuel may also be passed on to passengers by the airlines in a highly competitive market. With Option 1 these effects are also expected earlier.

Option 0 (baseline scenario) would instead maintain a development risk which could cause uncertainty in the new technology development.

4.4.5. General aviation and proportionality issues

None identified.

4.4.6. Impact on ‘better regulation’ and harmonisation

One objective of Option 1 is to ensure that any proposed changes in Certification Specifications or advisory material could be included in 14 CFR parts 25 and 33. This has been achieved by close involvement of the FAA propulsion and power plant installation specialists in the rulemaking process. Option 1 would have a positive impact on harmonisation.

4.5. Comparison and conclusion

4.5.1. Comparison of options

Based on the impacts described above, the general conclusion is that Option 1 is preferred. This option will establish minimum standards acceptable to the Agency, ensure a level playing field for all manufacturers, reduce the risks associated with the development and acceptance of this technology and facilitate attainment of the potential environmental, economic and harmonisation benefits.

5. References

5.1. Affected regulations

None.

5.2. Affected CS, AMC and GM

CS-25

CS-E

5.3. Reference documents

— FAA report DOT/FAA/TC-13/34: Weight Assessment for Fuselage Shielding on Aircraft With Open-Rotor Engines and Composite Blade Loss. December 2013.

— ‘The Measure of Man and Woman, Human Factors in Design’ revised edition 2002. Alvin R Tilley

6. Appendices

APPENDIX 1: OPEN ROTOR DEFINITION

The objective was to find a definition of an open rotor engine based on technical characteristics that would unambiguously distinguish an open rotor engine both from a turbofan and a turboprop.

Such a definition is important to allow applicants and regulatory authorities to decide whether a proposed product should be subject to the requirements in the NPA or not.

Some history

In the 1980s the JAA attempted to define the propfans that were being investigated at that time. The JAA considered three definitions, but concluded none of them were satisfactory.

(a) A power unit which does not feature containment of the main propulsive rotor blades, the structural integrity of which must be assured at a level acceptable to the airworthiness authority.

(b) A propfan engine is a high bypass ratio engine, designed for aircraft cruise Mach numbers in excess of 0.6. If provided, the fan/propeller duct is not designed to provide means of blade containment.

(c) A propfan engine is a turbofan fitted with high velocity propellers.

Criteria considered by this ShG

Open rotor engine features	**Comment**
No casing	Clear discriminator relative to turbofan. **This criterion was retained.**
Number of open rotor blades	Current open rotor studies feature 10 to 12 blades per stage, whereas turboprops currently have 8 or less blades. Nevertheless, there is no technical basis for setting number of blades as a discriminating criterion.
Length of blades	Due to the higher number of blades, their length is typically smaller than turboprop blades, but there is no basis for setting a limit.
Contra-rotating stages	This is considered a key feature enabling open rotor engines to operate efficiently, close to turbofan mach numbers. Contra-rotating turboprops have not been certified outside the former Soviet Union. **This criterion was retained.**
Blade twist and sweep	No basis for setting a limit.
Variable pitch	Both turboprops and open rotor engines can have variable pitch blades.
Integration with nacelle	Clear criterion not possible.
Operates at turbofan fleet speed	Current studies aim to operate open-rotor-powered aircraft at speeds that make them suitable to be considered for the 150-seat single aisle market, that is, close to turbofan speeds. However, advanced turboprops are approaching this speed range, so a speed discriminator was not considered feasible.

Common rotation axis for open rotor and gas generator	There are turboprops with common rotation axis.
Retention of open rotor module relies on gas generator discs rather than shaft	While this criterion applies to a pusher configuration, it is not so clear for a puller. This criterion was included in the definition proposed by Boeing, see below.
Gas generator module encompassed within primary propulsive components	This would discriminate relative to a turboprop, but also most likely to a puller configuration also. This criterion was included in the definition proposed by Boeing, see below.
Open rotor module that cannot be distinguished as a separate entity	One result of this characteristic is the difficulty of testing the gas generator and open rotor module separately from each other, as is required for a turboprop engine and propeller combination. This criterion leads to the certification process for open rotor engines, see below. So it is implicit in the finally agreed definition of an open rotor engine, which refers to a turbine Engine, i.e. certified under CS-E. **Criterion implicitly retained**

Criteria which determine the certification process

Regulatory authority representatives on the group considered that the following features of open rotor engines make it impossible to certify separately the open rotor module and the gas generator.

