GUIDELINES FOR THE DESIGN OF AIRCRAFT WINDSHIELD/CANOPY SYSTEMS

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Chapter Eight
Combat Hazards

CHAPTER 8

COMBAT HAZARDS

SECTION 1
INTRODUCTION

If an aircraft is to function in a combat environment, the transparencies will be exposed to many widely varied phenomena which may include: ballistic impact; radar signals; and radiation particle weapons and nuclear blasts. Not all aircraft will be exposed to all of the phenomena noted, therefore, for each aircraft, an evaluation must be made to determine the kind of exposure and also the level of resistance to be used as a design goal. The mission profile is the starting point for determining the operational requirements that follow. It must be known where the aircraft flies in order to assess the hostile environment surrounding it. An unclassified description of those threats that are known are included in the individual sections dealing with that threat. As the quantified threat descriptions are highly classified, the following discussions will be in general terms. The specific means to protect against each threat is dependent upon the individual nature of the threat for each aircraft. This is clear when considering the protection necessary for a high altitude penetrating bomber (B-1) versus that of a hedge-hopping tank killer (such as the A-10).

To partially overcome the lack of specific data included herein because of classification, a reference/bibliography list is included for each topic.

SECTION 2
BALLISTIC IMPACT

8-200 INTRODUCTION

A common term for transparencies that are resistant to ballistic penetration (including fragments) is "transparent armor." The design of transparent armor begins with an analysis of the threat environemnt in which the aircraft is intended to operate. Then the specific threat level that the transparency must be designed to defeat must be determined so that the transparency cross-section will be adequate, and of the lightest weight practical. To determine the threat level, consideration must be given to: type of projectile or fragment, estimated muzzle or initial velocity, the altitude and attitude of the aircraft, the distance from the weapon or explosion point to the aircraft and the position of the transparent armor in relation to the direction of the threat. This information is used to predict the velocity and angularity of the threat when it impacts the transparency.

8-201 STANDARD

The Aircraft Structural Integrity Program (ASIP, see Section 4-201) (Reference 8.1) specifies that the design details for ballistic armor will be in accordance with MIL-STD-1288, "Aircrew Protection Requirements, Nonnuclear Weapons Threat." (Reference 8.2). Those portions of this standard which are applicable to transparencies are as follows:

8-201.1 Transparent Armor Materials

"A major factor in selecting armor materials is obtaining minimum areal density commensurate with protective requirements and design trade-offs. Another primary factor is front and rear face spall characteristics of the material. Materials which generate spall particles on the rear face when defeated shall not be used in crew stations unless suitable provisions are made to supress the spall and prevent aircrew injury. Other factors to be considered are cost, availability, multi-hit capability, ease of fabrication, material thickness, durability and material response to combat aircraft environmental conditions."

NOTE: Residual visibility through the transparency after impact is crucial since widespread crazing or cracking could result in subsequent aircraft loss.

"Another major factor in selecting armor material is its structural capacity to withstand crash or hard landing environments." (To preclude additional threat of injury to crewmembers.)

8-201.2 Installation

"Armor shall be incorporated either as an integral part of, or a parasitic addition to, the aircraft crew station or crew seat structure. The method used for a specific installation shall be selected considering such factors as: minimum weight penalty, operations required to remove and reinstall armor in the field, aircraft status (design, production, in service) at the time decision is made to install armor, space limitations, access for maintenance and cost. Load bearing integral armor installations shall be designed to withstand design loads for the structural member involved as well as ballistic impact loads resulting from the most severe design threat. Parasitic armor installations shall be designed to withstand in-flight and ballistic impact loads. When parasitic armor is located such that failure of the attachments will endanger any crewmember, the installation shall be designed to withstand crashload factors. Detailed data on parasitic armor installation techniques, including a method for calculating design loads resulting from projectile impact are contained in AFFDL-TR-68-5, AVLABS 67-78 and MIL-I-8675. Armor attachment methods and hardware will vary based on the particular installation problems. The following basic requirements shall be considered.

a. Attachments for composite and face hardened armor materials shall be designed so that the armor cannot be installed backwards (with soft face towards the incoming threat). Use of unsymmetrical fastener patterns is one method to accomplish this.

b. When armor must be removed and reinstalled for aircraft maintenance, the weight of a single armor panel shall not exceed 40 pounds or require special tools. Where practical, hinged or sliding armor panels shall be employed to facilitate maintenance access.

c. The bolt through method of armor attachment shall not be used where a projectile hit on the bolt will cause the bolt to become a secondary projectile endangering the aircrew.

d. Special attention shall be given to avoid attachment of armor to external surfaces of the aircraft in locations where failure of the attachments, separation of the armor panel, or pieces thereof, could damage engines, rotors, control surfaces, and other components critical to sustaining flight."

8-201.3 Type of Armor Protection

"Basic types of armor protection are:

a. Crew station armor. This includes . . . and transparent armor used in areas for external vision.

b. External armor. When aircraft and crew station configurations and other factors make it necessary to install crew protective armor on external surfaces of the aircraft, consideration shall be given to integrating armor and external structure. Attachment of parasitic armor to the external surfces of the aircraft shall be avoided where possible due to adverse aerodynamic effects involved. Thickness, contour, and installation will become major factors in selecting armor material for external applications since increases in drag must be minimized. Where possible, external armor installation shall be designed to protect other critical components for increased efficiency."

8-201.4 <u>Secondary Threat Protection</u>

"Selection of materials for use in aircraft crew station transparencies and interiors shall include consideration of spallation and spall suppression properties of the material. Metals, glass, and plastics which spall, shatter, or otherwise generate flying debris when hit by projectile or fragments shall be avoided."

8-202 BALLISTIC IMPACT ANALYSIS

When initially investigating possible windshield designs for combat aircraft, it is beneficial to be able to mathematically predict the ballistic response for different materials and designs. A theory has been developed that provides a reasonably accurate ballistic limit based on the properties of the threat (projectile or fragment, type material, etc.) and the proposed target. This would permit identification of promising designs and eliminate much of the early (and expensive) testing (References 8.3 and 8.4).

