AMC 25.773(b)(4) Pilot compartment non openable windows

ED Decision 2016/010/R

Total loss of external visibility is considered catastrophic. A sufficient field of view must exist to allow the pilot to safely operate the aeroplane during all operations, including taxi.

This field of view must remain clear in all operating conditions. Precipitation conditions such as outside ice, heavy rain, severe hail, as well as encounter with birds and insects must be considered.

This AMC material applies to conventional, multiple pane window systems, i.e. those which are composed of a main windshield and separate side panels assembled with structural posts. In the event a one piece 'uni-body wraparound' windshield is proposed, the applicant must meet the intent of the applicable rules, even though there are no separate side windows.

1. Ice and heavy rain

   — Unless system failures leading to loss of a sufficient field of view for safe operation are shown to be extremely improbable, the following provides acceptable means to show compliance with CS 25.773(b)(4):

   — Each main windshield should be equipped with an independent protection system. The systems should be designed so that no malfunction or failure of one system will adversely affect the other.

   — For each forward side window it should be shown that any ice accumulations (Appendix C icing conditions and any applicable Appendix O icing conditions) will not degrade visibility, or the applicant should provide individual window ice protection system capability.

   — The icing accretion limits should be determined by analysis and verified by test. The extent of icing of side windows should be verified during natural or simulated icing flight tests with window ice protection systems unpowered. A limited number of test points, sufficient to validate the analysis, are required within Appendix C or Appendix O.

   — For the demonstration of compliance under Appendix O icing conditions, the applicant may use a comparative analysis. AMC 25.1420(f) provides guidance for comparative analysis.

2. Hail, birds and insects

   It should be shown by flight tests that exceptional pilot skill is not required to land the aeroplane using the normal aeroplane instruments and the view provided through the main or side windows having the degree of impairment to vision resulting from the encounter of severe hail, birds or insects. Appropriate test data should substantiate the estimated damage or contamination to the main or forward side windows during such an encounter.

   It is unlikely that hail damage can be avoided. Rather than avoidance, the approach to ensure vision assuming hail strike has been to use damage assessment criteria contained in the ASTM International "Standard Test Method for Hail Impact Resistance of Aerospace Transparent Enclosures," ANSI/ASTM F 320-10 or equivalent. For the test set up to determine hail damage or windshield resistance to hail, reference can be made to ANSI/ASTM F 320-10, and "Global Climatic Data for Developing Military Products" MIL HDBK 310 (dated 23 June 1997).

   For each impacted window, ANSI/ASTM 320-10 is used to characterize a damage pattern on a limited area of the window. For test purpose, the simulated damage patterns should be applied to the full impacted window surfaces in order to simulate in a conservative manner the visibility degradation through the windows.

The applicant should propose and substantiate the aircraft conditions when hail strike occurs. In the absence of such substantiation, the conservative assumptions will be to consider the maximum aircraft nominal speed combined with the hailstone falling speed.

When the damages are such that there is no remaining visibility through the windshield after hail encounter, or when the ice protection system is no longer operating after the hail encounter, a typical test configuration would be to block visibility out of the forward main windows for the pilot flying, and use simulated damage (if any) and ice accretions (if applicable) on the side window(s).

When conducting flight tests, adequate forward vision should be maintained for a safety pilot while providing appropriate forward view degradation for the test pilot.

Means of compliance to address birds and insects should be proposed by the applicant. The Agency is not aware of any in-service occurrence involving a total loss of visibility through the windshield after birds or insects encounter.

[Amdt 25/16]
[Amdt 25/18]

AMC 25.773(c) Internal windshield and window fogging

ED Decision 2015/008/R

In absence of pilot compartment openable windows, if the failures of the means to prevent fogging cannot be shown to be extremely improbable, the applicant should show that a sufficient field of view is maintained to allow the pilot to safely operate the aeroplane during all operations, including taxi. This should be accomplished by the following:

— The extent of fogging should be established and verified during flight tests with the means to prevent fogging inoperative,

— If it is proposed that the flight crew must take action to remove inside fogging, the effectiveness of the associated operational procedure should be demonstrated by flight test.

