UNCLASSIFIED

AD NUMBER
AD093320
CLASSIFICATION CHANGES
TO: unclassified
FROM: secret
LIMITATION CHANGES
TO: Approved for public release, distribution unlimited
FROM: Distribution authorized to DoD only; Foreign Government Information; JAN 1956. Other requests shall be referred to British Embassy, 3100 Massachusetts Avenue, NW, Washington, DC 20008.
AUTHORITY
DSTL, AVIA 6/20187, 12 Nov 2009; DSTL, AVIA 6/20187, 12 Nov 2009

THIS PAGE IS UNCLASSIFIED

SECRET

AD 93320

Armed Services Technical Information Agency

Reproduced by

DOCUMENT SERVICE CENTER

KNOTT BUILDING, DAYTON, 2, OHIO

SECRET

REPORT
CHEM.504
STRUCTURES 194

REPORT
CHEM.504
STRUCTURES 194

SECRET - DISCREET

ROYAL AIRCRAFT ESTABLISHMENT
FARNBOROUGH, HANTS

REPORT No: CHEM.504, STRUCTURES 194

FC

REPORT ON A VISIT TO THE U.S.A. TO ATTEND THE SIXTH ANNUAL A.I.A. - W.A.D.C. CONFERENCE ON TRANSPARENT MATERIALS AND TO DISCUSS PROBLEMS RELATING TO AIRCRAFT TRANSPARENCIES

by

F.G.J.BROWN and E.W.RUSSELL

JANUARY, 1956

JDRP Control No. 560130
24 APR 1956

1. THIS INFORMATION IS DISCLOSED FOR OFFICIAL USE BY THE RECIPIENT GOVERNMENT. DISCLOSURE TO ANY OTHER GOVERNMENT OR RELEASE TO THE PRESS OR IN ANY OTHER WAY WOULD BE A BREACH OF THIS CONDITION.

2. THE INFORMATION SHOULD BE SAFEGUARDED UNDER RULES DESIGNED TO GIVE THE SAME STANDARD OF SECURITY AS THAT MAINTAINED BY HER MAJESTY'S GOVERNMENT IN THE UNITED KINGDOM.

3. THE INFORMATION CONTAINED IN THIS DOCUMENT SHOULD NOT BE CIRCULATED OUTSIDE GOVERNMENT DEPARTMENTS WITHOUT THE PRIOR PERMISSION OF THE MINISTRY OF SUPPLY.

4 THE RECIPIENT IS WARNED THAT INFORMATION CONTAINED IN THIS DOCUMENT MAY BE SUBJECT TO PRIVATELY - OWNED RIGHTS.

MINISTRY OF SUPPLY

THIS DOCUMENT IS THE PROPERTY OF H M. GOVERNMENT AND ATTENTION IS CALLED TO THE PENALTIES ATTACHING TO ANY INFRINGEMENT OF THE OFFICIAL SECRETS ACT, 1911-1939

It is intended for the use of the recipient only, and for communication to such officers under him as may require to be acquainted with its contents in the course of their duties. The officers exercising this power of communication are responsible that such information is imparted with due caution and reserve. Any person other than the authorised holder, upon obtaining possession of this document, by finding or otherwise, should forward it, together with his name and address, in a closed envelope to:-

THE SECRETARY, MINISTRY OF SUPPLY, LONDON, W.C.2

Letter postage need not be prepaid, other postage will be refunded. All persons are hereby warned that the unauthorised retention or destruction of this document is an offence against the Official Secrets Act

SECRET - DISCREET

MAY 21 1956

56AA 19961-SD-1-3

U.D.C. No. 06.076(73) : 629.13.012.13

Report No. Chem.504
Structures 194

January, 1956

ROYAL AIRCRAFT ESTABLISHMENT, FARNBOROUGH

Report on a Visit to the U.S.A. to Attend the Sixth Annual A.I.A. - W.A.D.C. Conference on Transparent Materials and to Discuss Problems Relating to Aircraft Transparencies

by

F. G. J. Brown
and
E. W. Russell

R.A.E. Ref: Chem/490/EWR
Structures/194/FGJB

SUMMARY

This report is an account of a visit by the authors to the U.S.A. to attend the Sixth Annual A.I.A. - W.A.D.C. Conference on Transparent Materials and to discuss problems of common interest to the U.K. and the U.S.A. in the field of aircraft transparencies.