8-203 MATERIALS AND APPLICATION

The theory of ballistic impact also indicates the importance of sequencing the target materials. The dominating factors, as the projectile or fragment impacts the target and decelerates, are density, then strength, and finally a material with elastic properites (such as polycarbonate) to absorb the residual kinetic energy of the impact. There is an optimal way of layering a transparency for armor protection that makes the best use of the energy per unit mass absorbed by the target ($E*$) and the material density. On the outside face of an armor, the velocity of the projectile will be high initially and the energy deposited in the initial layer will also be high. It is desirable for this initial layer to break up the projectile or produce rapid deformation to increase its frontal area (by generating a large decelerating pressure on the front face of the projectile). To do this it is necessary to have a material which is strong and dense as the outer layer. In this initial layer the density of the armor is the most important parameter. This layer should be followed by a layer with the highest possible coefficient of energy per unit mass absorbed during plastic deformation ($E*_p$), to absorb, dissipatively, the kinetic energy of the projectile and maintain a high frontal pressure. Finally, on the back of this armor, when the projectile has been decelerated to a relatively low velocity (approximately 1000 FPS), there should be a material with a very high coefficient of elastic energy per unit mass ($E*_e$), to absorb the remaining energy elastically and not result in injurious spallation. The selection of any material for transparent armor protection must include consideration of the other factors discussed in the document. Those factors which have a major influence on ballistic considerations are weight, optics, spall hazard, cost, and durability. Only recently have alternate materials to glass for transparent armor become available. First acrylic (methyl methacrylate) which provided improved spall characteristics to glass and then polycarbonate which provided crack resistance through flexibility.

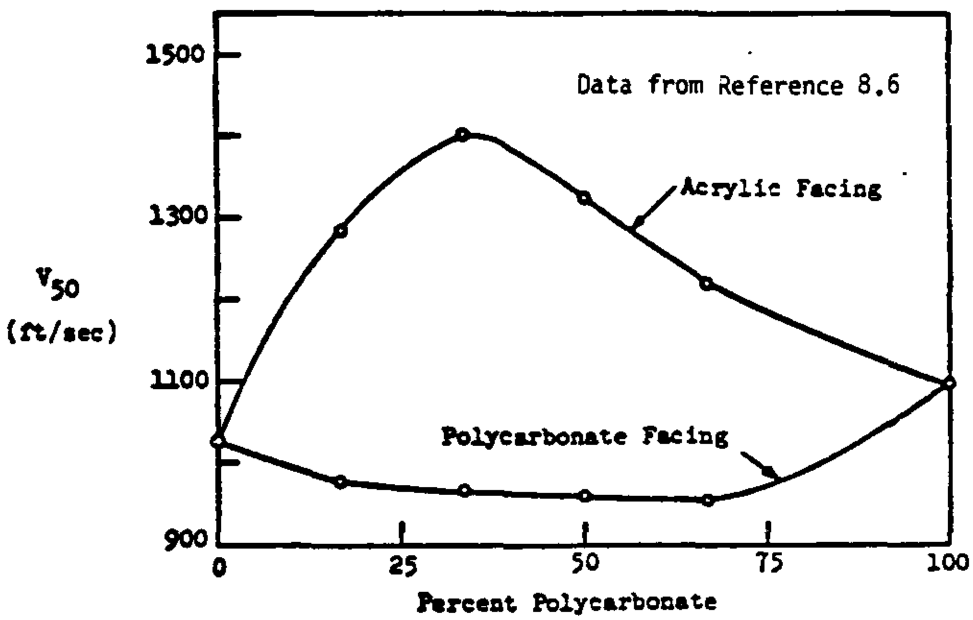
Within a few years after polycarbonate appeared in 1959-60 there were many ballistic resistant applications and many of them occurred, in contrast to methyl methacrylate, as a monolithic material. While monolithic polycarbonate does not seem to offer any significent ballistic defeat capability at reasonable distances, this materials' toughness, crack propagation resistance and nonspalling characteristics often result in a projectile penetration hole which is smaller than the projectile and with minimal glazing material removal. A comparison of these three materials is shown in Table 8.1 for the lowest level of protection against high powered small arms. A rating of (1) indicate the most favorable material and a rating of (3) indicates the least favorable.

TABLE 8.1. HIGH POWERED SMALL ARMS

MATERIAL	DURABILITY	TRANS-PARENCY	MAINT-ENANCE	SPALL HAZARD	WEIGHT (SQ.FT.)	THICKNESS-NESS	RESIDUAL VISIBILITY	COST
BULLET RESISTANT GLASS	1	2	1	3	3 (15#)	2 (1-3/16")	3	1
METHYL METHACRYLATE	2	1	2	2	2 (7.75#)	3 (1-1/4")	2	2
POLYCARBONATE	3	3	3	1	1 (6.2#)	1 (1")	1	3

(REFERENCE 8.5)

As can be seen, polycarbonate compares favorably with other transparent materials. However, it has been found in this field, as in others, that a composite arrangement can be even more effective as shown in Figure 8.1. If one or two layers of glass or acrylic is laminated with a polycarbonate backing ply, the harder facing material tends to break up and turn the projectile sideways. This type of failure spreads the impact over a larger area and the polycarbonate back ply tends to absorb the remaining energy and contains both the projectile and all fragments. Basically, this method diverts the kinetic energy of the projectile, converts it into heat, and absorbs it. Since the polycarbonate has a lower acoustic impedance, it also does not spall as the glass and acrylic materials.



NOTE: V_{50} = velocity for 50% probability of complete penetration.

Figure 8.1. Ballistic Behavior of Acrylic-Polycarbonate Laminates.

Figure 8.1 illustrates the effectiveness of methyl methacrylate versus polycarbonate as face plies. At the extreme left is shown the ballistic resistance of 100% methyl methacrylate with a V_{50} of 1040 ft./sec. At the extreme right is 100% polycarbonate witha V_{50} of 1100 ft./sec. With the methyl methacrylate facing the impact (upper curve) the optimum ballistic resistance of the combinations tested accreued at a 2:1 weight ration of methyl methacrylate to polycarbonate with V_{50} of 1400 ft./sec. which is in good agreement with the optimum ratio for glass to plastic. With the ductile polycarbonate facing the impact, however, (lower curve) there was a reduction in ballistic resistance compared to that of the homogeneous materials over the range of compositions investigated.