[Amdt 25/16]

CS 25.775 Windshields and windows

ED Decision 2016/010/R

(See AMC 25.775)

(a) Internal panes must be made of non-splintering material.

(b) Windshield panes directly in front of the pilots in the normal conduct of their duties, and the supporting structures for these panes, must withstand, without penetration, the bird impact conditions specified in CS 25.631.

(c) Unless it can be shown by analysis or tests that the probability of occurrence of a critical windshield fragmentation condition is of a low order, the aeroplane must have a means to minimise the danger to the pilots from flying windshield fragments due to bird impact. This must be shown for each transparent pane in the cockpit that –

(1) Appears in the front view of the aeroplane;

(2) Is inclined 15° or more to the longitudinal axis of the aeroplane; and

(3) Has any part of the pane located where its fragmentation will constitute a hazard to the pilots.

(d) The design of windshields and windows in pressurised aeroplanes must be based on factors peculiar to high altitude operation, including the effects of continuous and cyclic pressurisation loadings, the inherent characteristics of the material used, and the effects of temperatures and temperature differentials. The windshield and window panels must be capable of withstanding the maximum cabin pressure differential loads combined with critical aerodynamic pressure and temperature effects after any single failure in the installation or associated systems. It may be assumed that, after a single failure that is obvious to the flight crew (established under CS 25.1523), the cabin pressure differential is reduced from the maximum, in accordance with appropriate operating limitations, to allow continued safe flight of the aeroplane with a cabin pressure altitude of not more than 4572m (15 000 ft) (see AMC 25.775(d)).

(e) The windshield panels in front of the pilots must be arranged so that, assuming the loss of vision through any one panel, one or more panels remain available for use by a pilot seated at a pilot station to permit continued safe flight and landing.

[Amdt 25/18]

AMC 25.775(d) Windshields and windows

ED Decision 2021/015/R

1. PURPOSE. This AMC sets forth an acceptable means, but not the only means, of demonstrating compliance with the provisions of CS-25 pertaining to the certification requirements for windshields, windows, and mounting structure. Guidance information is provided for showing compliance with CS 25.775(d), relating to structural design of windshields and windows for aeroplanes with pressurised cabins.

2. RELATED CS PARAGRAPHS.

CS 25.775	Windshields and windows.
CS 25.365	Pressurised compartment loads.
CS 25.773(b)(3)(ii)	Pilot compartment view.
CS 25.571	Damage-tolerance and fatigue evaluation of structure

3. DEFINITIONS.

   a. Annealed glass. Glass that has had the internal stresses reduced to low values by heat treatment to a suitable temperature and controlled cooling.

   b. Chemically toughened glass. Annealed glass immersed in a bath of molten salt resulting in an ion exchange between the salt and the glass. The composition of the salt is such that this ion exchange causes the surface of the glass to be distorted (expansion), thus putting the surface in a state of compression.

c. Creep. The change in dimension of a material under load over a period of time, not including the initial instantaneous elastic deformation. The time dependent part of strain resulting from an applied stress.

d. Cross-linking. The setting up of chemical links between molecular chains.

e. Modulus of Rupture (MOR). The maximum tensile or compressive longitudinal stress in a surface fibre of a beam loaded to failure in bending calculated from elastic theory.

f. Mounting. The structure that attaches the panel to the aircraft structure.

g. Notch sensitive. The extent to which the sensitivity of a material to fracture is increased by the presence of a surface non-homogeneity, such as a notch, a sudden change in cross section, a crack, or a scratch. Low notch sensitivity is usually associated with ductile materials, and high notch sensitivity is usually associated with brittle materials.

h. Pane/Ply. The pane/ply is a single sheet of transparent material.

i. Panel. The panel is the complete windshield or window excluding the mounting.

j. Thermally toughened glass. Annealed glass heated to its softening temperature after which the outer surfaces are rapidly cooled in a quenching medium resulting in the outer surface being put into a state of compression with the core material in tension to maintain equilibrium.

k. Toughened glass. Annealed glass placed into a state of compressive residual stress, with the internal bulk in a compensating tensile stress. Toughening may be achieved by either thermal or chemical processes.

