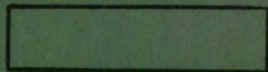


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TECHNICAL MEMORANDUM NO. LWL-CR-06P73A

REDUCTION OF REFLECTIONS FROM HELICOPTER
WINDSHIELDS, ROTOR BLADES AND ROTOR HUB

By
John A. DeBenedictis
John W. Woestman
Franklin Institute Research Laboratories
Philadelphia, Pa.

COUNTED IN

Franklin Report C3120-08
Prepared under Contract DAAD05-71-C-0422

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PREFACE

This work was conducted by the Franklin Institute Research Laboratories as Assignment #8 under Work Assignment Contract DAAD05-71-C-0422. It was the initial step under Task 06-P-73, Glare Reduction, conducted by the Applied Physics Branch, Advanced Development Division, U. S. Army Land Warfare Laboratory, Aberdeen Proving Ground, Maryland. Mr. G. B. Stevenson was the task officer from November 1971 until April 1972. Mr. H. C. Forst was task officer from April 1972 until November 1972 when Mr. G. E. Cook became task officer.

The objective of the task is to reduce the visual detection of Army Cobra and OH-58 helicopters by enemy ground personnel resulting from sun glints reflected from the aircraft's canopy, rotor blade and rotor hub. In addition to this report, emphasis has been placed on developing a vacuum deposited reduced reflection coating for stretched acrylic plastic; applying reduced reflection paint to the rotor, hub and drive shaft; developing a computer model of sun reflected from the Cobra canopy, and designing flat canopies for the Cobra.

ABSTRACT

This report addresses itself to the problem of reducing reflections from helicopters. Specific areas investigated are the windshields, rotor blades and rotor hub assembly. All feasible ideas, however remote, were solicited and considered.

Recommendations are divided into general sub-categories for each area and are presented with estimates of their potential effectiveness. The body of this report is composed of a technical discussion of every potential solution as well as related precautions to heed and specific evaluations to consider.

The references and bibliography provides the reader with an up-to-date comprehensive listing of studies, products and techniques related to the problem of reflected light from helicopters.

ACKNOWLEDGEMENTS

Many people contributed to the content of this report due to its very nature. The literature offered a great deal of leads while representatives of private industry were most willing to contribute as evidenced by the list of references.

Particular thanks were earned by numerous peers who participated in literature searches and idea generating sessions. Follow-up conferences with these same personnel proved fruitful.

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DEFINITIONS

The following definitions apply for the purposes of this report:

- WINDSHIELD:** All transparent surfaces on both helicopters being considered (OH-58 and AH-1G). Presently made of acrylic.
- ROTOR BLADES:** Large lift blades located above helicopter and horizontal to ground. Made of high grade aluminum.
- ROTOR HUB:** Rotor blade support assembly attaching rotor blades to top of fuselage including driving and control linkages. Made of uncoated polished machine steel.
- INTERNAL:** This term applies to the material itself. For instance, internal changes in the windshield will refer to actual material change, additives to the internal structure of the material or alloys incorporated within the material.
- EXTERNAL:** This term applies to anything that is not a part of the material in question. It may be something which is bonded to or coated on the material.
- PHYSICAL CHANGE:** Defines a change in dimension or contour
- ANGLES:** A normal angle is defined as 0° to 30° from the perpendicular line representing a ray of light impinging upon a surface.
- An intermediate angle is defined as 30° to 60°
- A grazing angle is defined as 60° to 90°

1. INTRODUCTION

The use of radar controlled anti-aircraft weapons is a threat which requires helicopters to be flown at "nap of the earth" (flying at low altitudes following the contours of the terrain). Recent testing using this technique has demonstrated an old problem which is now a major threat to helicopter survivability. Namely, light reflections from various surfaces of the helicopter cause a high rate of visual acquisitions and would be susceptible to optically controlled anti-aircraft weapons. The three main sources of reflections are windshields, rotor blades and rotor hub assembly in that order. This study generates, accumulates and evaluates techniques for the reduction of reflections from U.S. Army helicopter models AH-1G (Cobra attack craft) and OH-58 (observation craft).

Windshields (defined as all windows) offer a high degree of reflectivity (about 8%). They are currently made of a non-ballistic acrylic. Heretofore, coatings of various sorts have been applied to the windshields to reduce reflections. These coatings do in fact have a favorable effect without restricting visibility but the degree of reduction is insufficient to avoid visual detection. Windshields have been removed which completely eliminates reflections, however, it also seriously limits the aircraft's maximum speed and endangers occupants to airborne objects. One feasible solution to the problem involves changing the material from which the windshields are made and/or altering its internal structure such that light rays are permitted or directed to pass through the window, diverted along its axis, absorbed by the material or reflected in such a diverse manner so as to preclude detection. A second potential solution is to change the external environment. A good approach is to keep the rays of the sun from impinging directly upon the windshield. Shade covers of various sorts are worthy of consideration. Coatings such

as improvements on those already tried, offer potential aid. A third avenue of approach is to physically change the construction of the windshield in order to redirect the reflected rays out of harms way. Steep slopes or inverse curvatures are possibilities. These efforts are aimed at the basic causes of reflections, namely, the reflectivity of the outer surface of the material, the material itself and the physical orientation of the material with respect to the source of the problem (the sun).

Rotor (lift) blades (made of high strength aluminum) offer a distinct variance in the basic problem in that they sustain a high circular velocity. Stationary blades could be painted with any high quality flat paint to eliminate reflections but since the blades are moving rapidly in a circular path, light rays glancing off a given spot are effectively magnified by the retentive persistence of the eye of the observer. The result is an apparent mirror like reflecting surface. This solution could be aimed at higher quality non-reflective coatings but more realistically involves either eliminating the repetitive nature of the phenomenon which results in retinal persistence by changing the internal material, the surface layer or by covering the blades in some manner.

The rotor hub assembly (that part which supports and controls the rotor lift blades and attaches to the fuselage of the aircraft) is made of polished machine steel. This assembly has its own distinct idiosyncrasies. That is, the assembly is currently uncoated in order to allow visual inspection routines. Immediately prior to take-off, the pilot visually inspects the assembly for small cracks which could develop into failures during flight with catastrophic results. He also looks for excessive oil spillage from various pressurized ports (some degree of spillage is acceptable). In addition, the pilot might want to verify some critical dimension by measuring with a micrometer. Higher echelon maintainance includes dye and magnaflux test techniques. Efforts to solve reflection problems from the hub assembly can be divided into internal/material changes, surface changes and external changes but one must be careful to maintain the integrity of current inspection routines or to supply alternate inspection devices which can match or out perform current methods.

2. SUMMARY

This report attacks the problem of reducing or eliminating reflections from airborne helicopters. The surfaces which yield detectable reflections are the windshields, rotor blades and rotor hub. Techniques for reducing windshield reflections are categorized as internal methods, external methods (further sub-divided into eliminating the source, controlling light rays and eliminating the reflecting surface) and physical changes. Techniques for reducing rotor blade and rotor hub reflections are both categorized as internal material changes, surface changes and external changes.

The literature was thoroughly searched through: (1) Plastec Index (2) Science Abstracts (3) Chemical Abstracts (4) Engineering Index (5) Optics Technology (6) Applied Optics (7) Journal of American Optical Society (8) Government Report Announcement and (9) Defense Documentation Center (both non-classified and classified). Next, letters of inquiry were sent to all manufacturers referenced in prior studies as producer's of reflection reducing products or techniques. Telephone and personal contacts were employed where possible. A distinguished group of scientists and engineers from a multi-disciplinary background comprised a brainstorming team and source of subsequent counsel. Paper analysis of various ideas was explored where appropriate.

Internal methods of reducing reflections from windshields face the paradox that low refractive index materials are non-rigid. A major technological breakthrough is needed to make them applicable. Tinting approaches face the same type of paradox since increasing tinting reduces through vision and does not eliminate surface reflections. External methods offer many intriguing possibilities with the probable exception of single layer thin films. Any specific film addresses itself to a specific wavelength. Physical change schemes are limited only by cost

and aerodynamic penalties. Potentially useful ideas include (1) strategic flight patterns (referenced to sun and ground observer) (2) change of physical shape (small flat sections slightly misaligned with one another or inverse curvature) (3) shading techniques (baffles, screening, fabrics) (4) multilayer anti-reflection films (or continual flow of low reflective index material over windshield) (5) replace windshield with high velocity air stream (perhaps include protective netting or tubing) (6) windshield with gradient index of refraction (as per new fiber optics) and (7) smoke or steam cover for entire craft. (assuming visibility could be maintained)

Changing rotor blade material faces the challenge of a strong material with low reflectivity complicated by the high velocity of the rotating blades. Surface changes would have to undergo detailed stress and strength analysis. Useful approaches include (1) paints with low reflective index (2) paints using camouflage patterns (3) paints using complementary colors on alternate blades to utilize the persistence patterns of the human eye to advantage (4) a thin layer consisting of raised ridges designed to trap and scatter the light rays bonded to the blades and (5) "pitted cones" or sand blasted imperfections in the blade surfaces themselves.

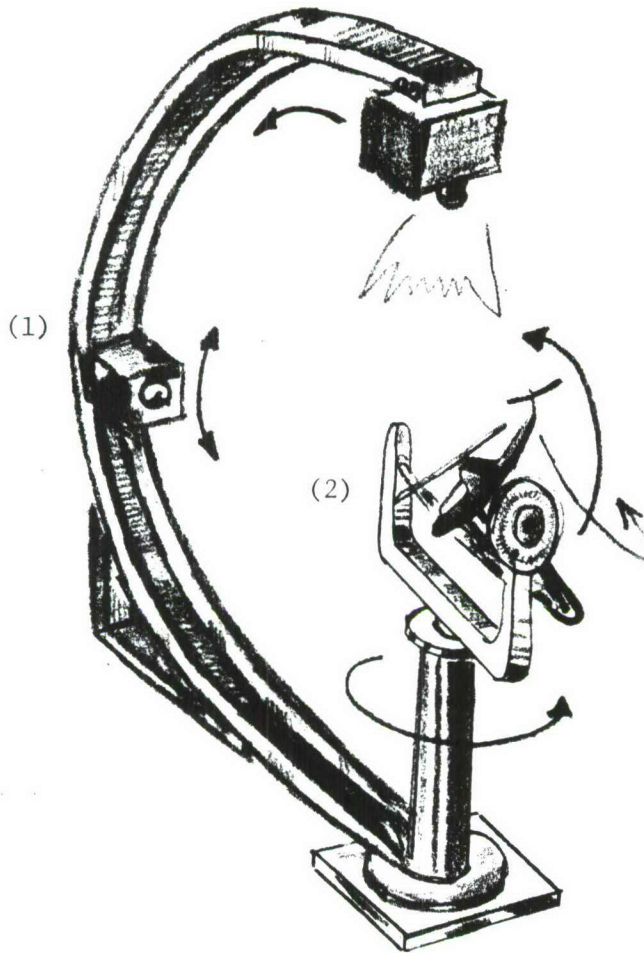
Rotor hub ideas not recommended for further study prior to alternate ideas are material changes (structural reasons) non-reflective permanent type coverings, as tapes (difficult to apply after inspection routines) and off-hub shading (aero dynamics). Good approaches include (1) snap-on covers (2) thin film stress coats (3) non-reflective dyes (either thin film to allow visual inspection for cracks or soluble film to allow easy removal) (4) paints applied in patterns designed not to obscure cracks and (5) anodizing or plating procedures.

3. RECOMMENDATIONS

3.1 Windshield

3.1.1 Model Analysis

Based upon the results of this investigation, the most promising approach to eliminating visual detection of helicopters via reflections from their windshields is to perform a detailed modelling and analysis of exactly what positions of aircraft *vs.* sun *vs.* ground observer render the ship vulnerable. This study should also pinpoint exactly what size and shape of transparent surface is essential to the crew and conducive to eliminating reflections. For instance, a pilot could learn which altitudes and directions of approach into a combat zone render his craft relatively safe from visual acquisition. This of course would be time of day dependent. More importantly, this type of detailed study could show how much improvement windshields with flat surfaces and inversely curved surfaces would have over the present curvatures. It is anticipated that a windshield made of small square flat sections, probably one or two inches square oriented in slightly different planes in respect to one another, would cause reflections to be concentrated and therefore, detectable only from a specific spot and even at that spot would only present a momentary flash to the observer. This approach is highly recommended. Present aircraft could be fitted with the new windshields in the field. Cost would be a factor but not prohibitive. Through vision would be maintained by controlling the minimum size of the squares. Figure 1 shows an exclusion angle testing setup which would allow a sophisticated investigation of the effects of sun angle and helicopter orientation while clearly defining danger zones in which the aircraft would be detectable by virtue of reflections. The semicircle member (1) allows for orienting the "sun" and mounting a light meter and/or camera. The cradle mechanism (2) is designed to rotate



- (1) Semi-circle of channel aluminum to support "sun" (light source) and "observer" (light meter and/or camera)
- (2) Cradle mechanism to mount and orient helicopter model or windshield test specimens.