Report No. Chem. 504
Structures 194

LIST OF CONTENTS

LIST OF CONTENTS (Cont'd)

LIST OF TABLES

LIST OF APPENDICES

LIST OF ILLUSTRATIONS

1 Introduction and Acknowledgements

The Sixth Annual A.I.A.-W.A.D.C. Conference on Transparent Materials was held in the Engineers' Club, Dayton, Ohio, on the 2nd and 3rd March, 1955. Mr. E.W. Russell and Mr. F.G.J. Brown of the R.A.E., and Dr. M.G. Church of Mat. R.D.7, M.O.S., attended the conference by invitation of the sponsoring bodies and a paper on the properties of glass was read to the conference by Mr. F.G.J. Brown.

Advantage was taken of the opportunity offered by this visit to the U.S.A. to discuss problems of common interest with members of the American aircraft, glass, plastics and rubber industries, and of Government and University research departments. The results of a number of discussions on rain erosion have already been reported in reference (1), and information relating to inorganic polymers, high temperature elastomers, and polymethyl-α-chloracrylate has been reported in references (2), (3) and (4). This report includes a summary of the papers presented to the A.I.A. -W.A.D.C. Conference, and of additional information obtained about developments in the fields of transparent plastics, glass, and reinforced structural plastics.

The authors wish to record their keen appreciation of the courtesy shown by the A.I.A. and U.S.A.F. in inviting them to attend the conference, and to thank all those with whom they discussed the other subjects mentioned in this report. They also wish to thank Mr. F.G.R. Cook and Miss Audrey Thompson of B.J.S.M./M.O.S.S. for much valuable help and advice and for the excellence of the arrangements made on their behalf.

2 The Sixth Annual A.I.A. - W.A.D.C. Conference

2.1 Morning Session, 2nd March

A list of those attending the conference is included as Appendix I to this report and the official agenda is included as Appendix II.

In the following account of the papers read at the conference use has been made of the abstracts available in the delegates' booklet prepared by the Materials Laboratory, W.A.D.C. For the most part these abstracts were very brief and they have been freely supplemented from manuscript notes taken during the proceedings. In two cases, full drafts were available and these papers have been reproduced as Appendices to this report. Throughout the report the titles of firms and Government Agencies have been abbreviated; these abbreviations are so well known that the authors have not thought it necessary to include a key to the full titles.

The conference was opened by Mr. V.G. Melquist, Assistant Director, Technical Service, A.I.A. who welcomed the delegates and introduced the Chairman, Mr. M.R. Whitmore, Director of the Materials Laboratory, W.A.D.C., Speaking on behalf of Colonel John V. Hearn, Jr., Chief of the Materials Laboratory, who was unable to be present, Mr. Whitmore referred to the great progress made in the past year particularly in the production and use of stretched acrylics. The most pressing problems now facing the aircraft industry were those of finding transparent materials having high strength at high temperatures, good resistance to abrasion and rain erosion, and the best possible optical properties. He felt that the exchange of views made possible by the conference would facilitate the solution of these problems. Mr. Whitmore was followed by Captain F.J. Wilcox, U.S.A.F. of the Materials Laboratory, W.A.D.C., who described recent changes in the organization of the Materials Laboratory. Responsibility for all

Transparent materials had been transferred to Mr. R.T. Schwartz, Chief of the Organic Materials Branch and Mr. L.J. Breidenbach had been made responsible for all plastic products.

2.11 Progress in the Development of High Temperature Interlayer Materials

This paper was given by Mr. Keith E. Polmanteer of the Dow Corning Corporation, Michigan.

Dow Corning have been working for some time on a transparent silicone polymer (Type J) which showed considerable promise as an interlayer material. This has now been superseded by an improved variety designated Type JA. The material is made in small batches at present and dirt inclusions cannot be avoided under these conditions. This accounts for some variation in haze between batches; Type JA is much better than Type J in this respect and is thought to be acceptable (see Table I).