Curves for the levels of protection provided by cast acrylic and polycarbonate (monolithic construction) against several different projectiles are presented in Figures 8.2 and 8.3. These curves and ranges are developed from a limited number of tests so they can only be considered as guides. The material's reaction is dependent on the projectile's weight, impacting shape, angle and impacting velocity as can be deduced from these figures. Ballistic tests to confirm the system's capability must include the specific projectile.

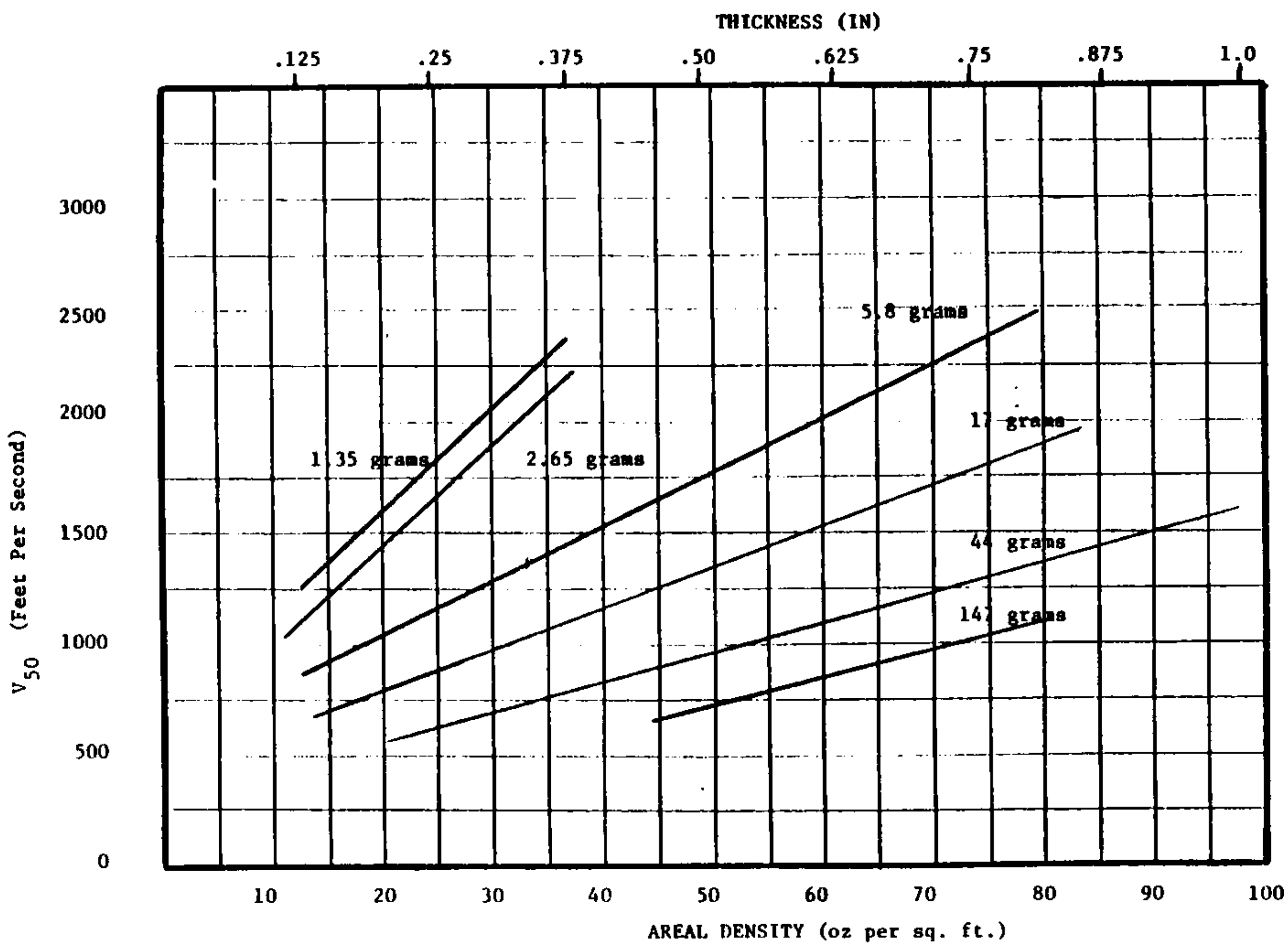


FIGURE 8.2 Penetrating Velocity of Fragment Simulating Projectiles on Cast Acrylic.