- Structural, dynamic and control interactions associated with full or partial blade release for a contra-rotating device.
- Complex control system for pitch control of each row of open rotor blades and engine integrated through a Full Authority Digital Engine Control (FADEC).
- Open rotor and engine power unit interrelated failure modes.

These considerations result in the conclusion that the ‘open rotor engine’ configurations currently being studied would have to be certified as a complete system under the revised CS-E proposed in the NPA.

Finally agreed definitions

For the preamble to the NPA

- Open Rotor Engine — A Turbine Engine featuring contra-rotating fan stages not enclosed within a casing.

For the preamble to the NPA and in CS-E 15

- Open Rotor — A Turbine Engine fan stage that is not enclosed within a casing.

Boeing proposed the following alternative definition:

An engine shall be considered an open rotor (open Fan):

- If the primary propulsive component (fan/propeller/rotor) is open and exposed, e.g. not surrounded by a containment casing;

And

- If the primary propulsive component hub and/or disk assembly rely on the gas generator disk(s) (blisk, drum, etc.) as primary structural member for retention of the primary propulsive rotor module.

Or

- If any portion of the gas generator module (compressor/combustion chamber/turbine) is encompassed within, or circumscribed by, the primary propulsive components (fan/propeller/rotor stages), e.g. a radial release of components from within the gas turbine module could impact the primary propulsive component(s) module (fan/propeller/rotor).

APPENDIX 2: CS-25 ISSUES NOT REQUIRING RULE CHANGES

Fire and Overheat Requirements

With the possibility of an open rotor 'pusher' configuration, where the open rotor module is behind the gas generator, open rotor module components may be exposed to normal engine exhaust and to nacelle fire conditions. In addition, the increasing use of composites on open rotor components may affect the open rotor module reaction to those fire/exhaust conditions. The concern is that exposure to fire or to flowpath gases may cause large parts of the open rotor to separate from the module with hazardous consequences. A thorough and systematic review of Certification Specifications and safety considerations to ensure open rotor module safety was carried out.

The following fire/overheat scenarios were reviewed:

— Normal operational exhaust effects on the engine components will be addressed during the engine certification process, and by CS 25.901(b)(2), CS 25.1301(a)(1),(3)and CS 25.1309(a), so CS 25.1121(c) is not applicable.

— Tailpipe fire. CS 25.863 applies.

— Fire in fire zone, with no breach of firewall. CS 25.863 and CS 25.1191(a) and (b) apply.

— Fire in fire zone, with breach of firewall. CS 25.863 and CS 25.867 apply.

Historically, CS-25 and 14 CFR Part 25 fire Certification Specifications have not been applied to turbomachinery. For example, the spaces within the engine casings are not divided into fire zones and flammable fluid zones.

However, the open rotor has turbomachinery (blades) outside the engine casings and outside the nacelle aerolines. As such, it is highly likely that Part 25 fire Certification Specifications will be applied to open rotor blades. This will need to be determined based on each projects design. No changes to CS-25 (or CS-E) on this issue are proposed.

Fail-safe cowlings

It is anticipated that open rotor engine designs will include 'pusher' type installations. Such installations could cause potential hazardous failure conditions, should an engine cowl forward of the open rotor depart the power plant and strike the open rotor blades. The open rotor blades will not be designed and tested to show a tolerance to cowl departure and potential damage.

The general concern for departing cowls was noted by FAA NPRM 89-25, regarding pusher propeller aircraft. The result of this NPRM and subsequent industry discussions were incorporated in the FAA (draft) Propulsion Mega AC 25-XXX, page Sub. E-9-48 for 14 CFR Part 25.1193. The result was the interpretation by the regulatory authorities that the aircraft manufacturers shall ensure that good design practices be put in place, that included fault-tolerant cowl retention, fail-safe latch design, considering potential power plant failures in the design and sizing of the cowls, latches and hinges.

It is expected that the aircraft can be confirmed fit and safe for flight by the flight crew during a 'walk-around' and/or maintenance prior to aircraft release.

Similar considerations presently addressed for fuselage mounted engines may be necessary, such as positioning the latches so that their security can be confirmed from the ground.