Table I

Properties of Silicone Interlayer and Glass Laminates

	Type J	Type JA
Tensile Strength - lb/in^2	750-1200	750-1200
Haze - %	3.2-6.6	1.8-3.0
Transmittance - %	84.5-87.0	86.5-87.5

Thermal stability data for Type JA material and for a Type J laminate are given in Tables II and III. The material does not adhere naturally to glass and the thermal stability of a laminate is influenced by the adhesive used; the figures given in Table III refer to a laminate in which the adhesion was 'reasonably good'. Oxidation and increasing cross-linking of this material accounts for the diminution of strength and elongation with increasing time of ageing at the elevated temperatures.

Table II

Thermal Stability of Type JA Interlayer

Hours at 450° F	Tensile strength lb/in^2	Elongation %	Hours at 480°F	Tensile strength lb/in^2	Elongation %
0	897	568	0	897	568
24	905	408	24	773	285
48	773	306	48	696	192
90	753	226	90	696	125

Table III

Thermal Stability of a Type J Laminate

Cumulative Thermal Ageing	Observations
None	No flaws
18 hr at 300°F	O.K.
+72 hr at 392°F	O.K.
+24 hr at 437°F	O.K. (charred lint and dirt specks)
+24 hr at 482°F	O.K.
+24 (48 total) hr at 482°F	O.K. (slightly yellow around edges)
+ 8 (56 total) hr at 482°F	Several small cracks in interlayer.

Both materials are elastic at all temperatures within their useful range and it is thought that any similar material which has good high temperature properties will also be elastic. This is a disadvantage because permanent peeling stresses are set up in an elastic material when it is used as an interlayer between rigid facing sheets unless the thickness of the interlayer is uniform within very close limits. The thickness variation at present is about ±0.001 in. on thicknesses between 0.030 in. and 0.060 in; this is sufficient to cause immediate or delayed peeling of the interlayer from the facing sheets unless this adhesion is very good. However, some flow of the present material occurs under a combination of high temperature and high pressure and the best results to date have been obtained by laminating at 300°F and 350 lb/in^2; the curing time under these conditions is at least 30 min. The thickness variation depends on the methods employed in manufacture of the material and could be reduced by improved techniques giving a better surface finish. Pre-calendering has been tried and gave better adhesion, but the calendered material contained air bubbles which made it unsuitable for optical transparencies. A thermosetting type of material could probably be made; in this case the cure would be completed during lamination and there would be some loss of thermal stability due to absorption of volatile by-products.

The future of these materials depends on the discovery of a satisfactory adhesive. Those in use at present are influenced by a number of factors including weather conditions and it is difficult to maintain consistent strength. A promising new adhesive is under development. Typical peel strength data for Type JA material laminated with glass are given in Table IV. The tear strength of the material is less than that of polyvinal butyral and in the tests of adhesive XA-4034 the material tore in stripping. No results were given for tests at low temperatures but the adhesion under these conditions is good.

/Table IV

Table IV

Peeling Tests of Type JA Interlayer

Adhesive 126-2-28A				Adhesive XA-4034			
Laminating Conditions			Peel Strength lb/in	Laminating Conditions			Peel Strength lb/in
Temperature °F	Pressure lb/in^2	Time Minutes		Temperature °F	Pressure lb/in^2	Time Minutes	
300	385	10	33.8	300	400	10	31.4
300	385	25	37.6	300	230	10	36.8
300	230	10	8.6	300	200	30	21.0
300	200	10	4.8				
300	200	30	7.2				

The tensile strength of Type JA material is shown by Figure 1; the strength is time sensitive and the values shown are for a straining rate of 20 in. per min.

For high velocity impacts the energy absorption of glass laminates based on Type JA is the same as for polyvinal butyral at laboratory temperature. Type JA material, however, differs from polyvinal butyral in that its energy absorption is constant over a wide range of temperature. No impact tests have yet been made on specimens after thermal ageing. The second-order transition temperature for Type JA is -120°F and the crystallization temperature is also extremely low.

This material is still in the research stage and is not ready for production. It is available in limited quantities in sizes up to 24 in. x 14 in. Larger sheets can be made but this presents difficulties with existing equipment and the physical properties of the larger sheets will be inferior to those now obtained. Assessment under realistic conditions is needed to show the value of the materials and Dow Corning would welcome enquiries for small quantities for this purpose.

2.12 Progress in the Development of Polymethyl α-Chloroacrylate

Dr. J.M. Wilkinson, Jr., of the General Aniline and Film Corporation presented this paper, using the trade name Gafite for their product.