4. BACKGROUND. Fail-safe designs have prevented depressurisations in a considerable number of windshield failure incidents. There are few transparent materials for aircraft windshield and window applications, and due to their inherent material characteristics, they are not as structurally versatile as metallic materials. Transparent materials commonly used in the construction of windshields and windows are glass, polymethyl-methacrylate (acrylic), polycarbonate, and interlayer materials. The characteristics of these materials require special engineering solutions for aircraft windshield and window panel designs.

a. Glass. In general, glass has good resistance to scratching and chemical attack, such as wiper action, solvents, and de-icing fluid. Windshield and window panel designs, however, should take into account its other unique properties, which are considerably different from metals.

(1) Glass exhibits no sharp change in physical properties when heated or cooled and has no definite melting point.

(2) Unlike metals, glass is a hard brittle material that does not exhibit plastic deformation.

(3) Glass is much stronger in compression than in tension. Fracture will occur, under any form of loading, when the induced deformation causes the tensile stress to exceed the Modulus of Rupture (MOR).

(4) The strength of glass varies with the rate of loading; the faster the rate of loading the higher the strength, as is the case for bird impact loading. In addition, glass fracture stress for a load of short duration will substantially exceed that for a sustained load.

(5) The strength of glass, whether annealed or toughened, can be reduced by edge and surface damage such as scratches, chips, and gouges. Failure is usually initiated at some point of mechanical damage on the surface. However, thermal or chemical toughening can considerably increase the fracture strength of annealed glass.

(6) Safety factors necessary on glass components. The safety factors necessary for glass components are significantly higher than for other materials used in aircraft construction because of: the loss of strength with duration of load, the variability in strength inherent in glass, and the thickness tolerances and high notch sensitivity.

(7) There are generally two types of toughened glass:

(a) Thermally toughened glass. The surface of annealed glass may be placed in a state of compression by heating the glass to its softening temperature after which the outer surfaces are rapidly cooled in a quenching medium. As mentioned, this results in the outer surface being put into a state of compression with the core material in tension to maintain equilibrium. The surface compressive layer in thermally toughened glass is approximately 18 percent of the total thickness of the glass. There are limitations on the minimum thickness of glass that can be effectively toughened by thermal processing. Very thin glass can not be effectively toughened by these methods. In general, toughening can increase the MOR of a piece of glass by approximately 3.5 to 20 times. Thermally toughened glass has significant stored energy within it. This energy is released to a certain extent when the glass fractures. Generally, the higher the stored energy the smaller particles are on fracture. Since thermal toughening leaves the glass with high compressive stresses in its surfaces, all cutting, grinding, or shaping must be done before toughening.

(b) Chemically toughened glass. Chemically toughening glass is achieved by immersion in a bath of molten salt of controlled composition. During the immersion process larger alkali ions in the salt replace smaller alkali ions in the surface of the glass. As a consequence of this unequal alkali ion exchange process, the structure of the surface of the glass is distorted by putting the surface in a state of compression similar to that of thermally toughened glass. Depending on the original glass composition and the bath processing, chemically toughened glass may have a compressive layer from 0.050 mm (0.002 inches) to over 0.50 mm (0.020 inches) regardless of the total glass thickness. The compression stress of chemically toughened glass can be made much higher than it can using thermal toughening. As the compressive layer in chemically toughened glass is much smaller than in thermally toughened glass, the stored energy within the glass does not cause the same visibility problems after failure. However, as with thermally toughened glass all cutting, grinding, and shaping must be done prior to toughening.

b. Polymethyl-methacrylate (acrylic). The acrylic materials used for aircraft transparent structural panels are unplasticised methyl-methacrylate based polymers. There are two basic forms of acrylic materials used in aircraft windshield and window panels, as-cast and biaxially stretched (stretched from a cross-linked base material).

