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Sept. 15, 1970 A. S. MAKAS 3,528,722

HIGH ORDER WAVE PLATE CORRECTION OF SUNLIGHT
POLARISCOPE EFFECT IN WINDOWS

Filed Oct. 30, 1968 2 Sheets-Sheet 1

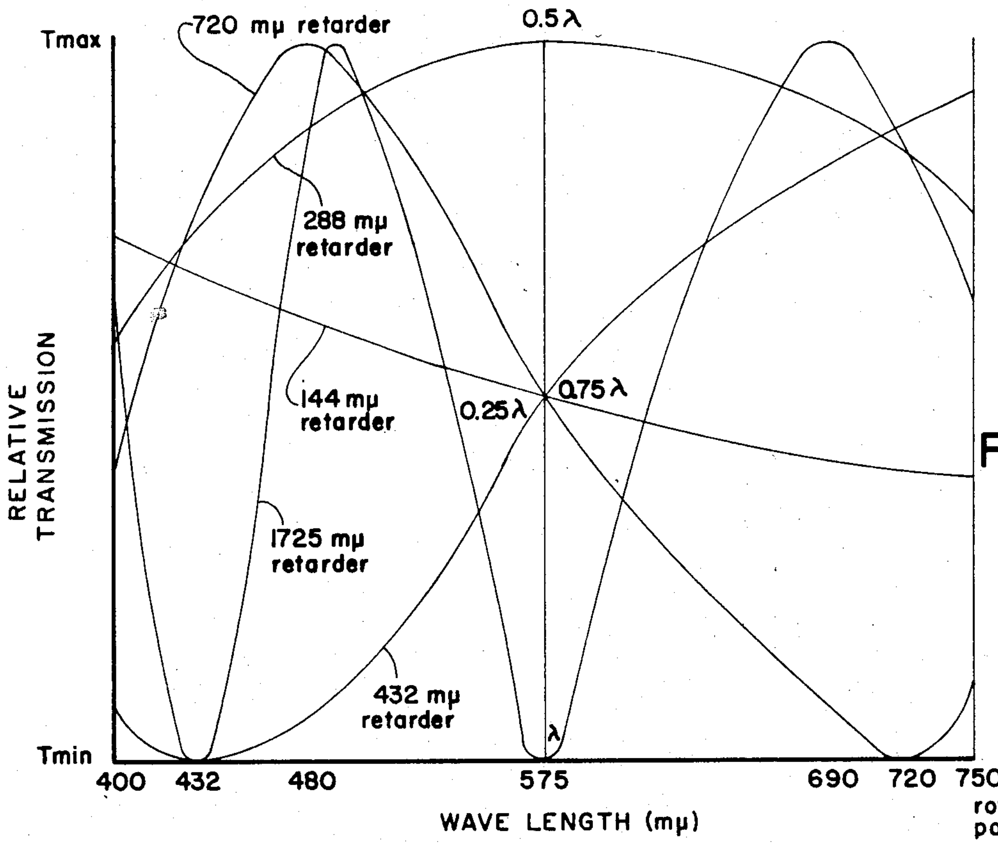

FIG. 1

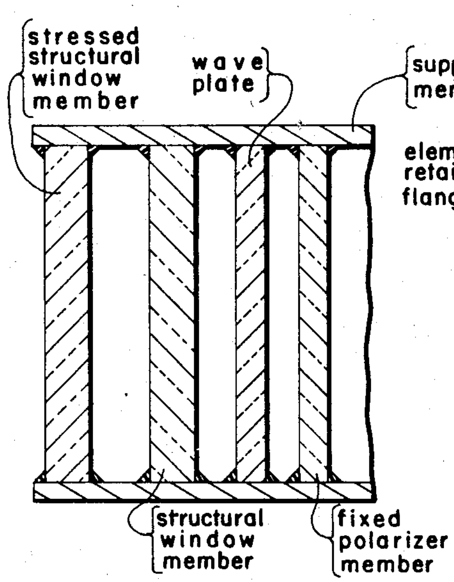

FIG. 2

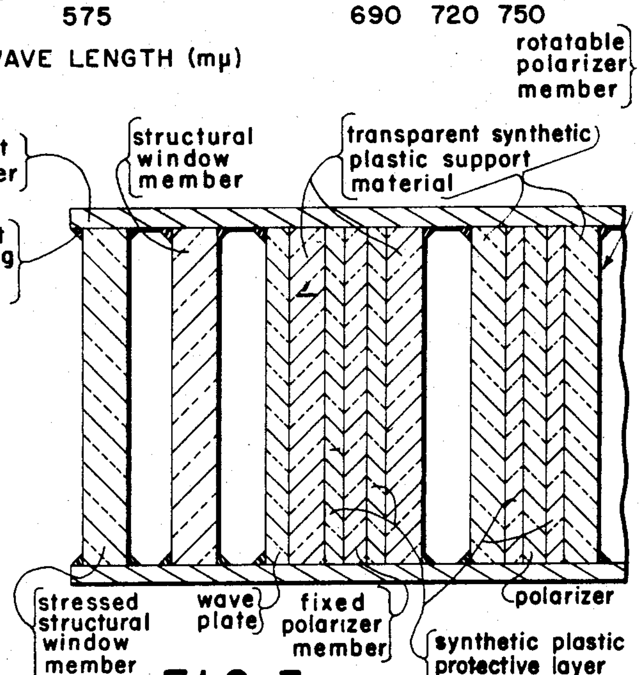

FIG. 3

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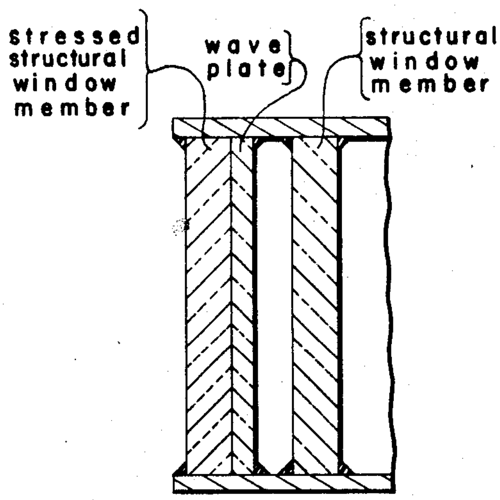

FIG. 4

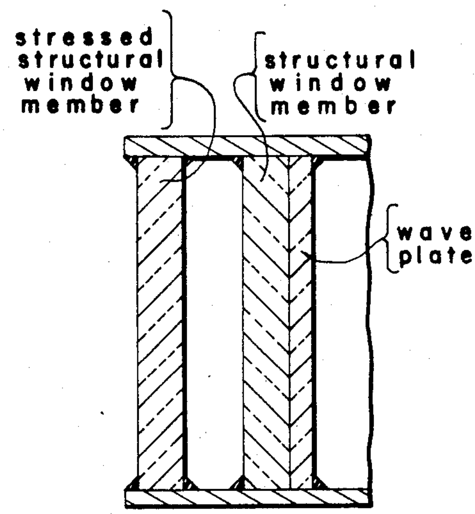

FIG. 5

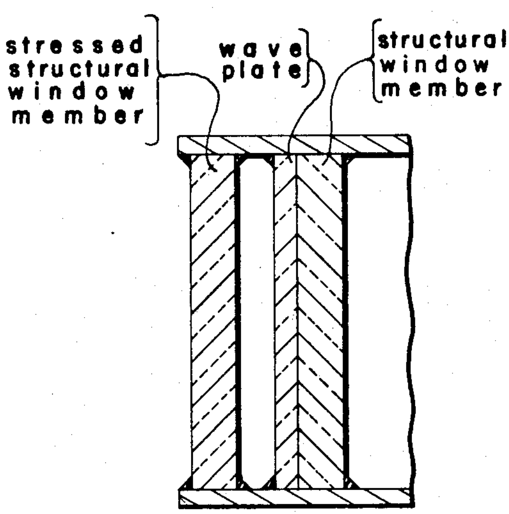

FIG. 6

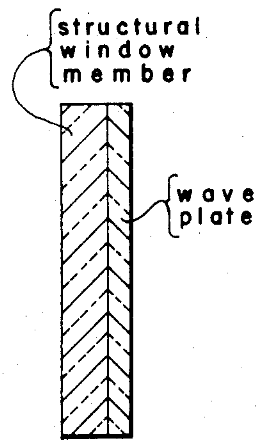

FIG. 7

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3,528,722

HIGH ORDER WAVE PLATE CORRECTION OF SUNLIGHT POLARISCOPE EFFECT IN WINDOWS

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Continuation-in-part of application Ser. No. 697,113, Jan. 11, 1968. This application Oct. 30, 1968, Ser. No. 771,970
Int. Cl. G01b 27/28
U.S. Cl. 350—157 18 Claims

ABSTRACT OF THE DISCLOSURE

When light-polarizing material is used inboard of stressed window members which are exposed to sunlight, the resultant polariscopic effect produces undesirable color patterns and striations. These may be relieved by incorporating a high order wave plate outboard of said light-polarizing material.