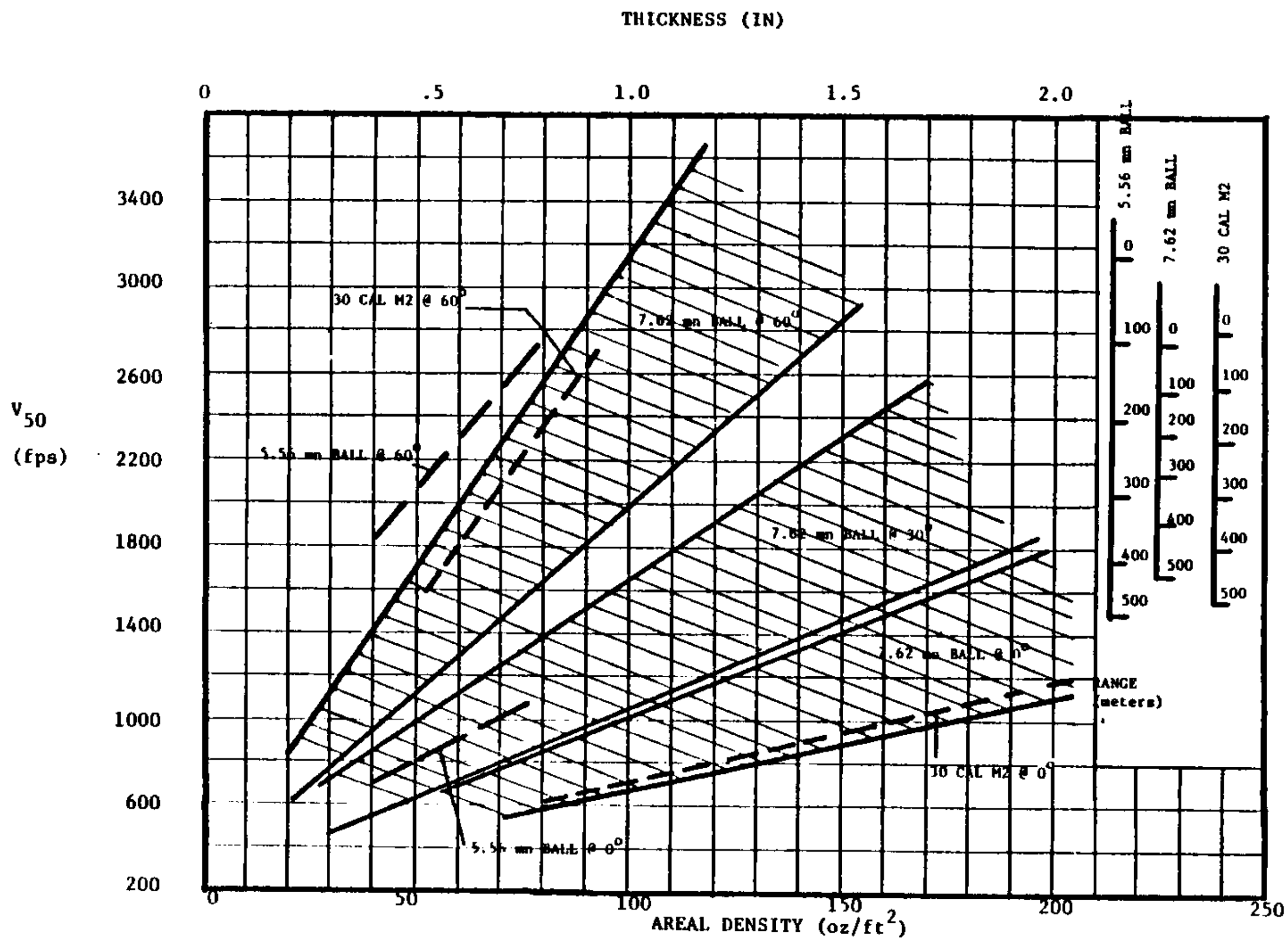


FIGURE 8.3. Penetrating Velocity Ranges for Polycarbonate Against Various Projectiles and at Various Obliquities.

The type of support which the transparency panel has will directly effect the panel's ballistic resistance. A flexible system which will allow material translation to absorb the force of impact will resist much greater threats than the rigid systems which rely on the material's hardness to break the projectile. As in the birdstrike event, if the material can deflect, delaminate or otherwise expend energy in an acceptable fashion, greater impact energies can be accepted. The influence which the shape and size of the projectile has on the material resistance is apparent in Figure 8.2 and 8.3.

From a reliability standpoint it should be noted that a better material match for aircraft transparenccy systems would be the acrylic/polycarbonate laminated panel rather than the glass/polycarbonate, because of the larger differences in thermal expansion coefficients between the glass and polycarbonate. This material difference, under the wide thermal and humidity variations to be experienced in the field, would be far more susceptible to delamination.

8-204 BIRD IMPACT RESISTANCE VS. BALLISTIC RESISTANCE

Contrary to a once popular belief that "if a panel is bullet resistance it will be bird proof for any meaningful level," it has been observed that the structural responses of the target systems are far different. As an example, the windshield of the A-10 aircraft was successfully designed to meet some quite stringent ballistic resistance requirements, but when a qualification test was conducted, it was found that this same windshield system required redesign to successfully defeat the standard four pound bird.

SECTION 3

RADAR CROSS-SECTION (RCS)

8-300 INTRODUCTION

Radar Cross-Section (RCS) of an aircraft is a measure of its ability to be detected on the radar screen. This quantifiable factor is directly related to the effectiveness of the entire aircraft as a reflector of the incident radar signal. This effectiveness is a highly complex function of the aircraft shape, electromagnetic properties of the material which is reflecting the radar signal, incident angle, and the specific radar frequency being utilized. A term which is often confused with RCS is signature. Radar signature is the ability to detect and identify any object and is a function of the aircraft's RCS, the strength of the impinging signal, the weather, the distance between aircraft and radar equipment and the receiving equipment's ability to discriminate the signal.

For some types of aircraft, such as commercial or business, it is desirable to make the aircraft as visible a radar target as is practicable for traffic control and collision avoidance. Such is not the case for military aircraft. Most military missions require that the radar reflectivity be held to a minimum. It is generally much easier to enhance the reflectivity than it is to reduce it, therefore early planning to minimize RCS is necessary.

8-301 MILITARY REQUIREMENTS

No general requirements have been found which relate to the control of the radar cross-section (RCS) of aircraft windows, windshields and canopies. The contribution of the canopy to the total RCS of the aircraft must be determined for each aircraft configuration. A decision as to whether or not the canopy must have

RCS control measures applied is not one that can be made strictly on a weapons systems basis since this involves many important factors in addition to the absolute contribution of the canopy and cockpit to the total RCS of the aircraft. However, it is assumed that RCS control could be a design requirement.

8-302 RCS CONTROL

Since there are many surfaces within the crew enclosure that reflect and tend to enhance the return signal, the goal of the military aircraft transparency designer is to absorb the impinging signal or to reflect it before it enters the cockpit. At the present time, there are no candidate materials that are both transparent to light and absorb radar frequencies, although research into an absorbant transparent construction utilizing a clear liquid between two structural panes has shown some promise. Thus, the designer is left with the alternative of providing an effective radar reflective coating with the goal of reflecting the signal away from the receiver. The strength of an echo is also dependent on the shape of the panel. The strongest and narrowest reflected signal occurs when the reflecting surface is oriented normal to the impinging beam. Most aircraft transparencies have some advantage in this respect because their surfaces are sloped. The radar reflective coating which is to scatter the signal echo away from the receiving antenna while preventing the signal from reflecting off internal cockpit surfaces, must be properly incorporated into the transparency design. Because of strongly conflicting design factors from other requirements, program requirements for RCS control must be established early during the aircraft conceptual stage. If RCS control is a firm requirement, program management must assign a high priority to establishing the overall RCS control plan because all parts of the aircraft must be involved. The high reflectivity potentials of the windshield/canopy area must be dealt with while the windshield/canopy and overall cockpit geometry are still somewhat fluid. The details of RCS control are a very specialized field.