Power plant installation design requirements shall ensure a fail-safe design. No additional regulatory or advisory material need to be added, as the criterion noted above, from the FAA (draft) Propulsion Mega AC 25-XXX, is being used by the aircraft manufacturers for new designs.

Any further discussions/issues on this topic will be addressed through the use of Special Conditions and Issue Papers.

Icing

CS 25.1093 was reviewed with respect to their adequacy for open rotor engines. It was concluded that no changes were required. Due to the smaller open rotor engine inlet, the required size for the ice slab tests according to CS-E 780 (when amended by NPA 2011-04) would be much smaller than that for a turbofan engine with the same engine thrust class. Therefore, engine and airframe manufacturers would need to define a slab size compatible with the respective aircraft and engine capabilities and representative of the installation.

CS 25.901 Installation

CS 25.901(c) lists those failure conditions that do not need to comply with CS 25.1309(b). Of course, if some of these failure conditions can comply with CS 25.1309(b), so much the better. It turns out that it is practical to ensure some open rotor blade failure cases (included within CS 25.901(c)(2)) can comply with CS 25.1309(b). These failure cases are specified in CS 25.903(d)(1). Consequently, these failure cases that can comply with CS 25.1309(b) do not need to be specified in CS 25.901(c)(2), which therefore does not need to be changed.

CS-25 Propeller requirements which are not applicable to open rotor engine installations

As explained above, open rotor engines will be certified as Engines, under CS-E amended as proposed by this NPA. However, there are many references in CS-25 requirements to propellers and turbo-propeller-powered aircraft, which are potentially applicable to open rotor engine installations, due to the similarity between propellers and the open rotor module of open rotor engines. These references to propellers have been reviewed and the vast majority of them have been determined to be adequate and applicable to open rotor engines. See section 2.4.1 for the explanation of the proposed changes to these requirements to make them applicable to open rotor installations. In this Appendix 2, the justification is given for not making certain references to propellers and turbo-propeller-powered aircraft applicable to open rotor engine installations.

CS 25.33 Propeller speed and pitch limits

…

(b) *There must be a propeller speed-limiting means at the governor. It must limit the maximum possible governed engine speed to a value not exceeding the maximum allowable rpm.*

(c) *The means used to limit the low pitch position of the propeller blades must be set so that the engine does not exceed 103 % of the maximum allowable engine rpm or 99 % of an approved maximum overspeed, whichever is greater, with —*

   (1) *The propeller blades at the low pitch limit and governor inoperative;*

(2) The aeroplane stationary under standard atmospheric conditions with no wind; and

(3) The engines operating at the maximum take-off torque limit for turbo-propeller-engine-powered aeroplanes.

…

These requirements date from earlier turboprop technology. CS-E 50, 52 and 54 for open rotor engine control system are managing open rotor engine control integrity. These CS-25 requirements are not applicable to open rotor engine installations.

CS 25.779 Motion and effect of cockpit controls

…

(b) Power plant and auxiliary controls –

(1) Power plant.

Controls	*Motion and effect*
Propellers	*Forward to increase rpm*

…

On open rotor engine installations, there will not be a pilot control of open rotor speed, so this reference to propellers is not applicable to open rotor engine installations.

CS 25.901 Installation

…

(c) The power plant installation must comply with CS 25.1309, except that the effects of the following need not comply with CS 25.1309(b):

(1) Engine case burn through or rupture;

(2) Uncontained engine rotor failure; and

(3) Propeller debris release.

…

CS 25.901(c)(3) exempts propeller debris release from CS 25.1309(b) for both direct impact effects and unbalance effects, both effects being addressed by CS 25.905(d) for propellers. For the open rotor engine, CS 25.901(c)(2) applies. So, 25.901(c)(3) is not applicable to open rotor engines.

CS 25.905 Propellers

…

(b) Engine power and propeller shaft rotational speed may not exceed the limits for which the propeller is certificated. (See CS P-50.)

This requirement is necessary for propeller installations because the engine and propeller are certified separately. For open rotor engine installations, this issue will automatically be addressed by the open rotor engine being certified as a whole under CS-E. So, CS 25.905(b) is not applicable to open rotor engines.

…

(c) Each component of the propeller blade pitch control system must meet the requirements of CS-P 420.