(1) As-cast acrylic material: Forming acrylic material to a certain shape by pouring it into a mould and letting it harden without applying external pressure. Although not as notch sensitive as glass, unstretched acrylics have a notch sensitivity. This unplasticised methyl-methacrylate base polymer has good forming characteristics, optical characteristics and outdoor weathering properties.

(2) Biaxially stretched acrylic material: Stretching acrylic material aligns the polymer chains to give a laminar structure parallel to the axis of stretch, which enhances resistance to crazing, reduces crack propagation rates, and improves tensile properties. Stretching acrylic material reduces the materials formability. In addition, stretched acrylics have less notch sensitivity than unstretched acrylics.

(3) Properties. Compared with glass, these acrylics are soft and tough. In general, increasing the temperature causes a decrease in the mechanical properties of the material, increased temperature does not affect acrylic elongation and impact properties.

(4) Crazing. Both basic forms of acrylics used in aircraft transparencies are affected by crazing. Crazing is a network of fine cracks that extend over the surface of the plastic sheet (it is not confined to acrylic materials) and are often difficult to discern. These fine cracks tend to be perpendicular to the surface, very narrow, and are usually less than 0.025mm (.0010 inches) in depth. Crazing is induced by prolonged exposure to surface tensile stresses above a critical level or by exposure to organic fluids and vapours.

(a) Stress crazing may be derived from: residual stresses caused by poor forming practice; residual surface stresses induced by machining, polishing, or gouging; and prolonged loading inducing relatively high tensile stresses at a surface.

(b) Stress crazing has a severe effect on the mechanical properties of acrylics; however, the effects are reduced in stretched materials.

(c) Stress crazing affects the transparency of acrylics. Generally, stretched acrylic panels will be replaced due to loss of transparency from stress crazing before significant structural degradation occurs.

(5) Chemical resistance of acrylic materials. Typically, acrylic materials are resistant to inorganic chemicals and to some organic compounds, such as aliphatic (paraffin) hydrocarbons, hydrogenated aromatic compounds, fats, and oils.

(a) Acrylic materials are attacked and weakened by some organic compounds such as aromatic hydrocarbons (benzene), esters (generally in the form of solvents, and some de-icing fluids), ketones (acetone), and chlorinated hydrocarbons. Some hydraulic fluids are very detrimental to acrylic materials.

(b) Some detrimental compounds can induce crazing; others may dissolve the acrylic or be absorbed in the material. Crazing induced by solvent and other organic compounds has more severe effects on the mechanical properties than stress crazing. Dissolution of the acrylic and chemical absorption into the acrylic degrades the mechanical properties.

c. Polycarbonate. Polycarbonate is an amorphous thermoplastic with a glass transition temperature about 150°C, which shows large strain-to-break and high impact strength properties throughout the normal temperature range experienced by transport aircraft. Polycarbonate not only has significantly greater impact strength properties but also higher static strength properties when compared to acrylic materials.

(1) Polycarbonate exhibits very high deflections under impact conditions, which can result in higher loading into the aircraft structure, compared to glass or acrylic windshield and window panels.

(2) Polycarbonate polymer is very susceptible to degradation by the environment, due to moisture absorption and solvent stress cracking, as well as UV degradation. It is possible to prevent degradation by using good design and production practices and incorporating coatings and other forms of encapsulation. Polycarbonate also suffers from phenomena known as physical aging. This results in the change from ductile properties to brittle properties that occur when polycarbonate is exposed to temperatures between 80°C and 130°C.

(3) Polycarbonate and stretched acrylic fatigue properties are similar to metals when working (design) stresses are used for operating pressure loading design.

d. Interlayer Materials. Interlayer materials are transparent adhesive materials used to laminate glass and plastic structural plies for aircraft applications. Current choices are limited to plasticised polyvinyl butyral (incompatible with polycarbonate), polyurethane, and silicone. The most commonly used are true thermoplastics, but some polyurethanes and all silicones contain some cross-linking.