However, the RCS control specialists will need the consultation and close cooperation of the windshield/canopy specialists if the preliminary design decisions are to result in a viable solution. RCS reduction can also involve highly classifiedd information. Therefor, it would be beneficial if some windshield specilists have the necessary security clearance to enable full participation in the design trade studies that lead to the final design approach definition.

8-303 RCS CONTROL TECHNIQUE

The technical intent of RCS control is to substantially reduce the radar signal reflected from the aircraft. The ideal, but presently impracticable, solution to RCS control would be to absorb all of the radar energy which reaches the canopy area. An alternate, currently more practicable solution is to coat the canopy with a highly conductive, but transparent coating which will reflect the radar signal rather than allow its two-way transmissiion into and out of the cockpit area, as is the general case for clear canopies. Recent investigations have shown that wire grids (.002 inch dia copper wires spaced at .100 inch) have radar reflection characteristics equivalent to coated surfaces. A full-scale transparency for the purpose of RCS reduction has yet to be produced. Although, Section 8-404 does describe an operational application of embedded wire grids for purposes of EMP attenuation. In the case of electrically heated windshields, power limitations and other factors might limit a particular heated area if the design objective of 100 percent windshield area anti-icing could not be accommodated. Therefore, it would be important to coat the entire windshield area with a conductive coating, preferably with a similar light transmission loss to preclude a visual distortion. The unheated areas, if any, would have to be electrically isolated from all portions of the heated area. This is accomplished by application masking, or by later removal of the coating. The area which has no coating should be kept small in order to limit the entry of radar signals into the cockpit, and to avoid visually disturbing differences in the light transmission for various areas of the windshield. These non-conducting areas are referred to as "deletion lines" and would normally be in the order of (0.030 inch) in width. The exact width of these deletion lines and their significance would depend upon the detailed design of the windshield and its temperature controller. Ideally, the deletion lines would not take on the form of a nonconducting slot which is resonant at the radar frequency, since such a slot would reradiate a strong signal, noticeably increasing the transients induced.

The RCS coating should be void-free and continous down to the edges of the canopy, whenever other constraints are not of overriding importance. Because of the fragile nature of most highly conductive transparent coatings they should not be placed on the outer surface of the canopy, but located on an internal surface of a multi-layer canopy or at least protected by a second coating which is relatively abrasion resistant.

The RCS coating will be an effective radar reflector even if it is not grounded to the aircraft metal fuselage because the wavelength of the radar signal is usually very small compared to the linear dimensions of the RCS coating. However, the electrical influence of triboelectric charging and lightning dictates a safer installation if the RCS coating is fully grounded to the aircraft structure. Refer to Section 7-700, Atmospheric Electricity, for more information on P-Static and lighting attachment on conductive coatings.

The mechanical adhesion of the RCS coating to the canopy materials may be significantly less than the adhesion between the basic canopy materials. Since these coatings and their applications are considered highly proprietary by some of the manufacturers, the possible effect of adhesion on the overall canopy design must be considered.

8-304 RCS CONTROL DESIGN RECOMMENDATIONS

The addition of an RCS coating to a canopy can significantly complicate the design and qualification of the final aircraft installation. Therefore, it is recommended that RCS coatings not be employed where their need is not fully justified.

When an RCS coating is required, the design must provide for the possible increase in electrical stress on the material lying between the outer surface and RCS coating. The coating should be constructed with peripheral electrical bus bars capable of conducting significant current for a few microseconds (References 8.7 and 8.8). Bus bar cross-sections used in conventional electrically heated coatings (2-4 mil thick, 5/16 - 3/8 inch wide) should be adequate. The bus bars should be multipoint grounded to the aircraft fuselage by low impedance straps. These straps should be two or more inches wide, but need not be more than a few thousandths of an inch thick. The high frequency pulse current is conducted only on the outer surface of the strap, therefore, thicker metal does not contribute to a better conductor.

The construction of a canopy provides a metal frame to which the transparency is joined. The frame in turn joins to the fuselage in an interface that is usually not conducive to providing the required low impedance path to the fuselage structure. The canopy tiedown points probably represent the best starting point for the location of the RCS grounding straps, as the remainder of the interface is usually a nonmetallic seal. Because of the electromechanical complexity of most of the grounding concepts studied so far, it is strongly recommended that the final design candidate be tested. The testing should be combined with tests on the canopy surface flash path grounding to be provided for triboelectric discharges and lightning flashes.

SECTION 4

NUCLEAR EXPLOSION

8-400 INTRODUCTION

Most modern military aircraft are to be designed for possible exposure to a nuclear environment at some point in their design service life. The windshield designer is concerned with the response of the aircraft to this environment. The several levels of the systems response defined in MIL-A-8869, "Airplane Strength and Rigidity, Nuclear Weapons Effects" (Reference 8.9) are:

a. "Sure Safe - Essentially no damage.
b. "Mission Completion - degree of damage still allows complete delivery of weapon, and perhaps return to base (although not necessarily).
c. "Mission-Kill - The aircraft cannot complete the mission due to damage.
d. "Sure-Kill - Assures that the aircraft cannot continue the mission." and that:

"The transparency system shall be capable of withstanding the same level of response as the basic airframe due to loads and transient phenomena resulting from a nuclear detonation." (MIL-A-8869)

There are four phenomena associated with a nuclear detonation that are of concern to the transparency designer: (1) nuclear blast, (2) thermal radiation, (3) Nuclear Electro-Magnetic Pulse (NEMP) and (4) nuclear flash.

The transparency system must protect the aircrew and allow for mission completion. This guide discusses general requirements, but specific criteria must be established for each aircraft design to define what degree of damage is allowable within each system of the aircraft.