Figure 1 Exclusion Angle Analysis Test Set-up

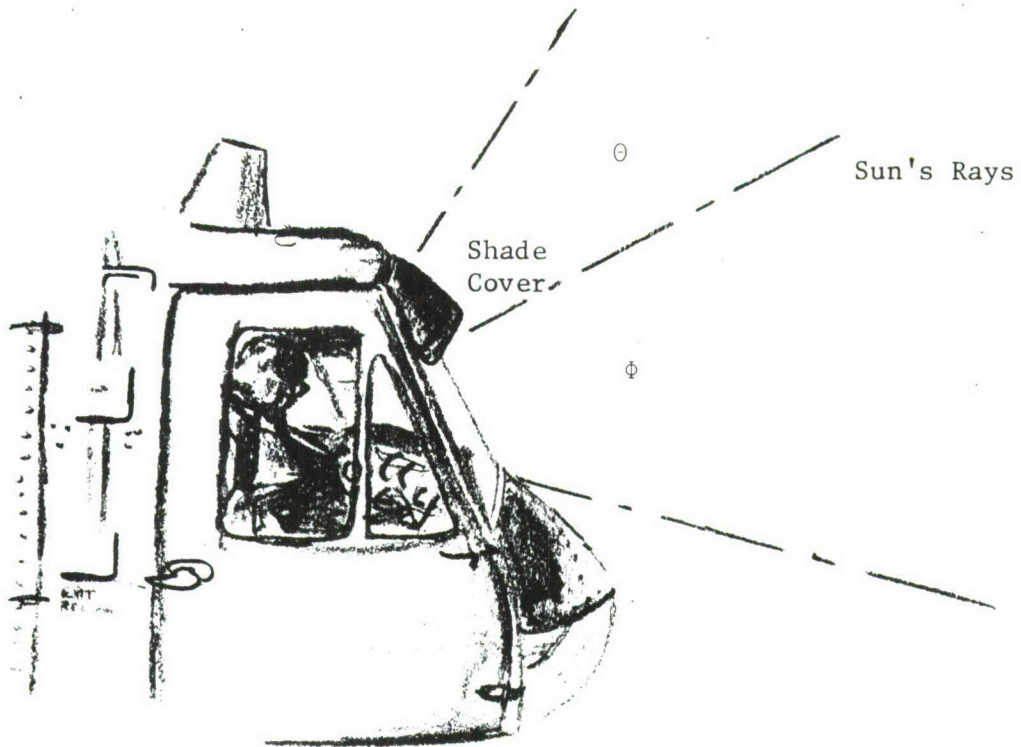
360° and to support the helicopter at any point thereby allowing the experimenter to study conditions at any point in time and at all angles. In addition, samples of windshields and shapes could be substituted for the helicopter model.

3.1.2 Shading Techniques

A second sound approach would be to keep the sun's rays from hitting the windshield. This could be accomplished with a shading technique. The more interesting ideas include an external sun visor type baffle similar to those used on automobiles in the early 1950's. Window screening or mosquito netting also has potential. Means for removing them during flight would be necessary in the event the mission carries into low light level areas or times. A honeycomb type windshield cover to trap the reflecting rays is also worthy of further investigation. All of these schemes could be evaluated in the laboratory in a setup similar to that discussed in 3.1.1. Figure 2 shows examples of shading.

3.1.3 Coatings

Coatings present an inherent problem in that they are designed to eliminate a specific wavelength and although are reasonably effective across a band of wavelengths, they are only a partial solution to the entire visual spectrum. Recent developments in ease of applying multiple layers of thin films make this approach worthy of further investigation. Another coating approach would be to allow a material of low refractive index to continually flow over the windshield. Such materials exist but are not potential replacements for windshields because they are in the non-rigid state. The scheme of ejection from a window washer type spray would enable the pilot to selectively use potential advantages of the material. Effects on through vision would have to be studied. This idea might prove to be the most effective and simplest to employ or perhaps it could most effectively be used in conjunction with other means.



OH-58 Helicopter

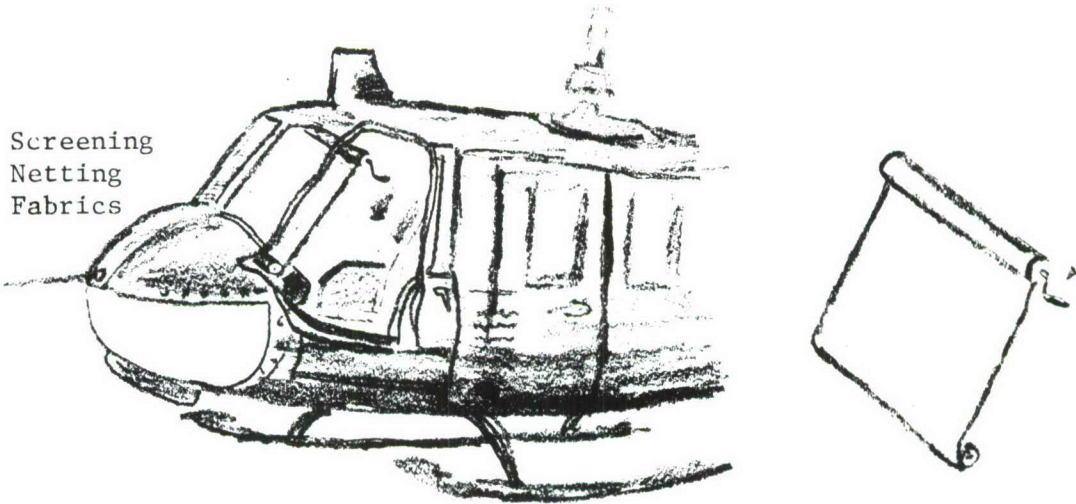
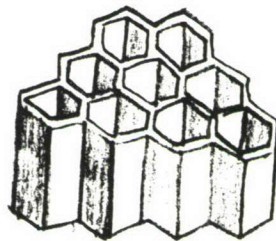
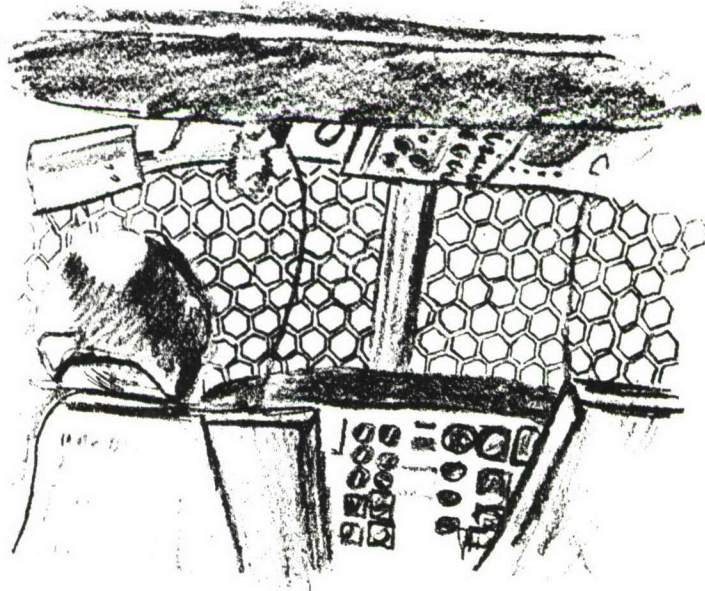


Figure 2 Shading Techniques



Honeycomb Structure

Figure 2 (Continued)

3.1.4 Windshield Replacement

Replacing the windshield leads to many technical hurdles. The most feasible replacement for the windshield would be a high velocity air stream which would be capable of maintaining cockpit environment integrity and preventing entrance of foreign objects into the cockpit during flight. This high velocity airstream would maintain aerodynamic air flow and be driven by the helicopters turbine. The penalty would be cost of development and fuel consumption. A refinement of this idea would be to use small diameter transparent tubes horizontally across the windshield area spaced a few inches apart. These tubes would serve to prevent large foreign objects from entering the cockpit and allow use of a much lower velocity jet of air to assure internal environment integrity. See Figure 3.

3.1.5 Gradient Index of Refraction

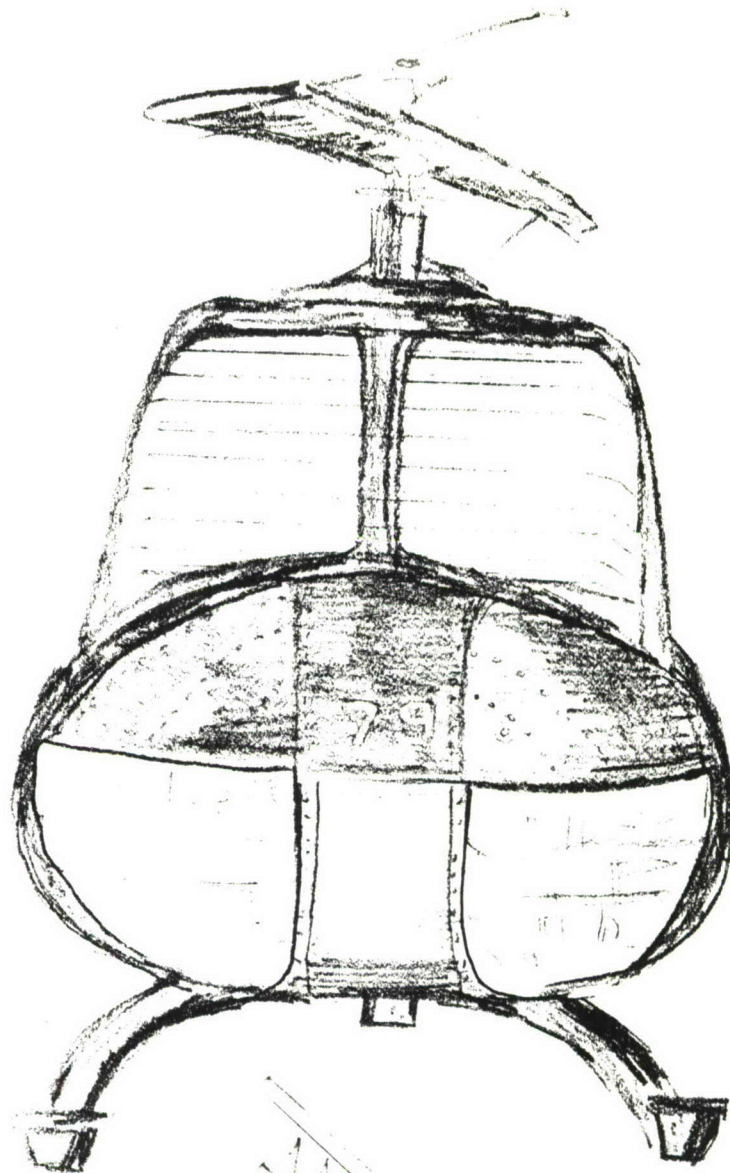
Reports or recent developments in fiber optics by Japanese firms indicate that they have a technique which effectively offers a gradient index of refraction to a travelling light ray. Details of this technique are unavailable at the moment but could prove to be an ideal solution. Further inquiries are indicated.

3.1.6 Smoke Screens

A scheme which would eject a steam or smoke screen would not only solve all reflection problems but would hide the aircraft from other means of visual acquisition (of course, a lonely cloud on a perfectly clear day could have the opposite effect). This idea has many technical hurdles but is worthy of at least a feasibility study since it does offer potential total solution to visual acquisition.

3.1.7 Other Techniques

General categories of approach which do not warrant further study at this time in light of alternatives include (1) replace windshield material (materials with low refractive indices are non-rigid) (2) tinting



Air Flow

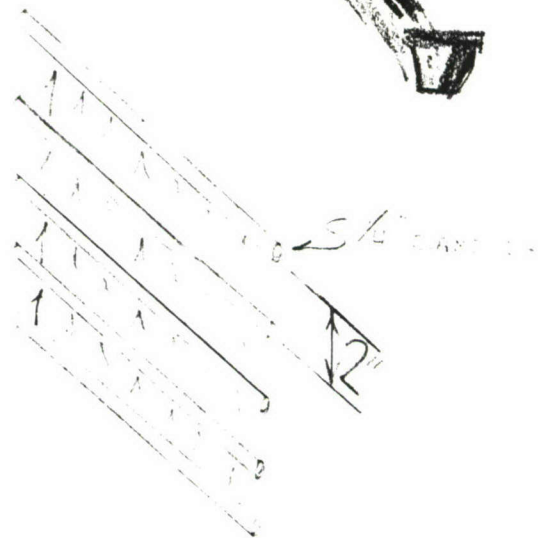


Figure 3 Elimination of Windshield

(the nature of tinting yields decreased visibility proportional to reduced reflection) (3) single layer anti-reflection coatings (the best industry has to offer is far from adequate).

3.2 Rotor Blades

3.2.1 Flat Paints

Paints with low reflective index should be evaluated due to ease of investigation and potential of success. All major companies make a flat black paint. Binding material in paint also contributes to gloss characteristics. A complete solution may necessitate repainting of the blades at short intervals.

3.2.2 Camouflage Paints

Paints could be applied in a camouflage type pattern should the foregoing effort prove ineffective. The camouflage technique would be aimed at preventing the high circular velocity pattern of the blades from offering the eye of the observer a repetitious display of reflections which are integrated into a bright flash.

3.2.3 Paint Schemes

Another scheme using paints would be to paint alternate blades complementary colors. This idea may be extended to patterns of complementary colors on alternate blades. The high velocity would cancel the color persistence. Perhaps it would favorably affect reflections.

3.2.4 Surface Change

A thin strip of tough material with raised ridges on its upper surface could be bonded to the blades to avoid creating stress analysis problems. These ridges, properly designed, could probably aid in the aerodynamics by preventing laminar air flow down the axis of the blades. Another similar scheme would be to create a large number of indentations in the upper surface of the rotor blades. These indentations would tend to trap and redirect any light rays, of course, this approach demands a detailed stress analysis before implementation. (See Figure 4).