(1) Interlayer materials are considered to be non-structural because they do not directly support aircraft loads. However, glass windshields are often attached to the airframe structure through metal inserts bonded to the interlayer. For such designs the residual strength of the windshield in a condition where all glass plies have failed may be dependent upon the strength of the interlayer. In addition, the shear coupling effectiveness of the interlayer has a great influence on the stiffness of the laminate.

(2) Most interlayer materials are susceptible to moisture ingress into the laminate and are protected by compatible sealants in aircraft service.

(3) Interlayer materials, like structural plies, have a useful service life that is controlled by the surface degradation and removal of the transparency for optical reasons.

5. INTRODUCTION. The recommended methods for showing compliance with CS 25.775(d) for typical designs of windshields and windows are given in paragraph 7, Test and Analysis. Typical designs of windshields and cockpit side windows are laminated multi-plied constructions, consisting of at least two structural plies, facing plies, adhesive interlayers, protective coatings, embedded electroconductive heater films or wires, and mounting structure. Typically the structural plies are made from thermally or chemically toughened glass, or transparent polymeric materials such as polymethylmethacrylate (acrylic) and polycarbonate. These plies

may be protected from abrasion, mechanical, and environmental damage by use of facing plies and/or protective coatings. The facing and structural plies are laminated together with adhesive interlayer material of poly-vinyl butyral (PVB), polyurethane, or silicone. Cabin window designs are typically multi-paned construction consisting of two structural panes (a main load bearing pane and a fail-safe pane), inner facing panes, protective coatings, and mounting structure. Generally, the two structural panes are made from polymethyl-methacrylate and separated by an air gap. However, there are some cabin window designs that have laminated structural panes. The designs with the structural panes separated by an air gap usually are such that the fail-safe pane is not loaded unless the main pane has failed.

6. GENERAL CONSIDERATIONS FOR DESIGN.

a. Items to be considered in designing the mounting for suitability over the ranges of loading and climatic conditions include but are not limited to:

(1) Deflection of the panes and mounting under pressure,

(2) Deflection of the mounting structure as a result of fuselage deflection,

(3) Differential contraction and expansion between the panes and the mounting,

(4) Deflection of the panel resulting from temperature gradient across the thickness of the panel, and

(5) Long term deformation (creep) particularly of non-metallic parts.

b. Fatigue and stress crazing should be evaluated for assemblies using polymeric structural plies. One way to reduce the occurrence of fatigue and stress crazing is by limiting the maximum working stress level over the complete panel assembly, making due allowance for expected in service deterioration resulting from weathering, minor damage, environmental attack, and the use of chemicals/cleaning fluids. This analysis should be based on:

(1) The appropriate strength of the polymer as declared by the material manufacturer under sustained loading,

(2) The panel assembly maintained at its normal working temperature as given by the windshield/window heating system, if installed, and

(3) The ambient temperature on the outside and the cabin temperature on the inside. The most adverse likely ambient temperature should be covered.

7. TESTS AND ANALYSIS. The windshield and window panels must be capable of withstanding the maximum cabin pressure differential loads combined with critical aerodynamic pressure and temperature effects for intact and single failure conditions in the installation of associated systems. When substantiation is shown by test evidence, the test apparatus should closely simulate the structural behaviour (e.g., deformation under pressure loads) of the aircraft mounting structure up to the ultimate load conditions. Analysis may be used if previous testing can validate it. The effects of the following material characteristics should be evaluated and accounted for in the design and test results: notch sensitivity, fatigue, crazing, aging effects, corrosion (degradation by fluids), temperature, UV degradation, material stability, creep, and the function and working life of the interlayer. An acceptable route for the strength substantiation of a windshield or window panel is set out below.

a. Ultimate Static Strength.

(1) Conduct a detailed structural analysis using an appropriate structural analysis method to identify the highest stressed areas of the windshield or window panel. Subsequently confirm the structural analysis by subjecting a representatively mounted and instrumented windshield or window panel to ultimate load conditions. The panel should be subjected to the most adverse combinations of pressure loading, including the maximum internal pressure, external aerodynamic pressure, temperature effects, and where appropriate, flight loads.