8-401 MILITARY REQUIREMENTS

The nuclear weapons effects analyses of MIL-STD-1530 (Reference 8.1) requires that the manufacturer comply with the detail requirements of MIL-A-8869. The objectives of this analyses are:

a. "Verify that the design of the airframe will successfully resist the specified environmental conditions with no more than the specified residual damage.

b. "Determine the structural capability envelope and crew radiation protection envelope for other degrees of survivability (damage) as may be required.

"The contractor shall prepare detail design criteria and shall conduct the nuclear weapons effects analyses for transient thermal, overpressure, and gust loads and provide the substantiation of allowable structural limits on the structures critical for these conditions. The contractor shall also prepare and report the nuclear weapons effects capabillity envelope, including crew radiation, for a specified range of variations of weapon delivery trajectories, weapon size, aircraft escape maneuvers, and the resulting damage limits." (MIL-STD-1530)

8-402 NUCLEAR BLAST

Of the four effects of a nuclear explosion, only one is of a structural nature, i.e. nuclear blast. The effect of a nuclear blast on the transparency is an external over-pressure load and gust loads. If a pressure profile is plotted versus time, it will be seen that the pressure quickly builds to a peak and then the over-pressure gradully diminishes until it actually goes into a region of negative pressure. These pressure loads are additive to other aircraft flight loads on the transparency and support structure. The airframe is least vulnerable when the blast wave comes directly at the nose (head-on), but this direction places the windshield in a position of high pressure loading. The magnitude of the pressure load is affected by the size and shape of the transparency. The requirment here is that the transparency system and support structure shall survive a 2.0 psi overpressure load, which is the same load magnitude from a nuclear blast that the rest of the aircraft is expected to survive.

8-403 THERMAL RADIATION

The predominant form of energy released as a result of a nuclear detonation is thermal radiation. Thermal radiation, as used in this text, may be defined as the radiation emitted from the heated air of the fireball within the first minute following the explosion. The temperature at the burst point is estimated to be several tens of million degrees which heats up the surrounding air thus creating what we know as a "fireball." This fireball then reradiates the thermal energy in the form of a short period thermal pulse. This radiation travels at the speed of light, therefore, the time to reach a given target is insignificant.

When this thermal radiation strikes the transparency, part will be reflected, part will be absorbed and part will pass on through. It is the absorbed portion that produces heat and causes the temperature of the transparency to rise. This rise in temperature is of concern to the designer because it; (1) reduces the material's resistance to other hazards and the exterior environment, (2) causes increased thermal stresses within the transparency as a result of temperature gradients, and (3) causes stresses between the transparency and its support structure due to the effects of different coefficients of thermal expansion. In order to reduce the effects of radiation, it should be a goal of the designer to reflect most of it away from the aircraft, otherwise, it will heat the transparency or pass through and heat the air in the cockpit and/or injure the crew. The response of the transparency is the same as a high temperature thermal shock exposure.

Recent developments utilizing photochromic techniques to cause a clear transparency to become opqaue prior to the thermal wave impacting the system have shown much promise; Reference 8.10. The technique utilizes the ultraviolet wave front which precedes the thermal wave to activate the optical changes. By the time the thermal wave hits, the clear transparency is opaque, allowing it to absorb a larger percentage of the heat flux. Combining this capability with other infrared filters effectively reduces the thermal energy transmitted to less than 10 percent of the incident energy. This technique is currently undergoing full-scale transparency evalulation.

At the present time there is very little information available on either transmission or absorption versus wavelength for the plastic materials used in the windshields available in the unclassified literature that could be used even for preliminary estimates of performance. There are, however, test facilities at both Kirtland Air Force Base, Weapons Laboratory, and Air Force Wright Aeronautical Laboratories, Wright-Patterson AFB to test sample cross-sections for potential degradation due to simulated exposure. Verification of the available analytical techniques through this testing of the specimens is difficult since methods do not exist to measure the material's temperature without affecting the test or being affected by the test. Also, the energy source used in current tests does not totally or exactly duplicate the nuclear "fireball" source of energy.

8-404 NUCLEAR ELECTRO-MAGNETIC PULSE (NEMP)

An Exoatmospheric (high altitude) nuclear detonation will produce EMP. In a broad sense, the EMP is a short burst of high intensity radio frequency energy which is radiated from its source and subsequently received by the aircraft on which the windshield is mounted. The radiated spectrum and energy content of the EMP are dependent on the specific bomb characteristics and on the location of the blast. Reference 8.11 discuses the frequency spectrum generally recognized for EMP. A single high altitude burst can cover thousands of square miles of the earth's surface with very high intensity EMP radiation containing high energy in those portions of the spectrum where the aircraft is an efficient antenna for reception of this energy.

This broad-band electromagnetic pulse will excite various structural paths along the airframe and cause very high currents or voltages to exist on the surface of the aircraft. Surface discontinuities, especially transparencies, allow some of the external signal to penetrate to the fuselage interior where the signals can interfere with the electrical wiring and will be transmitted to sensitive electrical/electronic equipment. Without special design considerations this EMP energy can upset the normal electrical circuit operation and may destroy sensitive components.

The NEMP environment presented to the windshield or canopy cannot be determined without a detailed NEMP study of the entire aircraft. The consequences of the NEMP that does enter the aircraft via the windshield/canopy likewise must be determined on the basis of the NEMP protection plan for the whole aircraft. Decisions such as window size, support post quantity and general placement, space allocation for suppressor hardware, type of anti-icing (electric or hot air) will influence the overall NEMP protection plan. Judicious coordination and integration of the NEMP protective measures with the lightning and P-static protection approach as well as the elctromagnetic compatibility approach can result in system simplification and optimization of the transient protection hardware that must be located at the windshield/canopy periphery.

The necessary coordination can best be accomplished through the establishment of an EMP control plan (Reference 8.12) that will define the requirements and track the design as it progresses. The act of making an item resistant to the effects of EMP is known as "EMP hardening."

8-404.1 Interaction of NEMP with Transparency Design

Protection of aircraft systems from adverse effects of NEMP is a highly complex field which must involve the whole aircraft and most of the disciplines associated with its design. Windshield/canopy designers are an important part of the protection team because the optical transparencies of an aircraft can be one of the principal sources of NEMP signal entry into the aircraft.