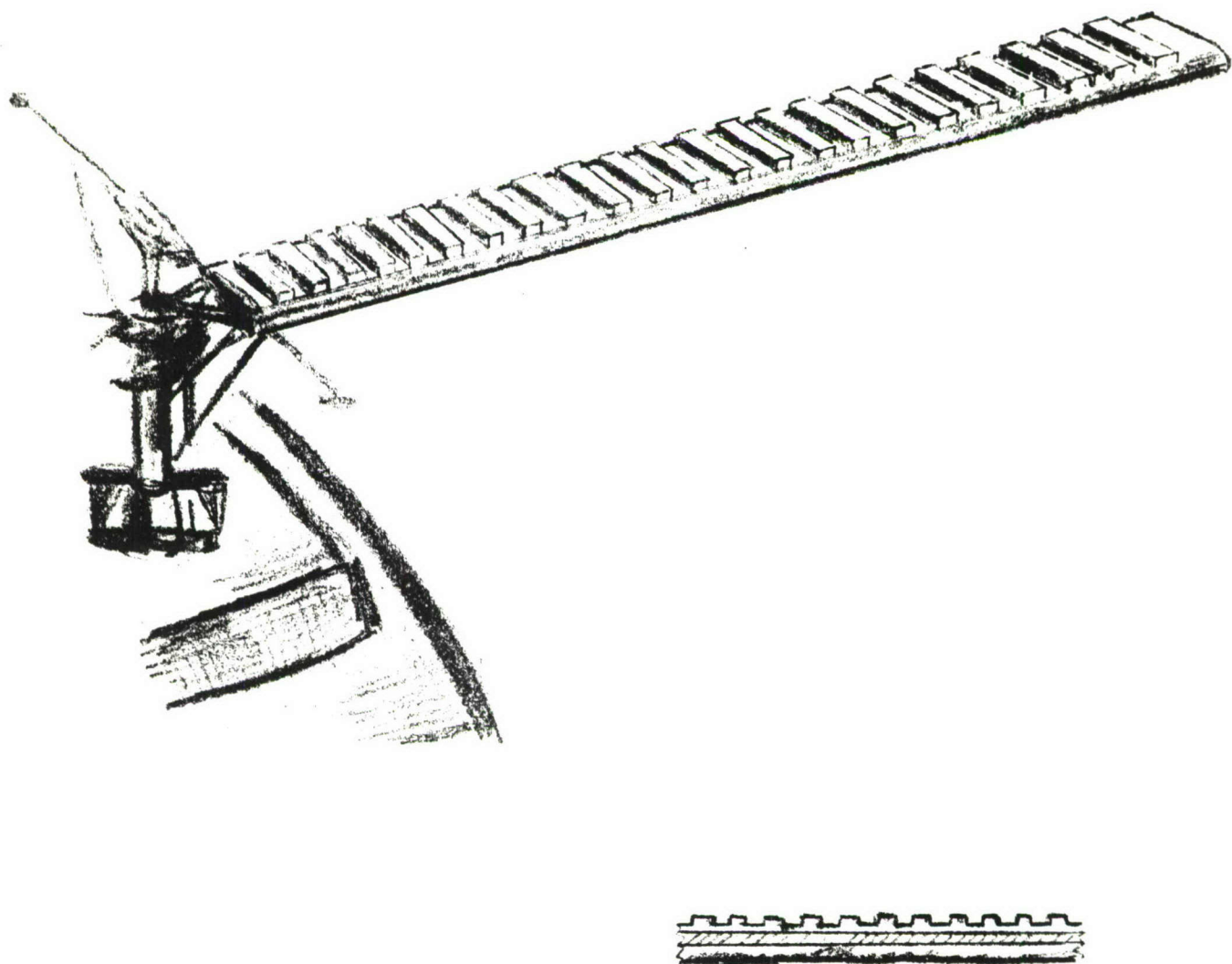


Figure 4 Rotor Blade Surface Changes

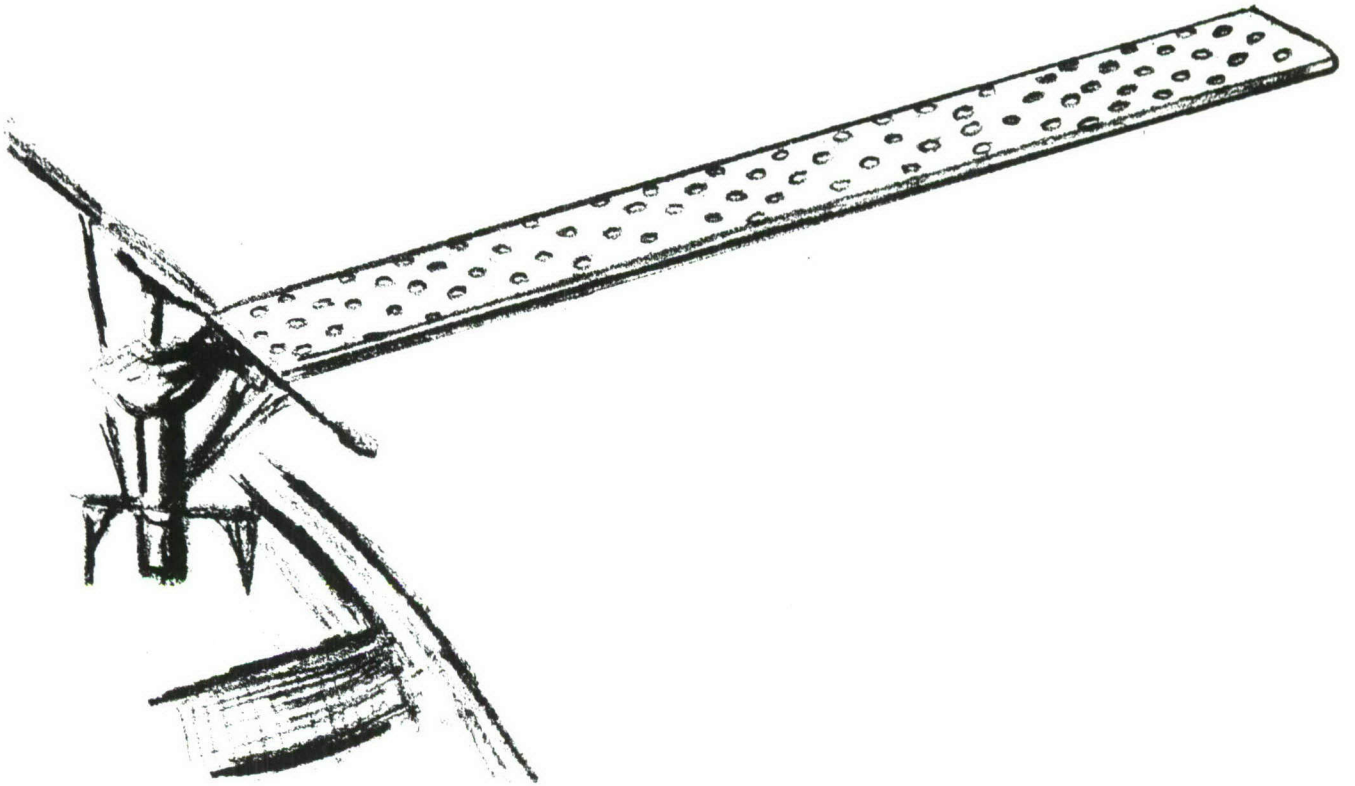


Figure 4 (Continued)

3.2.5 Other Techniques

General categories of approach which do not warrant further study at this time in light of alternatives include (1) changing blade material (materials do not exist which can lift a helicopter and eliminate reflections) (2) thin film coatings (lift blades can accept heavy coatings such as paints).

3.3 Rotor Hub

3.3.1 Covers

Snap-on or zipper-up covers made of rubber or tough fiber would completely eliminate the problem. Present aircraft would need only to be fitted with anchoring hooks. Normal inspection procedures could take place before the cover is applied.

3.3.2 Stress Coats

Thin film stress coats could be applied to the rotor hub metal. Such coats actually aid in detecting cracks. Their brittle nature could, however, give false indications of impending ruptures. Test samples are needed to determine their value.

3.3.3 Dyes

Non-reflective dyes and dyestuffs could be applied in these coatings so as to not hide cracks or they could be sprayed on after inspection and removed with a solvent following the mission at hand.

3.3.4 Paint Patterns

Paints or thin coatings could be applied in a pattern such that cracks of a significant length would be visible between paint borders. This approach would probably not eliminate reflections but would reduce them somewhat.

3.3.5 Plating

Anodizing or plating could be used if the coatings were applied in very thin layers or if internal cracks would also crack the surface. This idea is not considered as good as the foregoing ideas but might be feasible should the former ideas prove insufficient.

3.3.6 Other Techniques

General categories of approach which do not warrant further study at this time in light of alternatives include (1) material change (due to structural requirements; different material could not eliminate reflections) (2) non-reflective tapes (difficult to apply and would wear rapidly and (3) shading from rotors (aerodynamic problems).

4. WINDSHIELDS (TECHNICAL DISCUSSION)

4.1 Reflections Reduced by Internal Means

4.1.1 Materials

Attempts at reducing reflections from windshield surfaces by internal means face the paradox that materials with low refractive indices in general are not very rigid. Plastec,⁽¹⁾ in a comprehensive report published in July of 1962, points out that for a material to be effective in reducing reflection, it would have to have an index of about 1.3 or less. Their conclusion, which is still valid, was "In consideration of the total picture, it appears remote that a durable solid of low refractive index, and a low reflectance potential, could exist." See Table 1.

4.1.2 Tinting

Much work has been done with tinting procedures; automobile, aircraft and building windows are commonly tinted. Sunglasses are another example. However, these efforts are most useful in respect to observer comfort. Libbey-Owens-Ford⁽²⁻³⁾ in response to an inquiry about tinting, writes in part, "The major stumbling block has always been operational procedures at dawn and dusk. While the reduction of light transmission is very desirable during operations in direct sunlight and can be corrected for during night operations, it is found to be unsatisfactory during the interim between day and night." Bell Helicopter Company and Hiller Aircraft Corporation use tinted windshields but their effort is measured in enhancement of pilot comfort. Reflections are reduced but not eliminated. Tinting relates to the light absorption capabilities of color, which are proportional to the degree of darkness of the color. Tinting can reduce reflection from about 8% to about 4% (therefore, it is not a total solution) but it also reduces visibility.

TABLE 1
INDEX OF REFRACTION - LIQUIDS AND SOLIDS*

| SUBSTANCE | STATE | REFRACTIVE INDEX |
|------------------------|---------|---------------------------|
| Nitrous Oxide | Liquid | 1.193 |
| Hydrocyanic Acid | " | 1.254 |
| Hydrogen Chlorine | " | 1.256 |
| Ethyl Trifluoroacetate | " | 1.306 |
| Phosphine | " | 1.317 |
| Hydrogen Bromide | " | 1.325 |
| Ammonia | " | 1.325 |
| Methyl Alcohol | " | 1.3283 |
| Nitrogen Dioxide | " | 1.330 |
| Sodium Fluoride | Solid | 1.3258 |
| Cryolithionite | " | 1.339 |
| Fluorite | Mineral | 1.4339 (Moh Hardness = 4) |
| Quartz | " | 1.5442 (" " = 8) |
| Diamond | " | 2.3195 (" " = 10) |

* From Handbook of Chemistry, N. A. Lange, 1946

4.1.3 Piped Light

The phenomenon - "piped light" - is investigated by the Plastec⁽¹⁾ report and dismissed on the grounds that the effective angle of incidence of a light ray is very specific for the process to be able to reduce exterior reflections. This phenomenon deserves mention here in that if reflections can be reduced from a large number of angles by other means (such as physical changes or flight path attack angles stabilization in reference to sun location - as will be discussed later in this report) then perhaps "piped-light" advantages can be utilized.

More specifically, "piped light", which has its most prominent manifestation in transparent plastics, relates to an angled light beam introduced at an edge of the material and reflected by the interiors of the plastic/air interfaces. By these interior reflections, the "edge lighting" is carried throughout the item. Under optimum design, the light emitted from the surfaces will be glareless and uniform. "Piped light" can also be introduced into a material through the surface, but only at a highly selected angle between the incident beam and a line normal to the surface. (That angle whose sine is the refractive index of the air divided by the refractive index of the material.) It is this specificity of effective angle of incidence which renders this concept unuseable in our application unless other measures force this criteria to be met.

4.1.4 Etching Techniques

The Radio Corporation of America has experimented with fluorine acid etching techniques which could be used to roughen the surface of the windshield and thereby scatter the reflected light rays, however, this would also scatter the through light and distort the pilot's vision. A compromise between scattering and through vision via degree of etching is not promising as an acceptable solution by itself since maintaining vision necessitates insufficient etching to significantly reduce reflections. Again, this approach should be considered in conjunction with other potential solutions. Techniques similar to this idea have been used in conjunction with television lenses.

4.1.5 Gradient Index of Refraction

A windshield with a gradient index of refraction is theoretically an ideal solution if such an item existed. For instance, a light ray passing through a median whose outer surface had an index of refraction of 1.0 and whose internal composition slowly changed in an increasing direction in an infinitesimal manner, one would expect absolutely no reflections while through transmission would be maintained. Japanese fiber optic companies advertise a new process which approximates this idea of a gradient index in their fiber optic probes. To date, no technical data has been received on this phenomenon.

4.1.6 Sapphire Windshields

Replacing the current acrylic windshields with sapphire windshields would offer a degree of reflection reduction as well as ballistic advantages (up to 30 caliber) and would be more compatible to glare reducing surface efforts. Unfortunately, this avenue of approach is cost prohibitive. It is, however, worthy of note in that a small critical portion of the windshield could easily be fitted with sapphire should parallel schemes confine the target area to a localized spot.

4.1.7 Glass

Dow Corning has developed an extremely hard glass capable of pounding nails. New processes could conceivably overcome the problems of sufficient radius of curvature to accommodate the present cockpit designs. This approach does not offer a direct solution in that means to eliminate the glare from the glass would still have to be developed. In addition, shattering glass adds to safety hazards and glass compromises weight considerations. The advantage of glass over acrylic is, therefore, questionable.

4.1.8 Lexan

Dow Corning has also developed a new polycarbonate (Lexan) which is very hard and resists abrasion. Commuter railroad trains are using this product for windows. It inherently offers a slightly reduced

reflection but one which is none-the-less objectionable. This approach also demands efforts to eliminate glare. Its advantage in respect to acrylic would have to be demonstrated.

4.1.9 Germanium

The use of germanium in conjunction with Infra-red see-through goggles offers the same obstacles as other internal changes. That is, the material itself does not eliminate glare. It would be advantageous only if the new material proved more susceptible to reflection eliminating schemes than would the old material.