This application is a continuation-in-part of copending application Ser. No. 697,113, filed on Jan. 11, 1968, in the name of Albert S. Makas, now abandoned.

This invention relates to the utilization of light polarizers in conjunction with stressed synthetic plastic materials in a composite window environment. More particularly, this invention relates to the utilization of high order wave plates to eliminate interference spectra which result from the polariscopic effect produced when a stressed translucent material is viewed between two light-polarizers.

It is a primary object of the present invention to eliminate undesirable interference spectra associated with the polariscopic effect produced when a stressed translucent material is viewed between sources of polarized light.

It is another object of the present invention to provide a composite window structure which is particularly useful in pressurized airplanes and comprises a stressed transparent member and a light-polarizer, wherein light passing therethrough is free of chromatic aberration associated with the polariscopic effect.

It is an additional object of the present invention to provide a synthetic plastic wave plate capable of at least seven wave lengths of retardation.

Still another object of the present invention is to provide a variable density window comprising a plurality of light polarizing elements and means associated therewith for controlling the light transmitted therethrough.

Other objects of the invention will in part be obvious and will in part appear hereinafter.

The invention accordingly comprises the product possessing the features, properties and the relation of components which are exemplified in the following detailed disclosure, and the scope of the application of which will be indicated in the claims.

For a fuller understanding of the nature and objects of the invention, reference should be had to the following detailed description taken in conjunction with the accompanying drawings wherein:

FIG. 1 is a graphical representation of wave length vs. relative transmission of white light passing through various retardation zones, T_{max} and T_{min} being the maximum and minimum light transmission possible, respectively, with a given system;

FIGS. 2 and 3 are cutaway side views of composite window structures within the scope of the present invention;

FIGS. 4, 5 and 6 are cutaway side views of composite window structure subcombinations within the scope of the present invention; and

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FIG. 7 is a cutaway view of a window member having a high order wave plate laminated thereto.

It is very often desirable to attenuate light entering a room or a transportation vehicle by the utilization of light-polarizing material. It may be additionally desired, and in fact is well known, to utilize a technique which comprises rotating one light-polarizer relative to another in order to achieve substantially complete extinction of any light incident thereto at the option of the operator. The need for such attenuation is generally most profound with respect to transportation vehicles and particularly airplanes which are often exposed to direct skylight without benefit of natural attenuation provided by cloud formations.

Skylight, by its nature, is rather highly polarized; that is, there is preferential alignment of the vibrating light waves due to particle scattering, etc. which produces a more or less ordered, rather than random wave configuration. This effect may easily be experienced by rotating a polarizer against skylight and noting the differences in intensity of the light passing therethrough. When the absorption axis of the polarizer is parallel to the primary plane of vibration of incident light, partial extinction occurs to a greater extent than would be achieved were the transmission axis of the polarizer aligned therewith.

In order to achieve a high degree of pressurization and safety for the interior of modern aircraft, the outer structural window members thereof are made of very highly stressed synthetic plastic material, usually polymethyl methacrylate (Plexiglas, Lucite), although polycarbonates such as Lexan, the condensation product resultant from the reaction of bisphenol A and phosgene, and diethylene glycol bis allyl carbonate, sold by Pittsburgh Plate Glass Company under the trade name CR–39, or any other suitable transparent material may be used. As a backup or failsafe procedure a second synthetic plastic structural window member, comprising a stressed or unstressed material, at the option of the operator, is inserted inboard of the outer stressed member. In the event that a light-polarizer is placed inboard of said stressed member or members, a polariscopic effect is noted; that is, the polarized light outboard of the window and the polarizer inboard of the window form an analyzer which vividily and chromatically portrays the stress pattern of the synthetic plastic window members. The maximum effect occurs when the polarizer absorption axis is 90° to the axis of the incoming polarized light. This polariscopic phenomenon is quite undesirable aesthetically and often causes passengers on an airplane needless worry since the pattern changes with changes in pressure.