(2) Establish allowable strength values including allowance for material production variability, material characteristics, long term degradation, and environmental effects for each structural ply from relevant coupon or sub-component test evidence. Check the critical design case to ensure that the allowables are not exceeded by the design ultimate stresses.

(3) In lieu of 7.a.(2) above, perform a test above ultimate pressure load to account for material production variability, material characteristics, long term degradation, and environmental effects. In lieu of a rational analysis substantiating the degree of increased loading above ultimate, a factor of 2.0 may be used (ultimate is defined as 1.5 times the pressure load defined in CS 25.365(d)). A separate test fixture may be needed to preclude loading the airframe above ultimate capability.

b. Fatigue. Conventional windshield and window panel materials exhibit good intrinsic fatigue resistance properties, but the variability in fatigue life is greater than that in aircraft quality metals. Thus a conventional cyclic fatigue test, but of extended duration, may be used to cover this variability. Testing at an elevated stress level for one aircraft lifetime could also give the necessary assurance of reliability. These approaches require consideration of the endurance of the metal parts of the mounting structure. Another approach that may be used in lieu of testing is to maintain the maximum working stresses in the windshield and window panel below values at which fatigue will occur. The maximum working stress level over the complete panel assembly should be shown by supporting evidence not to exceed values consistent with the avoidance of fatigue and stress crazing, considering deterioration resulting from weathering, minor damage and scratching in service, and use of cleaner fluids, etc. Fatigue resistance of the mounting structure should be covered separately as part of the fuselage fatigue substantiation.

c. Fail-Safe. Fail-safe strength capability of the windshield and window panels should be demonstrated after any single failure in the installation or associated systems. The demonstration should account for material characteristics and variability in service material degradation, critical temperature effects, maximum cabin differential pressure, and critical external aerodynamic pressure. The requirements of CS 25.571 for the windshield or window panels may be met by showing compliance with the fail-safe criteria in this AMC. Other single failures (besides the windshield and window panels) in the installation or associated systems should also be considered. An acceptable approach for demonstrating compliance is defined by the following method:

(1) Conduct an analysis to establish the critical main pressure bearing ply.

(2) To account for the dynamic effects of a ply failure, test the representatively mounted windshield and window panel by suddenly failing the critical ply under the maximum cabin differential pressure (maximum relief valve setting) combined with the critical external aerodynamic pressure with critical temperature effects included.

(a) For windshield and window panel failures obvious to the flightcrew, the test pressure may be reduced after initial critical pane failure to account for crew action defined in the flight manual procedures. The failed windshield or window panel should withstand this reduced pressure for the period of time that would be required to complete the flight.

(b) For windshield and window panel failures, which would not be obvious to a flightcrew, the test pressure should be held for a time sufficient to account for the remaining period of flight. During the period of time when the test pressure is held, the effects of creep (if creep could occur) should be considered.

(3) Check the fail-safe stresses in all intact structural plies determined in 7c(2) to ensure that they do not exceed the material allowables developed to account for material production variability, material characteristics, long term degradation, and environmental effects.

(4) In lieu of 7c(3) above, to account for material production variability, material characteristics, long term degradation, and environmental effects, additional fail-safe testing of the windshield and window panel to loads above the fail-safe loads following the procedures defined in 7c(2) above should be conducted. In lieu of a rational analysis substantiating the degree of increased loading, a factor may be used, as shown in the table below. The factored loads should be applied after the failure of the critical ply. A separate test fixture may be needed to preclude loading the airframe above ultimate capability. The panel tested in 7c(2) may be used for this test.

(5) Load Factors (applied after the failure of the critical ply):

Material	Factor
Glass	2.0
Stretched Acrylic	2.0
Cast Acrylic	4.0
Polycarbonate	4.0

(6) Other single failures in the installation or the associated systems as they affect the transparency should also be addressed. Such failures include broken fasteners, cracked mounting components, and malfunctions in windshield heat systems.