4.2 Reflections Reduced By External Means

Attacking the problem of reducing reflections by external means offers a host of interesting ideas. These possibilities can be subdivided into three basic modes of attack; (1) eliminate the source of the reflection (as flying at night or only on overcast days, or, more realistically, shading the windshield from the sun); (2) control and direct the light rays (as $1/4$ wavelength coating techniques to cancel reflections); and (3) eliminate the reflecting surface (as an open cockpit or air flow windshields).

4.2.1 Eliminate Source

4.2.1.1 Exclusion Angle Study

Eliminating the source of reflections (the sun) is limited to flying at night and on overcast days. Techniques of orienting the aircraft at certain angles with respect to the sun and the combat zone is a promising off-shoot of this principle. This is a technique that can be referenced back almost to the beginning of time when the first man used the sun at his back in the early morning hours to stalk a prey. Of course, this investigation must address itself to an in-depth study using this premise. If a standard operating procedure could be outlined which would tell the pilot of the aircraft precisely what ground observation areas he was exposed to dependent upon his particular craft and sun vs. ground angle,

which is of course time of day and angle of approach dependent, he could maintain an orientation such that his sphere of susceptibility was either limited or directed toward allied positions. This could uncover certain hours which are ideal attack times and certain taboo hours. A thorough investigation into what angles and aircraft positions are involved is indicated. (See Figure 1 for applicable test set-up.) This idea could also be enhanced with windshield coating and physical change possibilities to be discussed. Also, should a study such as this determine that vulnerability can be confined to a localized area, a patch of some sort could be attached to the windshield at that particular spot. Realistically, if such a spot exists, it most probably changes its orientation dependent upon time of day and approach angle. In this event, a system would be needed to move the "patch" on the outside of the window. Conceptually, this would be attempted by using a metallic patch and a magnet. Conceivably, the controlling magnet could be directed by monitoring sun position via photo-sensors.

4.2.1.2 Shade Covers

Another basic means of eliminating the sun would be shade type covers such as those found on certain automobiles (such as the Hudson and Buick) around the 1950's. The OH-58 observation helicopter would accommodate this principle nicely. It would involve a mere extension of the roof out over the windshield. (See Figure 2.) Just how far it would have to extend would depend upon the normal flight angle of the aircraft in respect to the ground and the incident rays of the sun at various times of day. The AH-1G could possibly be accommodated in the same manner with the overhead transparencies neglected if studies show that the craft seldom, if ever, is detected from that particular surface. Aerodynamics have to be considered but should offer little difficulties at helicopter velocities. Pilot visibility would be impaired in certain directions, as Figure 2 shows.

Bell Helicopter attempted some preliminary studies in covering the windshields with a cheesecloth. They reported some success. The cheesecloth type investigation should include such materials as burlap,

osnaburg, tissue paper, creped polyvinyl film and fabrics on the market which comprise such popular items as hairnets, stockings, and see-through blouses. In addition, ordinary window screen and mosquito netting offer possible solutions. Perhaps these items are most applicable in conjunction with other solutions. The material can be mounted such that it would be removable in flight in the event the mission extends into low light level hours. (See Figure 2).

Studies were conducted using the fabrics listed in Table 2. Polaroid pictures were taken of sun reflecting from an automobile windshield. Results were encouraging when the material was made of 50% avril rayon and 50% Bemberg rayon. Through vision is good when the viewed side of the material is brightly lit. A detailed study of various fabrics and mesh patterns is indicated.

TABLE 2
FABRIC MATERIAL

| <u>COLOR</u> | <u>COMPOSITION</u> | <u>MANUFACTURER</u> | <u>RESULTS</u> |
|--------------|-------------------------------------------|---------------------------------------------------------------------------------------------|----------------|
| Blue | 65% Polyester 35% Cotton | Georgia Fabrics 4440 Commerce Circle S.W. Atlanta, Georgia 30336 | Fair |
| Black | Remnants of undetermined fiber content | Same | Fair |
| White | Light Pellon Web fiber | Unknown | Poor |
| Brown | Unknown | Rosewood Fabrics 115 W. 40th Street New York, New York 10018 | Fair |
| Black | 50% Avril Rayon 50% Bemberger Rayon | SiBonne Company Division of Crown Textile 206 W. 40th St. New York, New York 10018 | Good |

The addition of a honeycomb type cover over all transparent areas offers an interesting avenue of approach. (See Figure 2.) The honeycomb would serve to trap rays and sunlight and theoretically would eliminate reflections. Problems include such parameters as how large the honeycombs would have to be in height and cross-sectional area to be effective and still maintain pilot visibility in all directions. Efforts at imbedding "venetian blind" effects into the windshield itself have proven unacceptable because vision is restricted in elevation. (That is, the pilot can see straight ahead but not up or down at sharp angles.) External honeycombs could be angled such that the pilot, from his normal flying position, could see quite adequately in all directions. Crew members in other positions would have some degree of reduced vision which may or may not be acceptable. Extensions of this principle involve such things as making the honeycomb cylinders conical in shape and making them adjustable. The adjustable feature could be manual or automatic and could respond to the sun position (via photo cells) pilot head position (through helmet mounted transducers) or pilot discretion. An inverse honeycomb, that is, something that would tend to block straight ahead, (therefore, aim it at the sun), would allow vision in all other directions. This idea is an interesting theoretical solution but currently impossible to facilitate in the real world.

Blocking off certain sections of the windows might be proven acceptable during certain phases of the flight. For instance, perhaps the deck mounted transparencies of the OH-58 are used exclusively for take-off and landing maneuvers, or perhaps the overhead transparencies of the AH-1G are used only for formation flying and combat zones where counter-attacks are anticipated. Moveable windshield covers at the pilot's control could conceivably eliminate reflection hazards from a significant portion of the aircraft at times it is most vulnerable to visual acquisition.

Another shading type scheme is to cover the windshield with some type of pattern which will allow adequate visibility while eliminating reflections. A polka-dot pattern or a series of some other geometric figure strategically placed is a remote possibility but not rated high in

respect to alternatives because the percentage of area necessary to cover is perhaps prohibitive for maintaining visibility.

Finally, if a rotor blade net could be developed which would not interfere with the aerodynamics, windshield and rotor hub reflections would be eliminated. An artist's conception of this scheme is shown in Figure 5. Obviously, this approach raises serious aerodynamic questions.

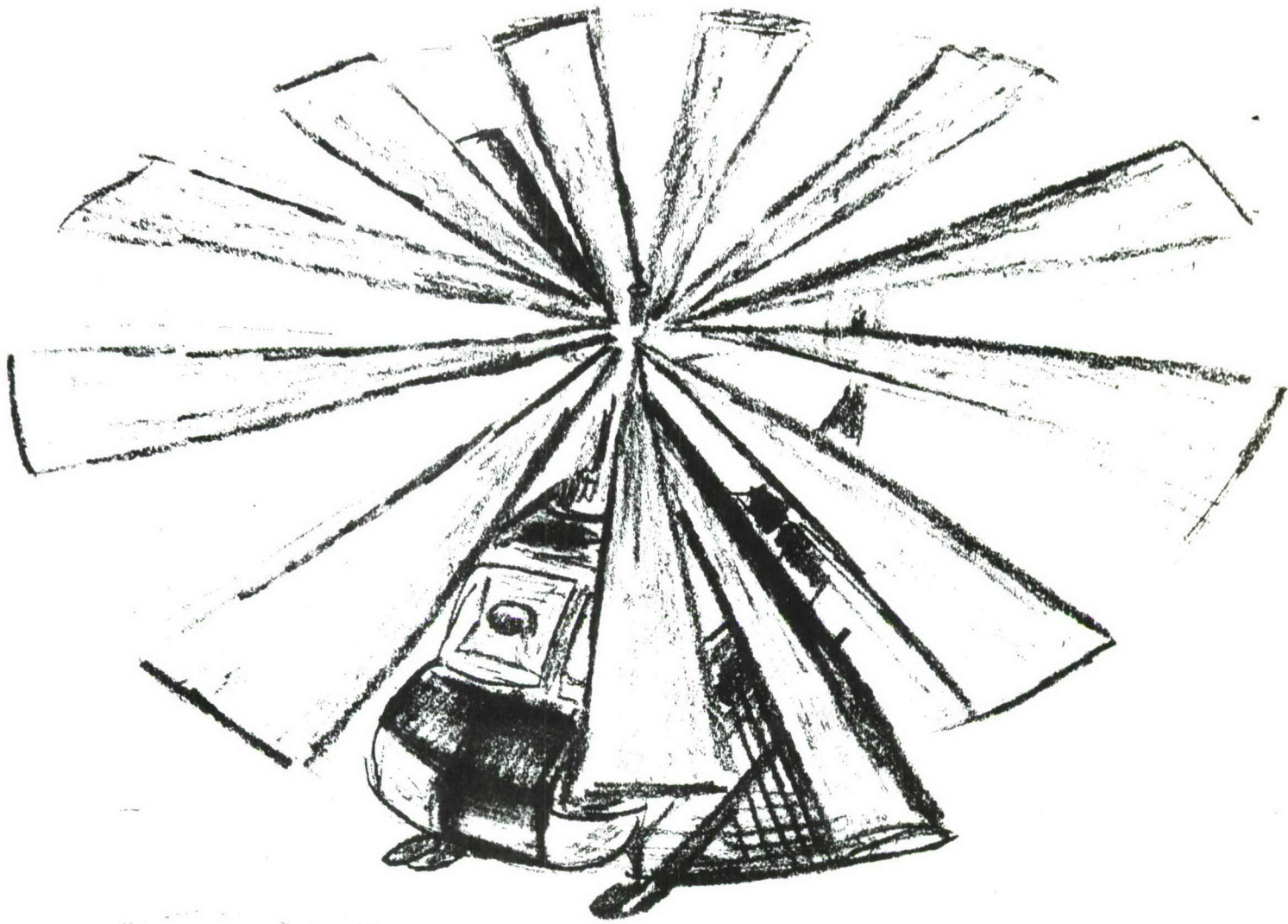


Figure 5 Artist's Conception of Rotor Blade Shade Net

An intriguing notion which could solve not only the reflection problem but visual detection even when the craft is silhouetted against the sky would be a cover of steam or smoke to make the area look like a cloud. This would need extensive studies to determine how much smoke or steam should be used, how it should be ejected and what affect it would have on pilot visibility. The potential benefit is, however, enormous. Perhaps a spraying technique which would result in a "hanging cloud" in front of and above the cockpit is possible.

4.2.2 Control and Direct Rays

4.2.2.1 Coatings Techniques

Controlling and systematically directing the light rays points toward standard $1/4$ wavelength coatings and multi-layer thin film techniques. A host of investigations have been aimed at these ideas. The pertinent phenomenon is the fact that when light strikes the surface of any body which has a different index of refraction than the ambient median, a portion of it is reflected. The amount of reflection increases with the refractive index of the surface material. If two light beams of the same intensity and wavelength are forced to shift their relative phases by an uneven number of half-wavelengths, the beams will interfere with and destroy one another.

Therefore, one method of eliminating reflections would be to introduce a second reflection of an intensity equal to the first with the proper phase shift. A thin film applied to the surface can accomplish this objective if the time it takes for a beam to pass through the film, reflect from the film-material surface interface and rejoin the externally reflected beam causes the two beams to cancel one another by virtue of the proper phase shift. An interesting by-product of this process is the fact that since the energy in the two light rays cannot be destroyed, it passes into the material and if it is transparent as in the case of a windshield, it increases the transmission of the windshield an amount equal to the decrease in reflection. The film, to be effective, must have a refractive index which is the square root of the windshield index. This leads us to the

problem of materials, namely, those with low enough refractive indices are non-rigid. A degree of reduced reflection can be achieved with materials whose indices are higher than the ideal. Unfortunately, this process is good for one particular wavelength and although it has a wide band effect, it does not eliminate reflection across the entire visible spectrum. An attempt to circumvent these problems lies in multiple layer techniques. If a material of higher refractive index of the window is first applied, then a second coating can satisfy the "square-root criteria" with a much higher refractive index.

Basically, two methods are available to deposit the material on a transparency: (1) vacuum evaporation and (2) solution process. Vacuum evaporation⁽⁴⁻⁵⁾ is relatively difficult in that it involves heating material in a vacuum chamber and depositing its vapors onto the transparency. The solution may be applied by spraying droplets on a spinning surface or withdrawal of the item from the solution under a controlled speed. For large items, the latter method is most applicable. The thickness of the film is controlled by the concentration, viscosity and surface tension of the solution and the speed with which the material is withdrawn.

An interesting concept which applies to all coating schemes is that in the absence of being able to eliminate reflections entirely across the visible spectrum, force those reflections which do remain to be a particular color, which of course is background dependent. If the helicopter is flying nap-of-the-earth in hilly green terrain, one would want to force all residual reflection to be green. The effectiveness of this approach is questionable at best due to the fact that a bright flash of green light is probably as detectable as a bright flash of white light. The thickness of the outer coating determines the color which will be reflected. Perhaps a pigment-less dye is appropriate.

4.2.2.2 Liquid Flow

Materials which have a low refractive index are not rigid, but one could devise a scheme to continually eject a thin spray of a liquid

over the surface of the existing windshield. This spraying need only take place in combat zones and would probably necessitate only a reservoir large enough to last the duration of a mission. It is possible that the rotor blade downdraft could be used in applying the substance. The particular liquid would be chosen by virtue of its refractive index. It is anticipated that its rate of flow and thickness are not critical considerations.

4.2.2.3 Commercial Products

DuPont manufactures a product called Sun-X⁽⁶⁻⁷⁾ whose main function is to exclude heat, glare and ultraviolet transmission to the inside. Its reflection reducing capabilities are apparently too limited for the purposes of this report. It would not be removable for low light level periods.

Abcite⁽⁸⁻⁹⁾ also produced by DuPont, offers an abrasion resistant coating for acrylic sheets whose qualities approach that of glass while maintaining the light weight, excellent optics and shatter-resistant qualities of acrylic sheet. It does contribute to reducing reflection but not to a large extent. It may prove useful in conjunction with other methods.