The stress pattern observed in airplane windows comprising a light-polarizing element, is due to birefringence occurring in the stressed material. In polymethyl methacrylate and similar type windows the maximum retardation produced by this birefringence is up to approximately 3 wave lengths, which is in a vivdly colored area.

Retardation may be regarded as the product of birefringence and the thickness of a given material. Thus, if the two refractive indices of a given birefringent material are denoted as n and n_1, the birefringence as $(n-n_1)=\Delta n$, and the thickness of the material is denoted as t, the retardation may be visualized as

$$\Gamma=(\Delta n)t$$

Since the thickness range and the birefringence of the members utilized in window configurations anticipated by the present invention are such that the retardations which result are of the order of magnitude of approximately 3 wave lengths, some method must be devised for causing a depolarization effect to thereby produce substantially white light.

It may be beneficial at this time to briefly mention the theory producing the various chromatic effects achieved with stressed synthetic plastic material of the type utilized herein a polariscopic environment. Let us assume, for example, that at one point in said material the stress produces a birefringence which causes approximately one-quarter wave length of retardation relative to 575 mμ light, which is in about the center of the visible spectrum, thus producing a 144 mμ retardation. Looking at FIG. 2, the inboard polarizer is positioned to produce maximum extinction with the incoming skylight, i.e., the absorption axis of the polarizer is parallel to the primary plane of vibration of the entering light. It will be seen, as is illustrated in FIG. 1, that for midspectrum light there will be an effect on transmission of a one-quater wave length retardation; for 400 mμ light there will be 144/400 or approximately one-third wave length retardation; and for the 750 mμ light there will be approximately 1/5 wave length retardation. It is evident that the resultant light will be slightly blue colored. If approximately 3/4 wave length of retardation is produced relative to 575 mμ light, again, with reference to FIG. 1, it may be seen that the resultant light would be approximately amber; while 1/2 wave length retardation relative to 575 mμ light produces greenish yellow light. Also included are graphical representations of the effect of 1.25 and 3.0 wave lengths of retardation, relative to 575 mμ light, on light which may be incident to the system of the present invention. For orders up until approximately 3.5 wave lengths retardation is achieved, very vivid simple colors are progressively evident. Over 3.5 wave lengths the colors are so profuse that they cannot be distinguished individually and are viewed as a less colorful mixture or as white light. Graphically, they may be visualized as curves containing many maxima and minima.

It is known that one light-polarizing member will not cause substantial extinction of polarized light when its absorption axis is parallel to the plane of vibration of said light if a birefringent material is placed between said polarizer and said polarized light because the birefringent material changes the linearity of the penetrating polarized light waves and causes the emission of waves which may be helical or elliptical in nature. It has additionally been found that when an axis of stress is 45° to either transmission or absorption axes of the crossed polarizers a maximum intensity of the interference spectra is reached. Where the axis of stress coincides with either transmission or absorption polarizer axis no effect is seen. The resultant pattern, therefore, evident to a viewer, appears as 4 distinct quadrants with maximum intensity at the center of each sector and minimum intensity along the polarizer axes.

It has been found that if a wave plate with approximately 10 to 15 wave lengths of retardation is inserted in a stressed window—light polarizer combination, outboard of the polarizer, effective depolarization of penetrating light is achieved, i.e., the polariscopic effect is obviated. Assuming that the retardation of the wave plate and window material are additive, it is evident that a wave plate with about 4 wave lengths retardation would be adequate to produce substantially white light. However, if the wave lengths of retardation capable of being provided by the wave plate, in relation to those of the stressed window, are subtractive, about 7 or 8 wave lengths of retardation would be required. In order to provide maximum effectiveness and account for retardation which may be imparted to the system by imperfect laminations, utilization of retarders on the order of 10 to 15 wave lengths of retardation is considered ideal. However, practically speaking, any material which will provide approximately 7 or more wave lengths of retardation may be utilized as, for example, oriented polyvinyl alcohol, various oriented polyesters, etc. It has been unexpectedly found that the best results are obtained when polyethylene terephthalate (Mylar, Melinex) is utilized, it having been uniaxially oriented. With material of this type up to 20 wave lengths of retardation, and perhaps more, may be achieved. An additional adavntage is gained with uniaxially oriented polyethylene terephthalate over other materials since the optical axes of this material are not evident to the viewer no matter what position is assumed, the critical angle being internal. Thus, there is no possibility of the viewer looking down an optical axis of the material and seeing only a black area surrounded by a chromatic environment.