NEMP signal entry via the windshield/canopy generally takes three forms: direct radiation through the electromagnetic aperture formed by window openings, coupling with exposed electrical circuitry, field coupling through the window aperture due to the NEMP indued current flowing on the airframe metal structure in the vicinity of the aperture. The latter is usually the more important because the whole airframe is a more efficient receptor of the higher energy portion of the radiated EMP spectrum than are the electrical receptors on the windshield or within the crew compartment when they are directly receiving the radiated NEMP.

Windshield peripheral structure is a major contributor to NEMP signal entry through a windshield. This is especially true for the vertical structural posts which usually interrupt the transparent area of the windshield systems of many aircraft configurations. These posts are the major electrical paths in the windshield area for the NEMP currents that flow on the outer skin of the aircraft. The NEMP magnetic flux encircles the posts and couples to electrical conductors within the cockpit and on the windshields as shown in Figure 8.4. Fore and aft overhead metal structure in canopies can have the same effect (Reference 8.13).

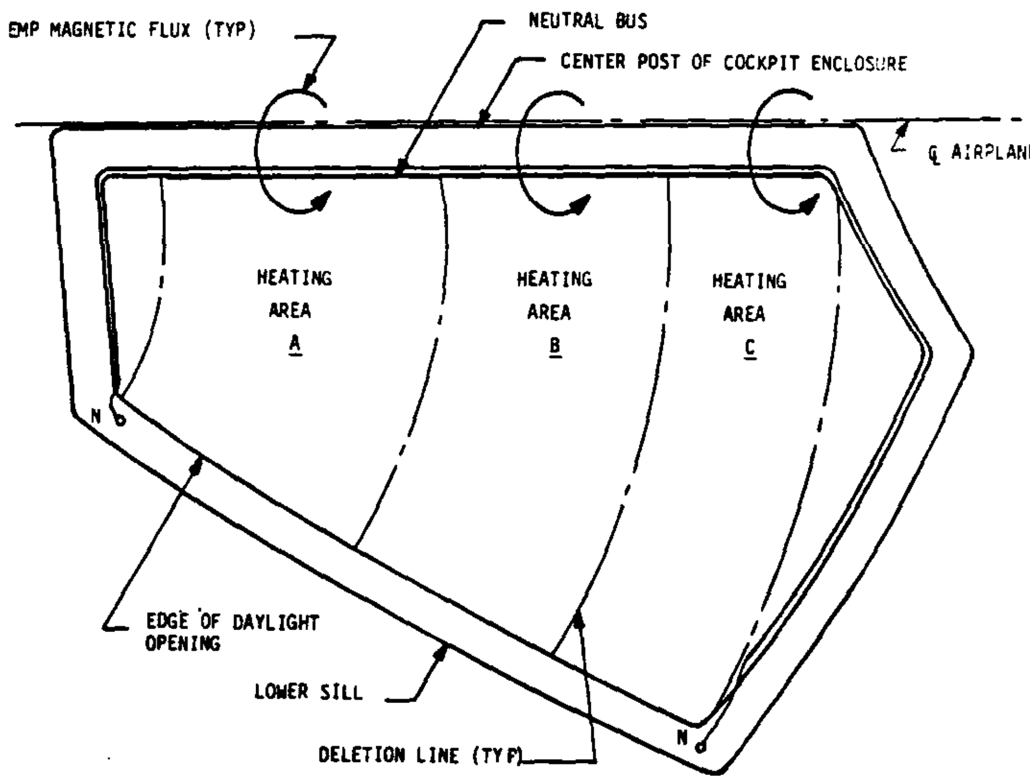


Figure 8.4. EMP Magnetic Field Coupling.

Anti-icing or defogging conductive coatings act as antennas for reception of the direct and fuselage-induced NEMP fields. Electrical wiring connected to these conductive coatings carries the potentially harmful NEMP signals to the connected or coupled electronic/electrical systems in the aircraft.

8-404.2 Control Measures

The most direct and seemingly obvious approach to excluding NEMP entry through windshields and canopies would be to erect a metal screen barrier within the cockpit and behind the windshield canopy. Copper screen has a proven effectiveness as an electromagnetic shield. (Reference 8.12) (The name "screen room," which is familiar to most electronic engineers, was derived from the early form of construction used for electromagnetically shielded test chambers.)

The major difficulty with this approach has been in achieving the low impedance peripheral electrical grounding to the aircraft structure necessary for shielding.

Another apparently obvious approach would be to use the anti-icing, defogging and RCS coatings which cover some windshields as NEMP shields. This approach also presents fundamental problems. Transparent conductive coatings have far too much electrical resistance to be completely effective magnetic field shields for the NEMP frequencies. Some published data (Reference 8.12) show attenuation values for typical anti-icing resistive coatings of more than 80 db in the NEMP frequency range of interest. This level of attenuation would be excellent - if it were only applicable. Confusion in this area is common among salespersons for shielding products. The data are often believed to be reliable, but actually apply to the electric field, not the magnetic field. It is the latter that represents the predominant signal entry field. Other data by the same author show typical magnetic field attenuation for these conductive coatings of only 10 to 20 db. This realistic level of attenuation is usually insufficient if no other protection or attenuation method is utilized.

The antenna effect created by anti-icing and defogging coatings has to be combatted by removing objectionable electrical transients from the wires which connect to these coatings. The general subject was covered in Chapter 7.