Sierracin Corporation⁽¹⁰⁾ writes that they use metallic coatings which exhibit lower reflective characteristics but is not anti-reflective in nature. They regret that they do not have an anti-reflective coating per se to offer. Again, the technology might prove useful as an ingredient in a multi-pronged approach.

Rohm and Haas⁽¹¹⁾ sent a listing of companies which are capable of applying coatings via the solution and/or evaporation process. They single out American Optical as the best supplier.

American Optical⁽¹²⁾ states that they no longer manufacture some experimental anti-reflection coatings Plastec looked at in 1962. They do have a liquid coating identified as AO-50M which is capable of reducing reflection by fifty percent. Their sample did in fact reduce reflections, but it is considered insufficient to avoid visual acquisition.

Bendix⁽¹³⁾ recommends Thin Film Engineering⁽¹⁴⁾ for coating procedures. Thin Film Engineering is currently pursuing a solution.

4.2.2.4 Vacuum Deposits

Vacuum deposited coatings are feasible. Their difficulty of application renders the solution process of applying thin films more attractive for initial studies.

However, Evaporated Coatings Inc.⁽¹⁵⁾ writes that their standard product can be applied to the substrate in question (acrylic) and conforms to the requirements outlined in MIL-C-675A "Coating of Glass Optical Elements (Anti-reflection)", It has a temperature stability from -20°F to +200°F, reduces reflection to less than 1% per surface and conforms to MIL-M-13508B (adherence, hardness and humidity).

Tests to determine if this process can be applied to present shapes and sizes of windshields are needed. A picture of their coating #6468 is impressive, but not sufficient to render an aircraft undetectable entirely. Perhaps this process in addition to removable fabric is an answer. Stokes Division⁽¹⁶⁾ of Penwalt Corporation also claims a vacuum vapor deposition process (metallizing) in addition to making reference to their solution application affiliates.

4.2.2.5 Solution Depositions

MBT Corporation⁽¹⁷⁾ uses silica for plastic lenses admitting that it is not as effective as vacuum depositions but points out that vacuum coatings are not acceptable for outer surfaces due to their softness (this may or may not be true with present technology). They recommend vacuum deposition on the interior surface with an MBT silica coating. They also allude to "texturing" the surface, a process they have visualized but not developed to date. Samples of MBT silica coated lenses were not sufficient to solve the problem by themselves.

Liberty Mirror⁽²⁻³⁾ offers a variety of solution type low reflectance coatings. Their hi-efficiency, low-reflectance coating is labeled no. 527. This coating can reduce reflectance to less than .5% average from 425 to 700 millimicrons per surface. (Uncoated glass has a reflectance of about 4% in the visible spectrum.) This coating is used on instrument dial covers and lenses. By itself, it would not render an aircraft undetectable.

The Human Engineering Laboratories⁽¹⁸⁾ conducted a study on reducing glare from aircraft instrument panels. Their comprehensive program was aimed at multiple layer coatings. This suggests an approach which appears to be more desirable than single layer coatings.

Coatings which have proven to be unsatisfactory are "Luxorb" manufactured by Nortronics, "Sun Shield", used by Heller Aircraft and sodium silicate, studied by the Naval Research Labs. Western Electric Corporation⁽¹⁹⁾ reports that they have no references on the subject in their Technical Information Center. DuPont Fabric Division⁽²⁰⁾ also reports no solution.

Art galleries⁽²¹⁾ commonly deal in a non-glare glass which is very effective in eliminating reflections. Unfortunately, the viewed object (painting) must be placed in physical contact with the transparent cover to be seen. The technology is apparently not applicable even if modified.

4.2.2.6 Multiple Layer Films

Polymer or plastics can be laid down in large sheets in thin films. By selecting the proper materials and with a sufficient number of layers, an acceptable solution is feasible. The Chemistry Department of The Franklin Institute Research Laboratories⁽²²⁾ has recently developed a technique whereby these thin layers can be readily applied. Studies are needed to prove the process useful in eliminating reflections to the degree desired. Multilayer theory is applicable.

Figure 6 shows the anti-reflectance curve of Bausch and Lomb's "Marc 8" coating process. The coating was placed on plexiglas and the curve was generated for the visible spectrum. Note that the results are excellent for a narrow band around 520 nanometers, fair for 500 to 700 but poor for the upper and lower regions of the spectrum.

4.2.2.7 Other Coatings

Minnesota Mining and Manufacturing produces a plastic layer which allows straight through vision only. This does not address itself directly to the problem but its characteristics could prove to be useful information in attacking the overall problem, in that, if one could develop the opposite phenomenon offered by this product, that is, see through every angle except straight ahead, then perhaps one could aim the resultant transparency directly at the sun in all cases to avoid ground observer detection.

Liquid crystal coatings should be evaluated in the same light, that is, they do not represent a direct solution (they change color with light intensity) but the underlying phenomenon could provide useful inputs.

4.2.3 Eliminate Surface

4.2.3.1 Open Cockpit

The most obvious means to eliminate the reflecting surface is to fly with all windshields removed. The government has conducted flight under these conditions. It is a feasible approach and does obviously eliminate all reflections from the transparencies which no longer exist. Hazards which this approach creates are unacceptable. They include a huge fuel consumption penalty and a significant loss of air speed (about 50%) as well as subjecting cockpit occupants to hazards such as airborne fowl and the elements.

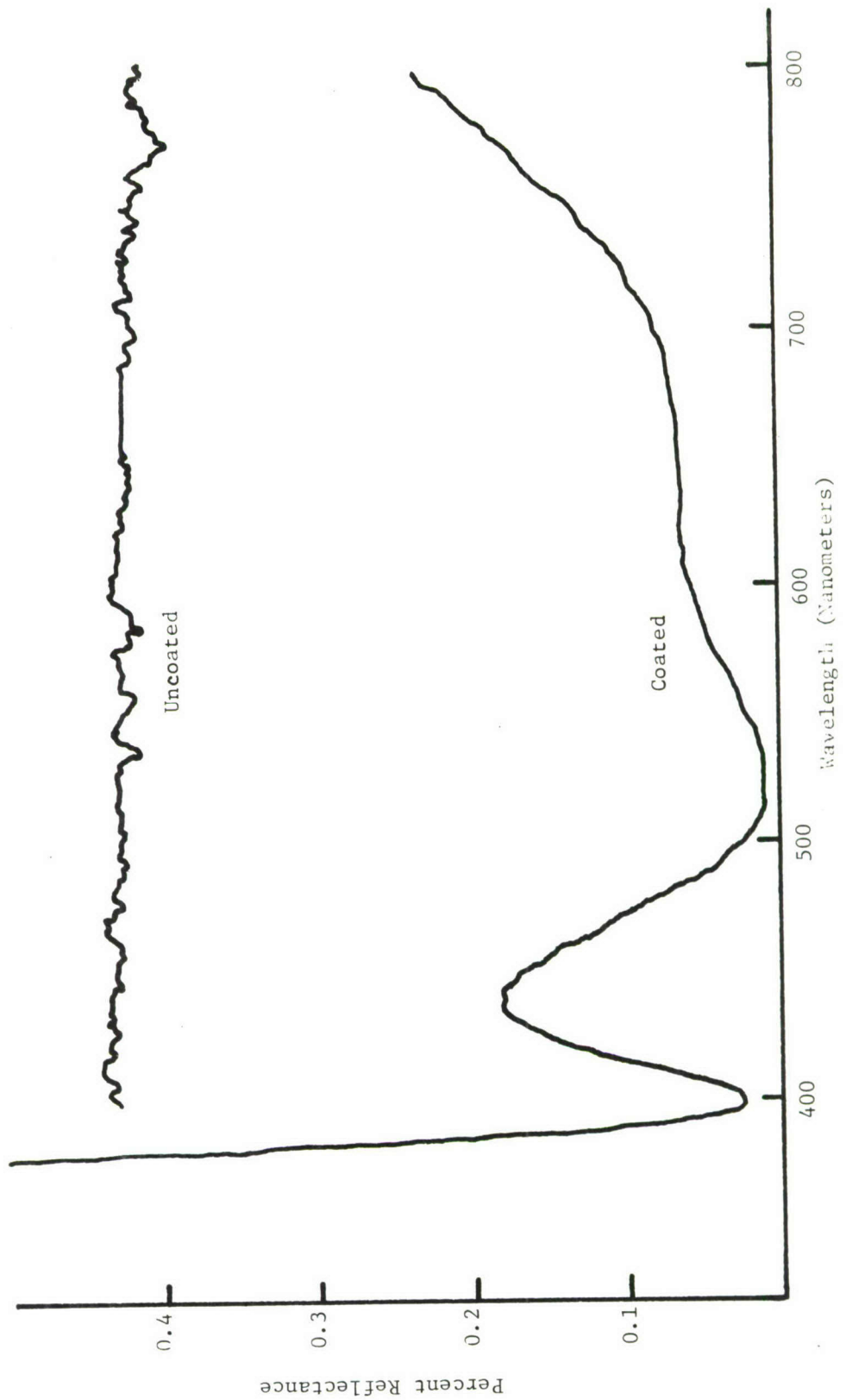


Figure 6 Bausch and Lomb "Marc 8" Anti-Reflectance Curve

4.2.3.2 Mesh Replacement

The next obvious extension of the open cockpit scheme would be to replace the windshields with a nylon mesh (or similar material) which would be designed to prevent any airborne objects from entering the cockpit. This, however, does not eliminate other serious objections outlined in 4.2.3.1.

4.2.3.3 Air Flow

Large mall type shopping centers in suburban areas frequently use a steady low velocity air flow to maintain inside atmosphere instead of cumbersome doors of one type or another. Extending this idea to eliminate helicopter windshields involves a much higher velocity air flow because the aircraft has motion. Air flow, by itself, would not prevent penetration of the cockpit by airborne fowl but could maintain the integrity of the internal environment and could probably maintain the aerodynamic integrity of the craft. The air flow would have to be serviced by the helicopter turbine which also implies a power output penalty.

4.2.3.4 Spaced Tubing with Air Flow

Figure 3 shows the best scheme to attack the problem by eliminating the windshield entirely. Small diameter transparent tubing (perhaps 1/4" diameter, spaced two inches apart) would serve to prevent invasion of the cockpit by foreign objects while air flow could be generated from within the tubing (from the aircraft turbine) in either an upward or downward direction from one tube to the next. The velocity would not have to be nearly as great as it would have to be without the tubing. The air flow would have to be sufficient to maintain cockpit atmosphere and aerodynamic integrity. The only detrimental factor remaining is the loading on the turbine which would result from generating the air flow. Also, a cover would be needed to prevent rain, wind, etc. from entering the cockpit when the aircraft is on the ground and the turbine is not operating.

4.3 REFLECTIONS REDUCED BY PHYSICAL CHANGE

4.3.1 Effects of Size and Shape Changes

Size, shape and position of reflecting surface in respect to observer, point of incidence and light source, are all factors in determining the resultant amount of reflected light. Bell Helicopter confirms that helicopters with smaller and flatter windshields are less likely to be visually detected by reflections.

Therefore, if one designed a windshield composed of small flat sections each located in a slightly different plane than its near neighbor, one could effectively eliminate reflection (or at least contain them to a small specific spot). Also worthy of analysis is a windshield consisting of inverse curvatures. Of course, any reduction in total area of exposed windshield would aid in problem solution. Making an optical system available to observers and/or gunners might lead to a lessening of the total required windshield area. Also along these lines would be a retractable windshield. If particular combat maneuvers are to take place at low speeds (as hovering in a valley and periodically elevating for observation) one could retract the windshield during this phase of the mission. Sloping the windshield away from the vertical would result in the range of sun angles over which reflections can be directed downward being reduced and the sun would have to be closer to zenith to generate groundward reflections. A test set-up as outlined in Figure 1 is needed to make size and shape determinations.

4.3.1.1 Paper Analysis of Inverse Curvatures

Examination of the principal of inverse curvature as applied to the craft windows will show the following significant data.

(1) Because the primary illumination source, that is, the sun is constantly above the relative horizon of the craft, for reflection to be directed towards the ground observer, the reflecting surface must be at a shallow angle with respect to the incident sun's rays (Case I and II Figure 7). In Case I the aircraft and sun are nearly on a line so that the observer looks into the sun, and his discernability is impaired. For Case II, however, spotting ability is enhanced.

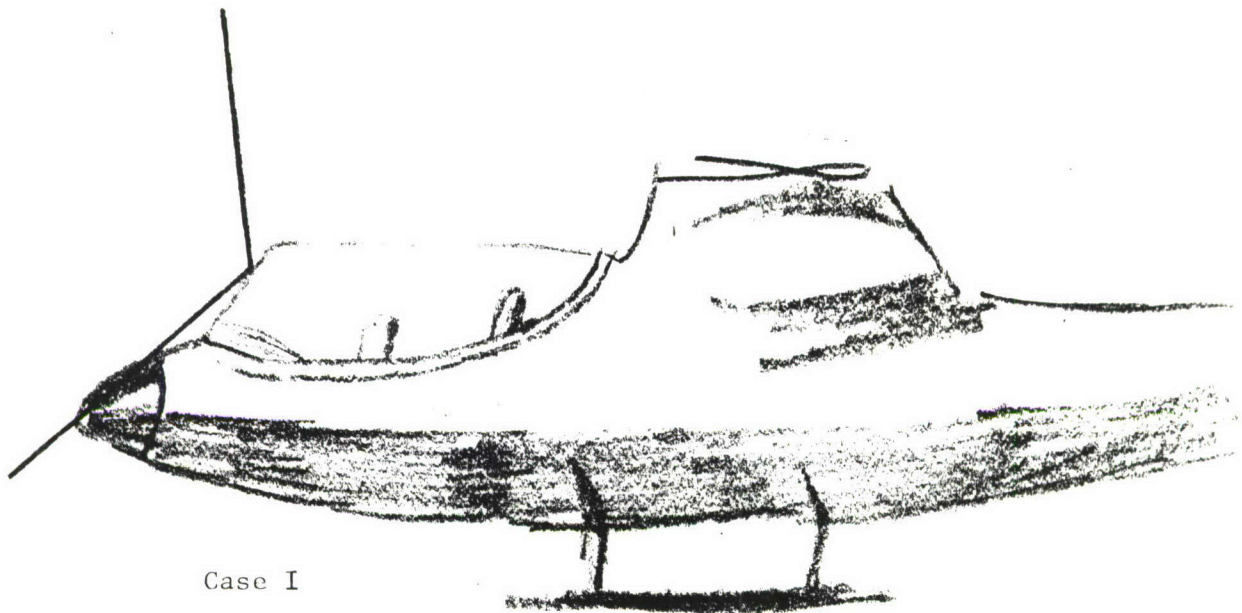
(2) If the windows in the upper hemisphere of the craft could be contoured so that few sun's rays could strike at a shallow angle, few rays would be directed groundward. Case III and IV Figure 8).