In all embodiments of the instant invention, greatest efficiency will be achieved when the plane of the optic axes of the wave plate is at a 45° angle to the axes of the fixed light-polarizing element. As the plane of the optic axes of the wave plate approaches an axis of the light-polarizing element, efficiency is lost until the polarizer axis and plane of the wave plate axes coincide—at which point the wave plate fails to produce the intended results.

Any suitable material which will produce the desired light-polarization effect may be utilized in the present invention. It has been found, however, that polymeric light-polarizing sheet material lends itself most readily to this function. The preferred material is a transparent sheet of polyvinyl alcohol containing substantially oriented molecules of dehydrated polyvinyl alcohol and deriving its light-polarizing properties essentially from said dehydrated molecules. The manufacture and utilization of such sheet material may be appreciated with reference to U.S. Pats. Nos. 2,173,304; 2,255,940; 2,306,108; 2,397,231; 2,445,555; 2,453,186 and 2,674,159, all incorporated herein by reference.

As a general rule, it may be stated that neither the polarizer nor the wave plate are structurally sufficiently rigid to be used by themselves. Therefore, in the most preferred embodiment of the present invention, both the polarizer and wave plate are laminated to a rigid synthetic plastic material such as, for example, polymethyl methacrylate, before insertion in the composite window structure. In the case of the wave plate, it has been found preferable to laminate it to the composite light-polarizing element. However, it is to be understood that, at the option of the operator, the wave plate may be laminated to a stressed or unstressed synthetic plastic airplane window component part. In the event it is laminated to a stressed member which, in the standard configuration, will comprise the outermost window component, it will preferably be on the inboard side thereof, as denoted in FIG. 4. Technically speaking, the wave plate will be operative for its intended purpose if laminated on the outboard side of the outermost member; however, constant exposure to the elements militates against such an embodiment. Regarding the inner, or failsafe component, the wave plate may be laminated on either the inboard or outboard side thereof as denoted in FIGS. 5 and 6, respectively. The prime criterion for determining a satisfactory position for the wave plate is that it must be located between the sources of polarized light, i.e., and sky and the light-polarizing element.

FIG. 2 denotes an embodiment of the present invention wherein a wave plate is used outboard of a light-polarizing element an dinboard of a stressed window member in an airplane window configuration. FIG. 3, which will be more completely described below, depicts a preferred embodiment of the present invention wherein a first light-polarizing material is laminated between structural members comprising a transparent synthetic plastic support material, with a wave plate laminated on the outboard side of said composite light-polarizing unit. Inboard of said member is a second light-polarizer laminated between structural transparent synthetic plastic support material, which composite member may be rotated at the option of the operator so that the axes of said second light-polarizer may be placed at varying angles to said first light-polarizer thereby providing varying degrees of extinction or transmission of penetrating light. Any adhesive materials suitable for laminating the wave plate-polarizer-support material composite structure may be utilized as long as said adhesive does not hinder the transmission of light. Adhesives which may be used in the environment of the present invention generally comprise low molecular weight polyesters which are cross-linked in situ with a suitable cross-linking agent. Exemplary of such materials is Adcote 1069, sold by Morton Chemical Company, which is a low molecular weight polyethylene terephthalate material, probably hydroxyl terminated, in conjunction with a polyisocyanate cross-linking agent. Other polyester materials found suitable for this purpose are Du Pont Adhesive No. 46960 and National Starch Adhesives Numbers 76–2575, 30–9057 and 30–9066. These adhesives are, typically, polyesters utilized in conjunction with a suitable cross-linking agent, such as a polyisocyanate. The adhesives may be used alone or applied in conjunction with other adhesives. The most preferred embodiment of the instant invention utilizes a uniaxially oriented polyethylene terephthalate wave plate bonded directly to a polymethyl methacrylate support member. The preferred bonding technique is to subcoat the wave plate with a polyester adhesive comprising Du Pont Adhesive 46960 with a polyisocyanate cross-linking agent. Over that subcoat is applied a thin layer of cellulose acetate butyrate from solution. Thereover is applied a thin layer of Adcote 1069, described above, with a polyisocyanate cross-linking agent. This subcoated structure is then laminated using a standard pressure roll technique to the polymethyl methacrylate support member by utilizing an adhesive material which consists of approximately 4% cellulose nitrate, whose viscosity is approximately 600 to 1000 seconds $^{-1}$, dissolved in methyl methacrylate, and utilized with a diisopropyl percarbonate catalyst present in an amount of about 1% by weight. This latter defined adhesive is further described in copending Ser. No. 697,019, filed in the name of Harold O. Buzzell on Jan. 11, 1968, and assigned to Polaroid Corporation.