A third design utilizes a mesh etched from a copper film. This design has been evaluated for use on the E-4 and was determined acceptable by the pilots. As with the parasitic screen previously mentioned, the mesh is an optical distraction, but apparently the pilots learn to compensate for the meshes existence. Typically the meshes evaluated had lines four mils wide and 2.8 mils thick, spaced every .10 inch. Flight evaluation results included that insects spattered on the windshield or empty sky tend to cause the pilot to focus on the mesh. (Reference 8.14)

8-405 NUCLEAR FLASH

A nuclear flash is a brilliant flash of light resulting from a nuclear detonation. Large amounts of energy are released by the burst, and heat up the surrounding air to form what we know as the "fireball." It is the surface brightness of this "fireball" that we see as a flash (e.g., 15 microseconds and continuing to 150 microseconds after the blast). For combat aircraft, a goal of the transparency designer would be to protect the aircrew from this flash which can cause eye injury ranging from temporary blindness to severe retinal burns. However, these injuries only occur when the "fireball" is in the direct field of vision of the observer. There are two ways of designing to defeat this phenomenon; (a) reduce the pilot's field of vision, and (b) filter the flash before it reaches the pilot's eyes.

a. When operating in an environment with a high probability of nuclear flash, a "screen" or curtain can be erected on the inside of the windshield which has a small aperture for forward vision. This curtain greatly reduces the transparent area of the windshield and thereby greatly reduces the probability that the flash will occur in the pilot's field of vision.

b. Filtering the flash before it eaches the eyes of the observer is a more desirable method because it does not restrict the pilot's field of view. Filtering the light does, however, affect the amount of light which reaches the pilot.

Simple systems such as broad-band filters which reduce the light transmission at all times are not appropriate against the nuclear flash since the light transmission reduction must be over 90% to eliminate flash blindness.

During the 1960's, photochromics were considered a viable means for flash blindness protection. The research effort, which was never a concentrated attack on the problem, ended in the early 1970's with no passive protective device developed. Organic materials which had sufficient response times also had a short fatigue characteristic where each use would drastically reduce the effectiveness against the next flash. And since lightning could activate the clear-to-opaque-to-clear cycle, the system's life was considered too abbreviated for reasonable application.

During the early 1970's an electrochromic capability was developed that is viable against the nuclear flash. This capability requires electrical activation for the crystalline material to darken. This capability cannot be cost-effectively used on aircraft transparencies because the crystalline structure must be grown absolutely pure, a statistical improbability for a large piece. Electrochemical materials are currently incoporated in PLZT protective goggles which can be worn when the aircrew is in an alert posture or in a combat situation. These goggles were developed by the Air Force Materials Laboratory, Wright-Patterson AFB, Ohio.

SECTION 5

DIRECTED RADIATION & PARTICLE WEAPONS

8-500 INTRODUCTION

Presently these categories of weapons are in their early stages of development. Any individual or company desiring specific information on these two combat threats must contact the appropriate Department of Defense or Department of Energy Office. The Materials Laboratory of the AF Wright Aeronautical Laboratories, (AFWAL/ML), Wright-Patterson AFB, OH, is the Air Force office of prime responsibililty (OPR) for laser hardening technology and has built up a capability for testing and evaluating laser hardening. The Air Force Weapons Laboratory (AFWL), Kirtland AFB NM is the Air Force office of prime responsibility for most other energy weapons. Other weapons categories which may be included, but are not discussed here, are microwave and ultrasonics.

8-501 LASERS

There are three basic approaches to defeating a laser threat: reflection, absorption and ablation.

Special multilayer coatings may be utilized to reflect the energy from low power laser threats, however, neither current transparencies nor associated coatings are capable of reflecting high power laser radiation. The second method, absorption, requires high thermal conductivity to disburse the heat before it can build up to a damaging level. Transparent plastics have low thermal conductivity and absorb most of the laser radiation at the surface leading to a very rapid rise in temperature with resulting boil off of material. Glasses have higher thermal conductivity, but again surface absorption of the radiation leads to a rapid temperature rise with resulting crazing and thermal fracture of the material. The third means, ablation, utilizes the low-thermal conductivity of plastics to an advantage. Most of the current efforts in laser hardening of transparencies are based on the development of polymers which, when rapidly heated form a tough char layer that ablates or recedes at a much slower rate than standard plastics. In most instances an opaque char spot only slightly larger than the impinging laser beam remains behind. This method requires a new or altered transparent material. New materials that show promise as candidates are characteristically brittle and thus, are not satisfactory as structural plies. In addition, they have a low resistance to weathering effects. For optimum use of these materials, a laminated composite design as shown in Figure 8.5 would be necessary. The outer-ply should be an abrasion resistant material as used in current laminated transparencies, immediately below (inboard of) this ply is the laser hardened material, followed by an interlayer, then the main structural ply, then another interlayer and an abrasion resistant inner-ply if necessary.

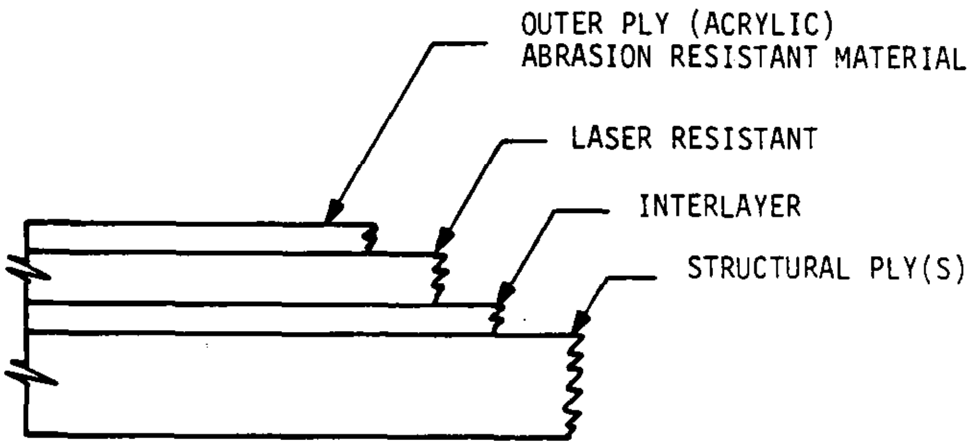


Figure 8.5. Laser Hardened Transparency Cross Section.

A second aspect of the laser impingement is the flash. Although the development of the protective char reduces the flash with time, the initial flash could lead to temporary flash blindness. Therefore, current technology is encouraging the use of personal protection devices such as the recently developed Nuclear Flash goggles. See Section 8-405.

8-502 HIGH ENERGY PARTICLE WEAPONS

Both the threat and the means of defeating the threat are highly classified subjects, barely in their infancy stages of development. Qualified investigators should seek information from the Air Force Weapons Laboratory, Kirtland AFB NM 87117.

SECTION 6

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