(3) If the windows could be so contoured that sun's rays which do strike an area of the window surface at a shallow angle subsequently impinge upon a second surface, it may be possible to cause the secondary reflections to be directed away from ground - Case V and VI. (Figure 9).

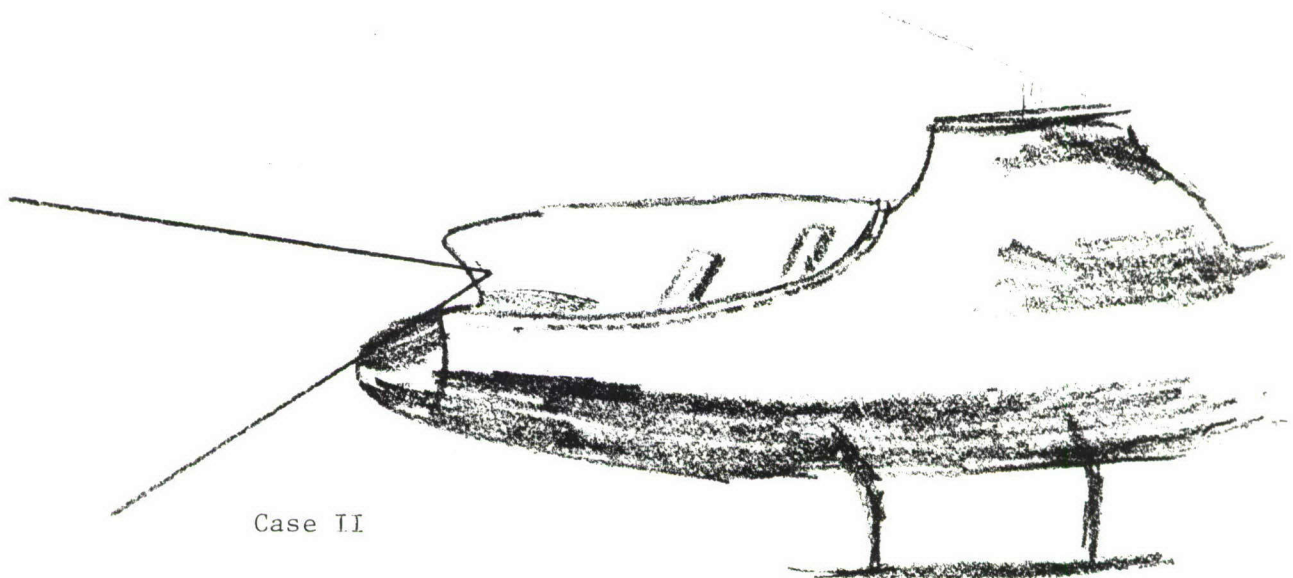
From these considerations we can construct Table 3 having first defined the following quantities. Let ϕ be the sun angle; ϕ is zero for the sun at zenith; it is plus for the sun forward of the craft and minus for the sun aft of the craft. Let α be the slope of the window (reflector); it is zero for the window parallel to the horizon; it is plus if the normal to the window is in the plus ϕ direction and minus if the normal is in the minus ϕ direction. Then Table 3 lists the range of α (ϕ) for no groundward reflections. N is 1 or 2 depending upon whether 1 or 2 reflections are required to avoid groundward reflections.

Table 3
RANGE OF SUN ANGLE ϕ AND WINDOW ANGLE α
FOR NO GROUNDWARD REFLECTIONS

| ϕ | α | N |
|--------|----------|---|
| -90 | 0 | 1 |
| -90 | 0 | 2 |
| 0 | 0 | 1 |
| 0 | 0 | 2 |

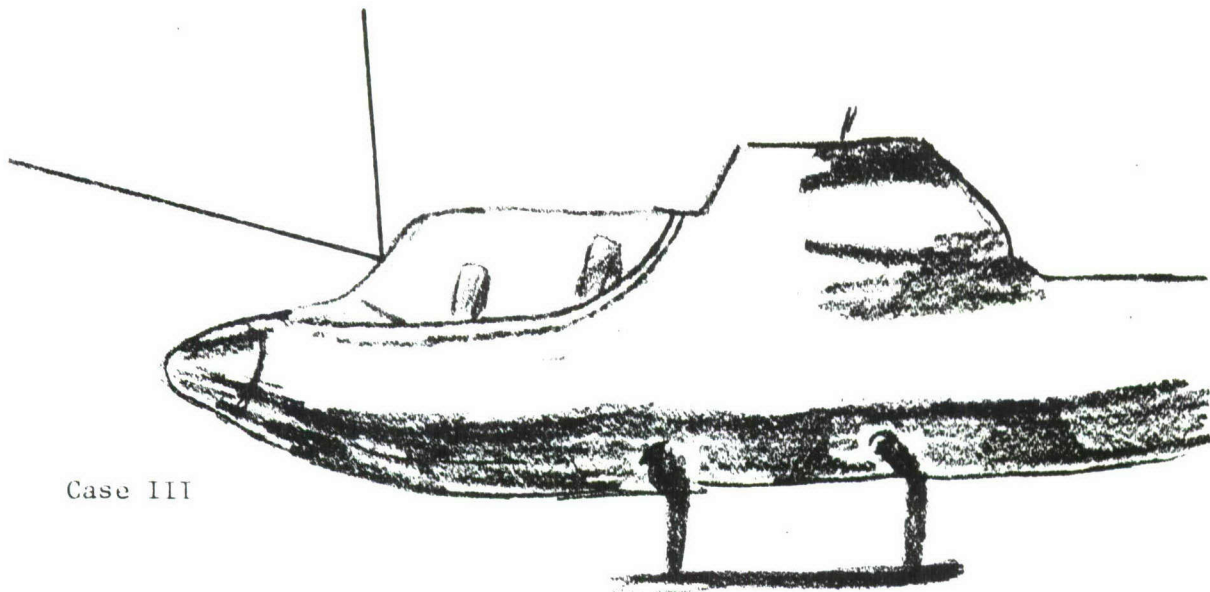


Case I

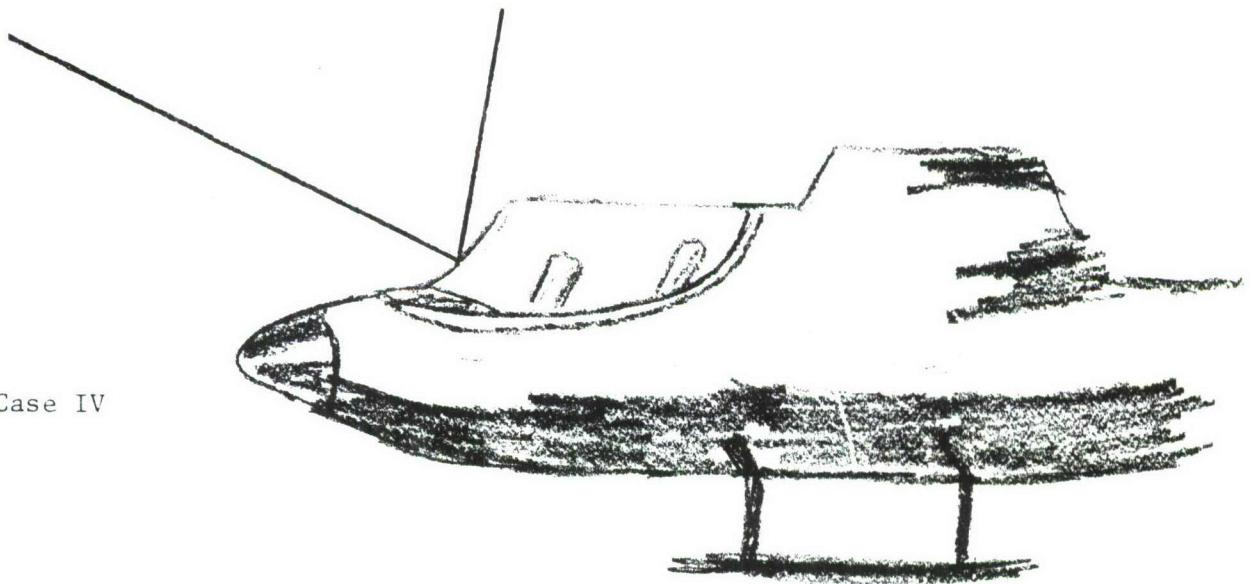


Case II

Figure 7 Flat Surface Windshield

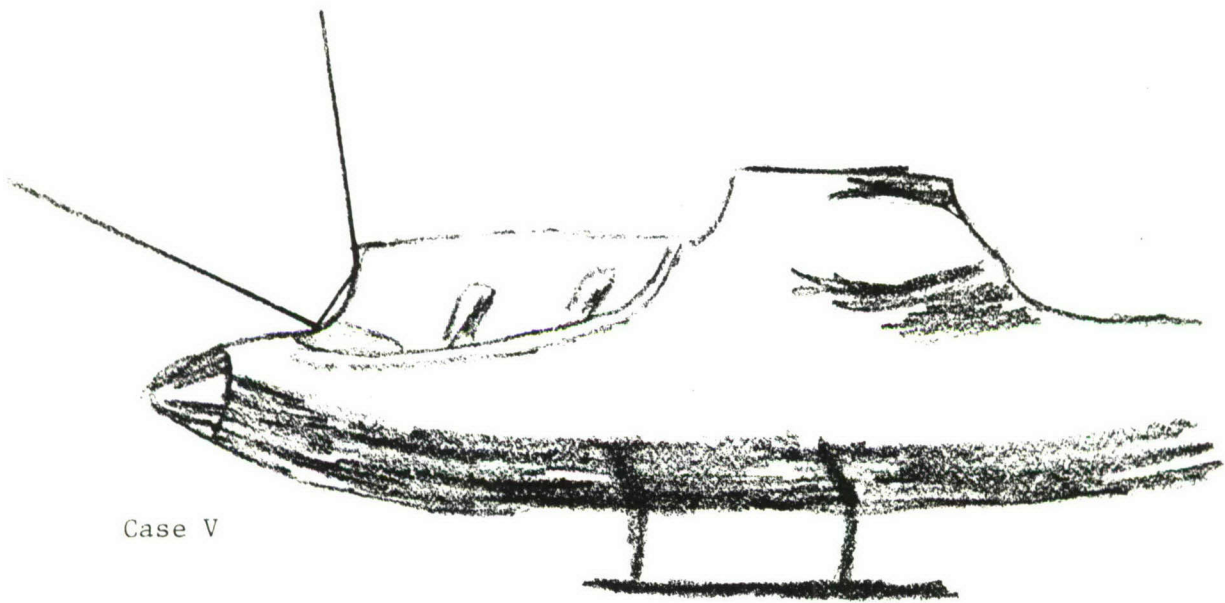


Case III

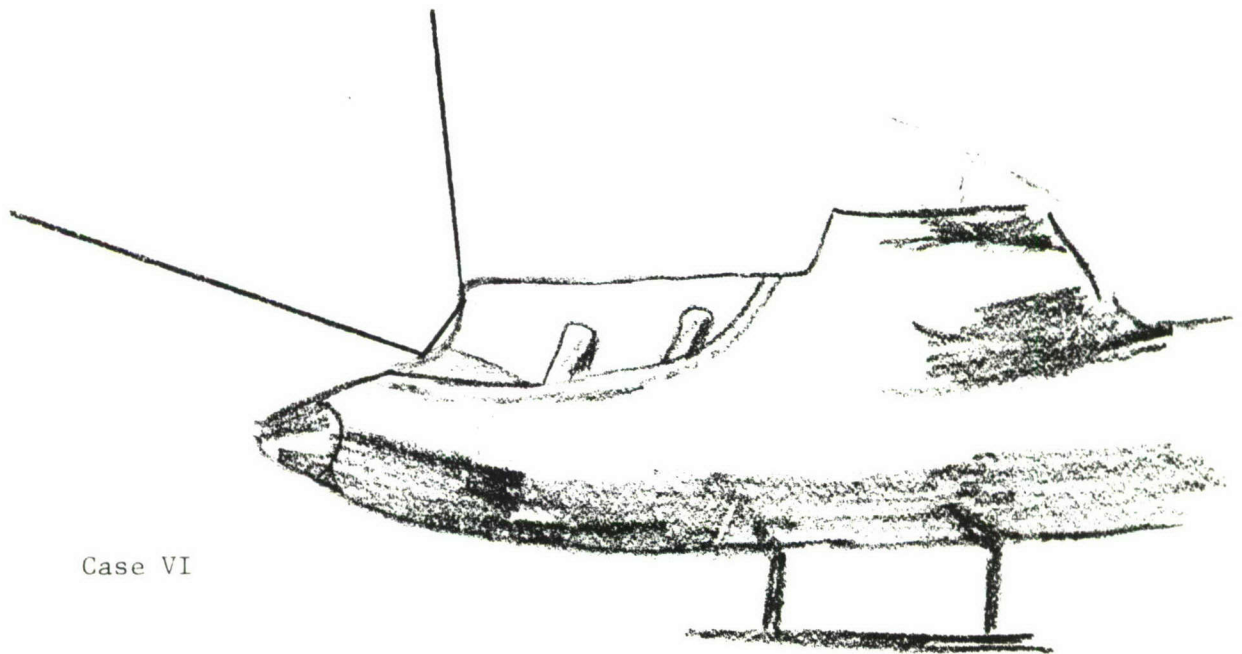


Case IV

Figure 8 Curved Surface Windshield



Case V



Case VI

Figure 9 Curved Surface Windshield

From a study of this table two possible configurations for upward view windows can be derived. For downward view windows there appears to be only one solution. Thus we arrived at two general configurations A and B (Figure 10) for which window profiles can be devised. Since the analysis thus far has considered only one dimension the choice may depend upon what is physically realizable in three dimensions. Configuration A has 5 regions of significance. These are included on the sketch.