In order to gain optimum qualities with regard to shrinkage and crazing of the light-polarizing material, it has been found beneficial to laminate the polarizer between layers of cellulose acetate butyrate or similar materials, as described in U.S. Pat. No. 2,674,159 and in the copending applications of Buzzell and Bloom, Ser. Nos. 577,578 and 577,576, respectively, both filed on Sept. 2, 1966, and assigned to Polaroid Corporation. Lamination of the cellulose acetate butyrate layers to the light-polarizing material may be accomplished, for example, either by subcoating the cellulose acetate butyrate material with a suitable compound such as, for example, cellulose nitrate, and then laminating the subcoated material to the polyvinyl alcohol light-polarizing sheet using a well-known pressure roll technique with a typical adhesive for such material, such as a 2% polyvinyl alcohol solution; or, alternatively, the lamination may be accomplished by the conversion of the surface of the cellulose acetate butyrate to cellulose, subcoating the surface with polyvinyl alcohol and pressure laminating the subcoated cellulose acetate butyrate to the light-polarizing material, as more fully discussed in the Buzzell application mentioned above.

The instant invention may be further appreciated with reference to FIG. 3, which is the preferred embodiment, wherein a stressed window member of about 0.5 inch in thickness is placed outboard of a stressed or unstressed failsafe window member about 0.25 to 0.5 inch thick, which is, in turn, outboard of a fixed light polarizing member comprising a laminate consisting of, in order, from the outboard side; a wave plate approximately 1.5–5 mils in thickness and preferaby 3 mils; a transparent synthetic plastic support member approximately 30–125 mils in thickness and preferably about 60 mils thick; a transparent synthetic plastic protective material layer approximately 4–30 mils in thickness and preferably about 5 mils thick; a light-polarizing member, as described

above, approximately .75–1.5 mils in thickness and preferably about .75 mil thick; and a second synthetic plastic protective material layer and a second transparent support layer of the same dimensions as said first support layer. Inboard of the member just described is a rotatable member comprising a synthetic plastic support material; a synthetic plastic protective material layer; a light-polarizing material; a second synthetic plastic protective material layer; and a second transparent support member; all of the same dimensions as described for the preceding element. In the preferred embodiment, the synthetic plastic protective material layers comprise cellulose acetate butyrate. The respective constituents of the composite window structure may be held together by any suitable mounting structure including an aperture capable of retaining the above-described light-transmitting means transverse thereof, such as a cylindrical member with suitable element-retaining flanges.

FIGS. 4, 5 and 6 depict subcombinations of alternate embodiments of the present invention and graphically denote various positions which the wave plate may occupy in the apparatus claimed herein. The bonding techniques and adhesives utilized in joining the wave plate to a given window member are identical to those described hereinbefore for laminating a wave plate to a support member.

In the variable density embodiment of the apparatus of the instant invention, at the option of the operator, a second, fixed light-polarizing element may be positioned with its axes parallel to the first light-polarizing element. Rotation of the rotatable light-polarizing element will then provide more complete extinction of incoming light, thereby increasing the efficiency of the system. In such an embodiment it is preferred to place said rotatable member between said fixed light-polarizing elements.

Throughout the specification the terms "inboard" and "outboard" have been extensively used. "Outboard" is considered to be the side through which light may enter the apparatus of the present invention, while "inboard" relates to the side through which transmitted light exits from said apparatus.

In addition, the term "structural," when applied to component elements of the herein claimed apparatus, defines such elements as being capable of maintaining the structural integrity of the article in which it is used, e.g., an aircraft, train, boat, etc., in conjunction with the body of said article.