…

This requirement is necessary for propeller installations to cover the case where the pitch control system is certified as part of the aircraft, not as part of the propeller. For open rotor engines, the pitch control system will be certified with the engine (CS-E 742 Components of the Open Rotor control system), so this requirement is not applicable to open rotor engines.

…

(d) Design precautions must be taken to minimise the hazards to the aeroplane in the event a propeller blade fails or is released by a hub failure. The hazards which must be considered include damage to structure and critical systems due to impact of a failed or released blade and the unbalance created by such failure or release. (See AMC 25.905 (d).)

…

In CS 25.905(d), the failure model is fixed in the requirement itself, allowing no flexibility. For the new technology of open rotor engines, where the details of any designs are at a very preliminary stage, the constraints on the failure model imposed by 25.905(d) are not appropriate. The failure model will depend on the design of the open rotor engine. In addition, this requirement allows minimisation with respect to unbalance effects. Open rotor engine installations will preclude Catastrophic effects due to unbalance loads. So, this requirement is not applicable to open rotor engines. Open rotor blade failure effects for open rotor engine installations are covered under CS 25.903(d)(1).

CS 25.929 Propeller De-icing

(a) If certification for flight in icing conditions is sought, there must be a means to prevent or remove hazardous ice accumulations that could form in the icing conditions defined in Appendices C and O on propellers or on accessories where ice accumulation would jeopardise engine performance (see AMC 25.929(a)).
(b) If combustible fluid is used for propeller de-icing, CS 25.1181 to CS 25.1185 and CS 25.1189 apply.

Open Rotors and their ice protection system (IPS) are part of the engine type design. The icing conditions referenced in CS 25.929(a), namely Appendices C and O, are covered by the icing conditions referenced in CS-E 780, namely Appendices C, O and P (via CS 25.1093(b)). AMC E 780 states that ‘the icing tests should be carried out with all IPS operating’. Therefore, the requirement CS 25.929, while appropriate for Open Rotors, is fully covered by CS-E 780. Consequently, CS 25.929 does not need to be made applicable to Open Rotors. AMC 25.929(a) contains guidance on propeller de-icing which is appropriate to be applied to Open Rotor de-icing. Since this advisory material is not in AMC E 780, reference to AMC 25.929(a) is added to AMC E 780.

CS 25.933 Reversing systems

…

(b) For propeller reversing systems —

(1) Each system intended for ground operation only must be designed so that no single failure (or reasonably likely combination of failures) or malfunction of the system will result in unwanted reverse thrust under any expected operating condition. Failure of structural elements need not be considered if this kind of failure is extremely remote.

(2) Compliance with this paragraph may be shown by failure analysis or testing, or both, for propeller systems that allow propeller blades to move from the flight low pitch position to a position that is substantially less than that at the normal flight low pitch position. The analysis may include or be supported by the analysis made to show compliance with the requirements of CS-P 70 for the propeller and associated installation components.

…

Open rotor reverse thrust will be certified under the requirements of CS 25.933(a), amended as proposed by this NPA to make them applicable to it. Therefore, CS 25.933(b) is not applicable.

CS 25.1149 Propeller speed and pitch controls

(a) There must be a separate propeller speed and pitch control for each propeller.

For open rotor engine installations, this requirement is already covered by CS 25.1143(a), so CS 25.1149(a) is not applicable to open rotor engines.

(b) The controls must be grouped and arranged to allow –

(1) Separate control of each propeller; and

(2) Simultaneous control of all propellers.

For open rotor engine installations, this requirement is already covered by CS 25.1143(b), so CS 25.1149(b) is not applicable to open rotor engines.

(c) The controls must allow synchronisation of all propellers.

Synchronisation here refers to speed synchronisation. This requirement addresses a noise rather than a safety issue, so does not need to be made applicable to open rotor engines.

(d) The propeller speed and pitch controls must be to the right of, and at least 25 mm (one inch) below, the pilot’s throttle controls

On open rotor engine installations, there will be only one control lever for engine power or thrust per engine. Open rotor speed and pitch will be controlled by FADEC according to the required thrust. There will not be pilot controls for open rotor blade speed and pitch, so this requirement is not applicable to open rotor engines.

CS 25.1305 Power plant instruments

…

(e) For turbo-propeller-powered aeroplanes. In addition to the power plant instruments required by sub-paragraphs (a) and (c) of this paragraph, the following power plant instruments are required:

(1) A torque indicator for each engine.