Region 1 is a horizontal section which is flat at the extreme (tip) and tapers into a positively sloping window. It is necessary to assure a secondary reflection for negative sun angles ϕ that are not included by region 2. Region 2 is a positive sloping region that will cause upward reflections for all angles ϕ between 0 and +90 degrees. It will also cause secondary reflections to be generated in region 3 for ϕ between 0 and -45 degrees. Sun angles ϕ between -45 and -90 degrees will not fall on region 2. In region 3 all sun angles ϕ from +90 through 0 to -45 will be reflected upward. Sun angles between -45 and -90 do not reach region 3. In the lower hemisphere, sun angles between +90 and ϕ_4 (See Configuration A) are accessible to region 4 to cause downward reflections. Therefore ϕ_4 should be made to approach +90 degrees as close as physically possible. Region 5 is inaccessible to sun's rays.

Considering Configuration B, region 1 is similar to region 1 of configuration A. Region 2 is at a negative $-\alpha$ slope. The closer this slope is made to -45 degrees the smaller region 1 needs to be. Region 3 and 4 are identical to regions 4 and 5 of configuration A, respectively.

Considering next the other dimensions (not in the plane of the paper) contiguous surfaces in other planes can only be convex even if they are concave beyond the contiguous regions. In other words, they have to somehow form the three-dimensional enclosure which is the body of the craft. It would seem that the smallest possible radii of curvature for these convex surfaces would be associated with the least amount of reflections.

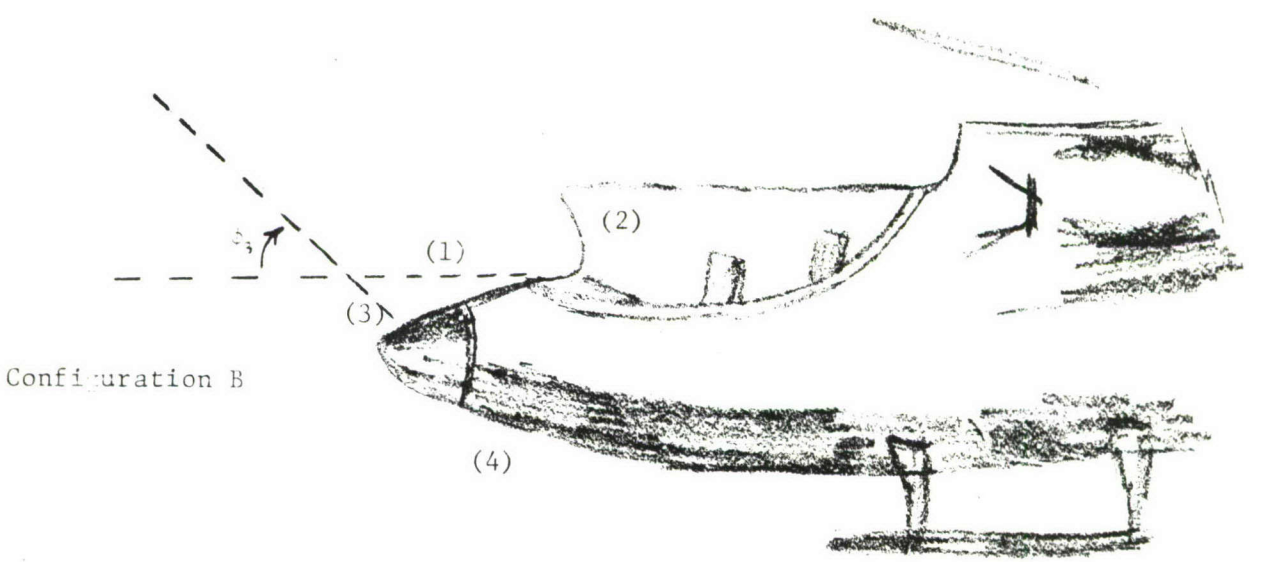
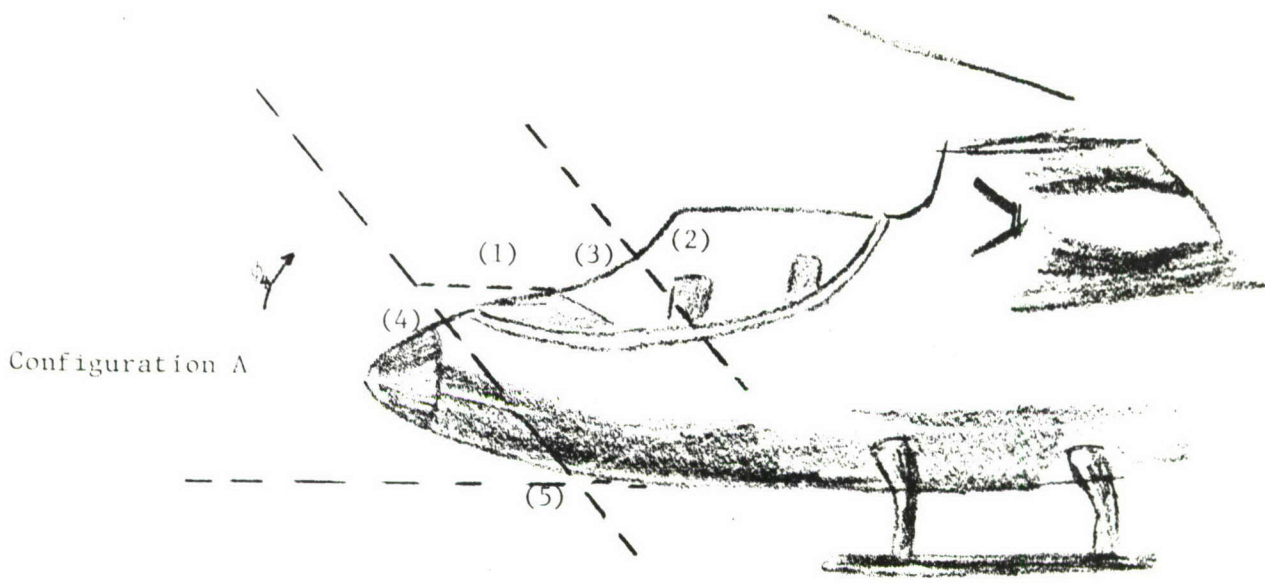


Figure 10 Configuration for Windshield Profiles

4.3.1.2 Windshield Vs. Pilot Positions

Another similar approach would be to limit the area of windshields by moving the transparent sections closer to the pilot. This would involve a redesign of the cockpit and its aerodynamics or one could cover the entire cockpit with non-transparent, non-reflecting solids and extend the pilots head out a convenient spot encased only in a helmet-type arrangement. This helmet could be anchored to the craft to afford the pilot the option of moving in and out as desired. Crew members may or may not need helmets of their own. This approach involves very high cost and technical risk.

Relocating the aircraft pilot would lead to eliminating reflections. If the pilot were in the rear of the craft, using optical assist equipment for frontal viewing, the craft would be undetectable via reflections from the target approach area. More realistically, the pilot could be located underneath the craft as in a dirigible design. This would create problems in formation flying and visual acquisition of counterattacking airborne craft.

4.3.1.3 Windshield Extrusions

The windshield could be constructed of cylindrically shaped extrusions (similar to adding an external honeycomb-Figure 2) angled such that the pilot is looking along its axis no matter which direction he turns his head (this assumes that he is always looking from his seated position). The height and diameter of the extrusions have to be determined.

4.4 Precautions

Efforts at changing the material from which the windshield is made must be cognizant of the fact that low refractive index materials are also by nature non-rigid. This approach could involve a continual spray of liquid material which would necessitate an ejecting mechanism.

Tinting approaches have a low probability of success since their effectiveness is contingent upon making the color darker and darker which

concurrently reduces the through vision. Tinting, at best, is a partial answer.

"Piped-light" is useful at only a single angle of incidence. Unless contour alterations can be designed in conjunction with sound flight techniques (therefore maintaining proper air craft vs. sun orientation) this phenomenon does not appear to be highly useful.

Surface etching⁽²³⁾ approaches offer through transmission distortion. Pilot visibility cannot be compromised. Sapphire windows generate cost problems and hard glass approaches implies safety faults.

External means of solving the problem must consider the aerodynamics of the proposed solution as well as the effect it might have on pilot performance. Consideration will also have to be given to what detrimental effects the solution might have on missions during overcast weather, dusk, dawn and/or night hours. Removable mechanisms might prove to be essential.

Other items to keep in mind include the fact that helicopters off-times fly in a "trail" or "v" formation of 5 to 8 aircraft. Visibility is critical for these maneuvers and rotor blade tip lights might be useful. Any solution should not render the aircraft untenable should the solution mechanism fail during a given mission.

Physical change approaches must consider that a drastic re-design could involve a 10-25 year lead time to build a new generation of aircraft and to train a new generation of pilots.

All ideas must consider the effect on the aircraft as well as the pilot, the degree of reduced reflection, the logistics involved and the technical risk generated.

4.5 Evaluation

Changing the material from which windshields are made offers little chance of being a total solution due to the fact that materials with

low refractive indices also display non-rigid properties. Tinting also is at best a partial solution. A windshield with a gradient index of refraction is an intriguing avenue of approach. Japanese fiber optics with this property should be investigated thoroughly.

External means of eliminating reflections offer a large variety of potentially acceptable solutions. Eliminating the source of reflections (or at least using it to advantage) implies the necessity for a study which would prove extremely useful in diagnosing many similar ideas. That is, the construction of a model to investigate exclusion angles in respect to helicopter position vs. sun and ground. This same model could serve to study the affects of reduced windshield area and changing slopes and contours. Shading techniques are also very promising and subseptible to simple laboratory evaluation using helicopter models and light measurements. Shading ideas involve everything from baffles to screening over the windshield itself. Liquids with low refractive indices and continually sprayed onto the windshield are worthy of further consideration. A typical automobile automatic windshield washing scheme could be used. Even flow would not be a necessity but complete covering would. Honeycomb covers are probably less desirable than other alternatives, since they would be oriented optimally for one individual only, but they do represent a workable solution should others prove incomplete. Smoke or steam covers, if practical, could solve all reflection problems plus other means of detection such as silhouette acquisition. Of course the ability to maintain vision through a cloud sufficient to conceal the aircraft has to be determined if the cloud cannot be generated to cluster in a specific area.

Controlling the light rays points to $1/4$ wavelength coatings and multiple thin film techniques. The nature of $1/4$ wavelength coatings (effective around a given wavelength) suggests that this approach offers an incomplete solution at best. Heretofore, multiple layer thin film approaches have been difficult to implement. Recent advances suggests that this may no longer be the case.

Studies in this area might prove to be fruitful. Smoke or steam covers are more difficult to evaluate in the lab but the fact that this scheme offers a total solution to not only the reflection problems but to all visual acquisition means makes it worthy of study.

Physical changes (reduced area, change of curvature, etc.) offer potentially good solutions. These schemes are also easily investigated in the lab in the nature of model building and reflecting pattern investigations. Large-scale redesign work is cost prohibitive and does not address itself to the problem for the current generation of helicopters. Replacing the windshield with a high velocity air flow would be expensive but could be adopted to present aircraft. It is worthy of further study.

5. ROTOR BLADES

5.1 Reflection Reduced by Internal Materials Changes

Changing internal characteristics of the material used would involve finding an alloy which would have sufficiently low reflectivity. All indications suggest that such material does not exist. This approach would involve an in-depth study of material combinations available. An alloy would have to match the strength and stress absorbing qualities of the high grade aluminum currently being used. The cost and technical risks involved are prohibitively high.

5.2 Reflections Reduced by Surface Deformation

Small irregularities (See Figure 4) could be drilled or sandblasted into the upper surface of the rotor blades. Drilling could be directed at creating cavities shaped like "pitted cones" or perhaps a smooth transitional surface like a golf ball. Sandblasting could be controlled with the mesh of sand, type of nozzle and velocity of blasting to create depths and patterns desired. Studies are needed to determine if such surface deformation would compromise the structural integrity of the blades. Perhaps critical stress points could be circumvented. These indentations might be susceptible to collecting debris such as sand and dust. These collections would tend to be dispelled during operation but such susceptibility could lead to rapid wear problems. Dust and sand when not concentrated as on a beach or desert environment, are non-reflective and could therefore be an asset in that respect. Anodizing the surface of the blades with addition of low reflectance coatings could prove useful but would raise questions concerning stress and aerodynamic stability. Sandoz Corporation⁽²⁴⁾ can supply the technical procedures if it is determined that anodizing (an electro-chemical oxidation of the surface - formed from the surface) will not jeopardize the strength of the

material. Black can be added to the anodizing to give a non-reflective standard and the resultant surface would be more resistant to abrasion. In addition, the surface could be vapor blasted to create scattering of light or some similar microroughening could be employed to force specular reflections toward zero.