Since certain changes may be made in the above product without departing from the scope of the invention herein involved, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. A light-transmitting window apparatus comprising an inboard side through which transmitted light may exit from said apparatus, and an outboard side, through which light may enter said apparatus, said apparatus comprising, in combination, a mounting structure having an aperture therein, said aperture containing a multiplicity of light-transmitting layer-like members mounted substantially transverse to the plane of the aperture including, from the outboard side, a first, structural, transparent, stressed plastic member; a wave plate of at least four wave lengths retardation; and a fixed light-polarizing member.

2. The invention of claim 1 wherein said wave plate is capable of providing at least seven wave lengths of retardation.

3. The invention of claim 2 wherein the plane of the optic axis of the wave plate is at about a 45° angle to an axis of the fixed light-polarizing element.

4. The invention of claim 3 wherein said wave plate comprises uniaxially oriented polyethylene terephthalate.

5. The invention of claim 3 wherein said wave plate is laminated to said stressed plastic member on the inboard side thereof.

6. The invention of claim 3 wherein said apparatus additionally contains a second transparent, synthetic plastic member inboard of said first structural member and outboard of said light-polarizing member.

7. The invention of claim 6 wherein said wave plate is laminated to said second synthetic plastic member.

8. The invention of claim 3 wherein said wave plate and said light-polarizing member comprise a single composite structure comprising, from the outboard side, said wave plate; a transparent synthetic plastic support element; a first transparent protective layer for said light-polarizing member; said light-polarizing member; and a second transparent protective layer for said light-polarizing member.

9. The invention of claim 8 wherein said composite structure additionally contains a transparent synthetic plastic support element inboard of said second transparent protective layer for said light-polarizing material and affixed thereto.

10. The invention of claim 3 wherein a rotatable light-polarizing member is positioned inboard of said fixed light-polarizing member.

11. The invention of claim 10 wherein said apparatus additionally contains a second structural, transparent, synthetic plastic member inboard of said first structural member and outboard of said light-polarizing member.

12. A light-transmitting window apparatus comprising an inboard side through which transmitted light exits from said apparatus and an outboard side through which light enters said apparatus, said apparatus comprising, in combination, a mounting structure having an aperture therein, said aperture containing a multiplicity of light-transmitting substantially layer-like members mounted transverse to the plane of the aperture comprising, from the outboard side; a first structural, transparent, stressed plastic member comprising polymethyl methacrylate of approximately 0.5 inch in thickness; a second structural, transparent plastic member comprising polymethyl methacrylate of approximately 0.25 inch in thickness; a composite structure comprising a synthetic plastic wave plate of at least four wave lengths retardation approximately 1.5 to 5 mils in thickness; a transparent plastic support element approximately 30 to 125 mils in thickness; a first transparent protective layer of cellulose acetate butyrate approximately 4 to 30 mils in thickness; a polymeric light-polarizing member approximately 0.75 to 1.5 mils in thickness; a second transparent protective layer of cellulose acetate butyrate of approximately 4 to 30 mils in thickness; and a second

transparent plastic support element of approximately 30 to 125 mils in thickness; and a rotatable member comprising a transparent plastic support element of approximately 30 to 125 mils in thickness; a first transparent protective layer of cellulose acetate butyrate approximately 4 to 30 mils in thickness; a polymeric light-polarizing member approximately 0.75 to 1.5 mils in thickness; a second transparent protective layer of cellulose acetate butyrate approximately 4 to 30 mils in thickness; and a second plastic transparent support element approximately 30 to 125 mils in thickness.

13. The invention of claim 11 wherein said wave plate is capable of providing at least seven wave lengths retardation.

14. The invention of claim 13 wherein the plane of the optic axis of the wave plate is at about a 45° angle to an axis of the fixed light-polarizing element.

15. The invention of claim 14 wherein each of said light-polarizing members comprise a transparent sheet of polyvinyl alcohol containing substantially oriented molecules of dehydrated polyvinyl alcohol.

16. The invention of claim 15 wherein said wave plate comprises uniaxially oriented polyethylene terephthalate.

17. The invention of claim 16 wherein said plastic support elements comprise polymethyl methacrylate.

18. The invention of claim 17, wherein said cellulose acetate butyrate protective layers are affixed to said polymethyl methacrylate support elements by means of an adhesive comprising approximately 95% methyl methacrylate, 4% cellulose nitrate wth a viscosity of 600 to 1,000 seconds^{-1} and 1% diisopropyl percarbonate initiator.

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