(2) Position indicating means to indicate to the flight crew when the propeller blade angle is below the flight low pitch position, for each propeller.

(3) Reserved

…

This requirement is not applicable to open-rotor-engine-powered aeroplanes, because a new CS 25.1305(g) addresses the power plant instruments required for those aeroplanes. See Section 2.4.1.6.

CS 25.1337 Power plant instruments

…

(e) Turbo-propeller blade position indicator.

Required turbo-propeller blade position indicators must begin indicating before the blade moves more than 8^{o} below the flight low pitch stop. The source of indication must directly sense the blade position.

This requirement is not applicable to open rotor blade position indication, because there is no action of the pilot on the pitch control, which is managed by FADEC, in compliance with CS-E 50. The proposed CS-E 54 specifies that an integrated automatic pitch control is necessary and no pilot direct control is allowed. See Appendix 4.

APPENDIX 3: CS-E ISSUES (INITIALLY IDENTIFIED AS POTENTIALLY APPLICABLE), NOT REQUIRING RULE CHANGES

The following requirements were identified as potentially requiring amendment to be applicable to the engine with an Open Rotor. However, following detailed review, it was confirmed that no update to the current requirement and/or corresponding AMC material were required:

CS-E 515 Engine Critical Parts

It was noted that Open Rotor blades under the CS-E 510 Safety Analysis requirement would be declared Engine Critical Parts. It was concluded that both the current CS-E 515 requirement and the corresponding AMC material did not require any amendment.

CS-E 540 Strike and Ingestion of Foreign Matter

Whilst it was noted that tail-mounted Open Rotor engines may be more susceptible to FOD such as ice released from the airframe or tyre debris, this would equally apply to tail-mounted turbofan engines. The larger diameter of the Open Rotor will inevitably result in the Open Rotor being more susceptible to the ingestion of foreign matter. However, it was concluded that both the current CS-E 540 requirement and the corresponding AMC material did not require any amendment.

CS-E 740 Endurance Tests

CS-P 390 Endurance Test is effectively covered by CS-E 740 Endurance Tests. It was therefore concluded that both the current CS-E 740 requirement and the corresponding AMC material did not require any amendment.

CS-E 745 Engine Acceleration

Whilst it was noted that the likely high inertia associated with the Open Rotor could adversely affect engine acceleration time to 95 % of rated take-off power, it was noted that CS-E 745(3) does allow a longer acceleration time (greater than 5 seconds) to be accepted if properly justified. It was concluded that both the current CS-E 745 requirement and the corresponding AMC material did not require any amendment.

APPENDIX 4: ISSUES IDENTIFIED REQUIRING FURTHER CONSIDERATION

The following requirements were identified as potentially necessitating additional consideration, therefore stakeholders are, in particular, encouraged to comment on this Appendix in addition to the proposed amendments.

CS 25.1337(e) Turbo-propeller blade position indicator

This requirement defines a margin of 8° relative to the flight low pitch stop at which the blade position indicator must start indicating. While the intent of this requirement is applicable to open rotor engines, with respect to an open rotor blade position sensor, this specific margin may not be appropriate. Therefore, the appropriate margin should be determined on a project basis by CRI.

CS-E 800 Bird Strike and Ingestion

A notable discussion point centred on the potential for an Open Rotor, due to it having variable pitch and low rotational speed, encountering increased bird impact energies below the 200 knots required by CS-E single large and large flocking bird requirements. Unlike a traditional turbofan therefore, any potential Open Rotor material loss as a result of increased impact energies below 200 knots cannot rely on a containment case to prevent any subsequent debris release. Additionally, it was noted the CS-P 360 Bird Impact requirement for a propeller is based on a critical point analysis, albeit with a smaller 4 lb bird. In the end, however, the group agreed that the current CS-E requirement does not require a critical point analysis and this approach should be retained for an engine with an Open Rotor.

For core ingestion and open rotor critical point analysis, the option to defer judgement to a specific rulemaking task following the ARAC TAE group, was examined, in order to consider the required number and weight of birds to be ingested.

Proposed AMC No 2 to CS 25.903(d)(1)

Detailed advisory material to show compliance with CS 25.903(d)(1) for shielding was not proposed. Shielding is likely to be design specific and therefore it is considered more appropriate to address shielding on a case-by-case basis and develop more detailed AMC in the future when more experience has been gained.