5.3 Reflection Reduced by External Means

5.3.1 Bonded Strips

Thin strips could be bonded to the upper surface of the blades. (See Figure 4). These strips could be very narrow. They would not interfere with the stress absorbing integrity of the blades since the blades themselves would not be defaced. The thin strips could house conic cavities or be constructed of grooves aligned to the air stream passing over the blades and angled to capture the reflections. These grooves would possibly aid the aerodynamics since they would interfere with air currents attempting to flow down the blade. A suitable bonding agent would have to be selected. Studies to determine if in fact the aerodynamics are not adversely affected or blade balance is not comprised or if in fact an existing bonding agent is capable of withstanding supersonic speeds would have to be conducted.

5.3.2 Paints

The paint industry⁽²⁵⁻²⁶⁻²⁷⁻²⁸⁾ offers many possible avenues of approach to the problem. Ideas include paints with a low reflective index, optically flat black paints, fibers in paint and a urethane varnish to hold the pigments and coatings. However, a basic fact makes the development of an ideal non-reflective paint impractical. Namely, the binding agent used in paint to make it adhere to a surface is the same agent which adds gloss to it. Syn-Mur Paint and Varnish⁽²⁹⁾ suggests that a lustre-less olive drab paint when applied in heavy coats might suffice. Buten⁽³⁰⁾ Paints concurs and adds that there have been no advances in "non-reflectivity" of paints since World War II. They support our hypothesis that the motion of the blades is the primary problem, not the

paint on the blades. M. A. Bruder and Sons⁽²⁶⁾ recommends an amorphous silica (about 320 mesh) with 50% solids. They claim that a varnish over an olive drab would be best but they are cognizant of the binder vs. gloss limitation. Finnaren and Haley⁽²⁷⁾ confirms that there are no recent advances in the state-of-the-art. Even their smooth matte flat wall paints yields "shiners" at angles which they refer to as "Flashing." They suggest a completely dead flat, coarse textured paint with large particulate sizes to help scatter the light. Their dead black product is a solvent base coating. Sherwin-Williams Company⁽²⁵⁻²⁸⁾ deals basically with organic pigments which are quite bright. They say we should use the zinc-chrome family. Their Kem Glo flat black might be useful. Polaroid Corporation⁽³⁶⁾ suggests commercial chemical solutions designed for blackening metals. They recommend MacDermid Corporation of Waterbury, Connecticut or Enthone of New Haven, Connecticut. In addition, Polaroid rates the use of two-part epoxy base paints very highly provided the surface can be vapor honed prior to painting. A study is needed to determine just what color is indeed the most non-reflective. Some experts say black is best while others defend olive drab. In addition, the value of additives such as fibers should be determined. The lack of surface adherence of flat paints could conceivably be improved with a concerted effort. Paints wear away from the front leading edge of rotor blades even when they are not handicapped by non-reflective requirements. Black paints used inside of Polaroid cameras are worthy of investigation.

5.3.3 Paint Pattern

A somewhat different approach still using the concept of paint is to paint a pattern of contrast on the blades to create an illusion. Some assistance may be possible by taking advantage of blade motion. For example, by painting alternate blades in complimenting colors, the integration performed by the eye of the observer may favorably alter his ability to discern the blades. In addition, camouflage type patterns of colors or perhaps geometric design might prove useful in reducing reflections.

5.3.4 Rotor Blade Coverings

Coating the blades with dyes or covering them with tape are worthy of consideration. Tapes would necessitate a bonding agent capable of withstanding supersonic speeds. The difficulty of application and probable tendency for exposed edges to shred make the tape possibilities less glamorous than the dyes. Dyes can be soluble without particles which would result in reducing reflections 90% over material containing reflecting pigments. A non-reflecting glass⁽³¹⁻³²⁾ or plastic covering for the rotor blades represents a potential solution, however, in light of alternatives, it is considered to be a relatively unattractive approach. This would not create the same problem as the windshield area because in this case, transmission would not be a critical parameter. Art dealers use a non-reflecting glass or plastic for covering paintings. This material has a rough surface which is not visually discernable when it is placed against the drawing. Transmission is good when the cover is in direct contact with the surface. Technical ramifications that would have to be studied include the means of bonding the glass or plastic to the blades and the strength and durability of the coating as well as any aerodynamic difficulties it might create.

5.3.5 Optical Illusions

An interesting approach to the rotor blade problem which could also apply to the entire helicopter would be to somehow trick the eye of the observer to make an incorrect identification of the object he is viewing. One feasible method to accomplish this would be to spray steam or smoke to make the entire area look like a cloud or mist cover or perhaps a flock of birds. Uncontrollable illumination of the area as well as varying angles of observer orientation presents problems. Effects of strong winds and rotor blade backwash would have to be evaluated.

5.3.6 Aerosol Applicators

An aerosol can containing a non-reflective agent could be sprayed onto the blades just prior to lift-off. This agent could be a

paint, varnish, "sticky" sand or dust or some type of dye. The value of an easily applied coating would be that it does not have to have long lasting qualities. This approach could be useful in light of the limitations on minimizing gloss in paint while maintaining paint binder integrity. A major drawback to this scheme is the difficulty of application in a field environment. Although the rotor hub and central portion of the rotor blades are accessible, the outer portion of the rotor blades extend out over the aircraft. A boom type approach would have to be employed. This represents a severe restriction.

5.4 Precautions

Internal material changes in the rotor suggest that the new material must equal or exceed the strength and durability requirements of the material now being used (high quality aluminum). In addition, it must completely eliminate reflections if the costs are to be justified. This may not be practical due to the huge contribution that the motion of the blades (5 revolutions per second) makes to the reflection problems.

Surface change techniques are worthy of serious consideration since this method is also applicable to present on-line craft. An indepth study into what effects deformation of the rotor blade surface has on both the aerodynamic stability and lift as well as the strength and stress capabilities of the blades is essential. Technical risks are significant.

External coatings eliminate most of the technical risks involved. Currently, paints are applied in varying thicknesses with no discernable effects. Problems to be encountered include ability of the coating to eliminate reflections, withstand supersonic speed and longevity (or ease of reapplication). Some need for periodic maintenance would be encountered.

5.5 Evaluation

Internal material change is feasible solution to the reflection problem, however, there is no guarantee at present that materials and/or alloys exist which would successfully eliminate reflections while also meeting or exceeding the requirements of rotor blades. Therefore, this

approach involves extensive research, development and testing. Hence, the cost is prohibitive in light of alternatives available.

Surface change techniques are available which have good indicators of success. These do involve deformation of blade surfaces which implies potential aerodynamic hazards as well as raising questions as to what affect such deformations would have on critical stress points within the blade. This approach is rather expensive in time and money but less so than internal material changes.

External techniques aimed at eliminating reflections from rotor blades offer high probabilities of success and are achievable on a short run basis. The paint industry has vast experience from which to draw. The most interesting ideas for using paints arise from camouflage efforts and patterns of paints on alternate blades which offer complimentary color patterns and hence would certainly cancel out color identification in a high velocity spinning mode and possibly have acceptable effects on reflections. Simple laboratory experiments could be performed in a relatively short period of time to evaluate paints, painting techniques and patterns of paints. These experiments would also apply to aerosol can type sprays and glass or plastic coatings although the latter efforts would be more difficult to implement and therefore, not recommended unless the ideas easier to evaluate prove fruitless or lacking in some respect. Steam or smoke covers could be studied in the laboratory with relative ease. Bonding thin sheets with raised ridges to the blades is also worthy of note.

6. ROTOR HUB

6.1 Reflection Reduced by Internal Material Changes

Efforts aimed at changing the material from which the rotor hub assembly is currently constructed is a strength and applicability of materials study which has been extensively researched in the literature and which has been incorporated into the present design criteria. Although alternative materials could virtually eliminate reflections, their limitations and technical risks preclude their serious consideration.

6.2 Reflection Reduced by Surface Changes

The hub assembly could be anodized⁽³³⁻³⁴⁻³⁵⁾ with a flat black matte finish. The process would involve an etching of the surface prior to anodizing. A clear oxide could be added which would be corrosion resistant. The surface would then be covered with a seal over the black dye. This process would virtually eliminate all reflections while it would have no detrimental effect on the aircraft or pilot performance. The lone drawback is that it does not allow the pilot to visually inspect for cracks prior to take-off. Its acceptance would hinge upon the feasibility of finding alternate inspection techniques.

6.3 Reflections Reduced by External Means

6.3.1 Plating

Black nickel plating techniques are directly applicable to the problem and have virtually the same pros and cons as does anodizing. Serious consideration rests upon development of alternative inspection systems. Present practice is for the pilot to visually inspect for cracks and/or excess oil spillage before each flight. He sometimes measures critical points to the nearest thousandths of an inch with a micrometer. In addition, periodic maintenance includes dye tests and magnaflux procedures

to check for cracks. There is a certain amount of oil spillage from pressurized parts which is acceptable. If one could devise an inspection technique which could identify the existence of cracks readily even though they may be covered with a black nickel plating, this idea would be ideal. Such a technique could involve a battery operated pocket pack tester or perhaps internal on-board monitoring equipment.

6.3.2 Paints

Application of a flat non-reflective paint would be acceptable if it were applied in a pattern such that it would significantly reduce the total surface area of the highly reflective metal but still leave enough metallic surface exposed to allow visual inspection for cracks. Aerosol cans which spray paint in a random spatter type array would serve the purpose. Organized patterns such as strips, polka dots and zig zag effects could prove to be useful. A high percentage of the surface could be painted with all oil parts left as they are at present. In essence, glare would be reduced to a fraction of its whole level by obscuring a high percentage of the reflecting area while leaving sufficient area untouched so as to not prevent adequate visual inspection. Studies would have to be conducted to determine which type pattern and what percentage of area would have to be covered in order to adhere to the criteria of success. Feasibly, thin coatings can be applied which would not hide cracks either.

6.3.3 Stress Coats

Materials which actually aid in detecting cracks (stress coat materials) are available and can be made non-reflective with additives. They have a high modulus and are brittle. This would meet or exceed all requirements except maintenance and replacement. The brittle feature could give excessive false indications of cracks which could result in unnecessary aborting of mission or perhaps eventual conditioning of the pilots to neglect crack indications which could have disastrous results.

6.3.4 Soluble Dyes

The application of dyes or dyestuffs which could be easily removed for inspection purposes is an acceptable alternative. After final inspection, immediately prior to lift-off, an aerosol can could be used to spray the entire surface. This could be accomplished in less than one minute. A solution dye with no particulate matter (therefore, no pigment reflection) is available. Such things as "bluing" used by machinists could be applicable. The reflection would be virtually eliminated, no detrimental effect on craft performance or pilot performance is involved while the logistics is complicated only by the application and removal of the dye. Maintenance complications are minimal. Extraneous removal, such as rain, is irrelevant in that rain is delivered by cloud covers which also serve to shade the sun and eliminate all reflections.

6.3.5 Tapes

Scotch magic tape could be used to cover the hub in its entirety or on a high percentage basis as discussed above. (This too is an effort at scattering the light rays). There are matte finish dye tapes available which would probably perform even better. This method would eliminate detectable reflections and have a negligible effect on the aerodynamics. They would take a significantly long time to apply and might have to be removed for adequate inspection. In lieu of alternatives, this restriction precludes further consideration of tape as a solution.

6.3.6 Adhering Particles

Ordinary dust or granular sand has properties which redirect rays of light. If the dust or sand would be applied with a substance which would cause it to stick to the hub assembly, yet would be "washable" with an appropriate solvent to accomodate subsequent inspections, it would solve the problem. Advantages and disadvantages are similar to those of applying dyes. Dyes are perhaps more readily available and more easily removed.

6.3.7 Covers

A snap on non-reflecting covering made out of a rubberized or tough fabric material would eliminate all detectable reflections. This cover would be snapped or zippered into place after final inspection. Its desirability would be contingent upon how much time and effort would be required to snap it into place. Dependant upon the particular model helicopter it is used on, it could be fastened to the roof and lifted up and snapped in place for combat missions. Its value rests in its ease of application vs. the ease of application of alternative ideas. A loose fit might have detrimental effects upon the aerodynamics.

6.3.8 Rotor Blade Shade Net

Mounting a shade net on the rotor blades (See Figure 5) themselves would solve virtually all the helicopter reflection problems (except for steep angles and rotor blade reflections). This shade net could be porous or even a series of "Maypole type" ribbons or perhaps semi-rigid extensions. Obviously, a serious aerodynamics question is raised. Its solution is beyond the scope of this report. Assuming the aerodynamics could be maintained with a properly designed shade net on, above or below the rotor blades, detection by reflective surfaces would be significantly minimized.

6.4 Precautions

All efforts aimed at changing the material that the rotor hub is made from face the rather stringent strength and durability requirements that the polished machine steel displays. In addition, costs to change hubs on a present aircraft would be quite high. Future generations of helicopters could benefit from this approach. Perhaps a proper alloy would solve the problem. The technical risk is significant.

Any etching or anodizing of the hub surface would have to be tested in respect to its effects upon maintaining lift integrity also. The technical risk is not as great as changing the material itself but degradation of stress absorbing qualities is a potential failing.

Efforts to apply coatings of an external nature greatly reduce or eliminate the technical risks involved. The life of these coatings would in general be limited. However, in many cases, it is desirable to use a soluble coating in order to accommodate visual inspection. External coatings create a maintenance problem. The degree of maintenance is contingent upon the particular coating selected.

6.5 Evaluation

Since changing the material that the rotor hub is made from generates a tremendous technical risk and involves a huge initial investment it should be considered only in long range plans and should be directed at future generations of helicopters.

Surface changes offer the same detriments as internal material changes except their magnitude is not so severe. Their solutions could apply to present on-line craft but not until the hubs with surfaces so treated are thoroughly tested. This group of ideas can be considered a medium range solution. Technical risks and costs are significant but not prohibitive.

External coatings rate blue ribbon treatment in that they offer virtually no technical risk, have no detrimental effect on the performance of the aircraft or the pilot, can eliminate all detectable reflection and require minimal efforts in maintenance and replacement. Their costs are almost negligible. They would apply to all aircraft and would be an immediate solution. Further research is needed to select the one coating which meets all the requirements best.

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