Gafite A produced in 1951 suffered from surface distortion, caused by impurities arising from the ready air oxidation of the monomer. In 1952 Gafite B was produced which, although non-distorting, was deficient in ultraviolet and thermal stability. For satisfactory forming no bubbling should occur in the sheet when heated at 195°C for 45 minutes. Improvements were made and a survey of the aircraft industry revealed a growing demand for the material, which reached the pilot plant stage in 1954. The improved Gafite C was now presented. By April this material should be available in quantity in sheets up to 72 by 84 in. Thicknesses of $\frac{1}{4}$ to 1.15 in. have been made. Problems of adhesion and of edge attachment have been satisfactorily investigated by the industry. An annealing process has been worked out. Pimples formed on the plastic surface during heating were attributed from observations in polarised light to strain release rather than to chemical instability, and in this connection it was known that the pilot plant was incapable of giving the highest product.

The degradation of PMCA is an exothermic process, the elimination of methyl chloride being the initial reaction. No bubbling was observed on heating for 24 hours at 130-135°C, but the time required for its appearance decreased over the temperature range 140-200°C from 12 hours to less than 30 minutes. In the light of these experiments 160-180°C is now considered the practical working range of temperature for manipulating the material.

As a target for improvement a flexural heat distortion temperature of 150°C is set. For homo-polymers 130-140°C appears to be the limit; formability may be diminished as the heat distortion temperature is raised. Good crazing resistance at high temperatures is expected.

2.13 Studies of the High Temperature Properties of Transparent Plastics

This paper was read by Mr. W.F. Bartoe, Chief Physicist of the Rohm and Haas Company. Since the paper was largely factual and is about to be published, a brief abstract only will be given here.

The widespread demand for the development of transparent plastics suitable for higher service temperatures has created new problems in their evaluation. It is difficult both to determine exact requirements and to simplify material evaluation.

Organic plastics do not in general exhibit sharp changes in their physical properties with increasing temperature. This makes it necessary to deal with their properties in terms of ranged indices, which are inconvenient for tabulation or discussion. Consequently some arbitrary definitions of temperature resistance have been developed, such as the heat distortion temperature, which is widely used but imperfectly understood.

Some of the most important factors influencing the apparent heat distortion temperature of plastics were discussed and the values observed for various types of linear, heat-resistant or cross-linked acrylics were related to other criteria of their high temperature resistance. A proposed approach to the service problem was based on a combination of the observed physical properties with heat transfer data under simulated high-speed flight and with specified performance requirements.

2.2 Afternoon Session, 2nd March

2.21 Progress in the Development of Stretched Transparent Plastic Material

2.211 Effects of Stretching Acrylic Plastics

This paper, read by Mr. O.L. Pierson of the Rohm and Haas Company, is reproduced in full as Appendix III to this report.

2.212 Contributions by Mr. Robert S. Ames and Mr. C.R. Frownfelter of the Goodyear Aircraft Corporation

Mr. Ames discussed a stretch forming process developed by the Goodyear Aircraft Corporation. He gave no details of the process but revealed that both stretching and shaping are accomplished in a single operation. The process is an economic one and is adaptable to a wide range of finished shapes. The optical quality of the shapings is equal to that of shapings made by the best conventional methods.

Goodyear's experience shows that $dW/_{dA}$ (see para.2.22) is the only reliable criterion of shatter resistance for formed components, and coupon specimens are taken from the edges of each shaping for measurements of this quantity. Measurement of the extent to which the material is stretched is not sufficient. Goodyear do not like the 'warm forming' process advocated by Rohm and Haas because it affects $dW/_{dA}$.

Mr. Frownfelter described gunfire tests of half scale canopies which had convinced Goodyear that the shatter resistance of a canopy can be reliably predicted from measurements of $dW/_{dA}$. In these tests the attack was made with a .45 revolver from a broadside position so that the missile passed through both sides of the transparency. The specimens used were half-scale models of the F.84F canopy. One specimen made from unstretched sheet failed in the first attack when carrying a hoop stress of 585 lb/in^2. A similar specimen made by the stretch-forming process did not fail when attacked while carrying a hoop stress of 1180 lb/in^2. One specimen was attacked four times at increasing internal pressures up to 12 lb/in^2 (corresponding to a hoop stress of 1180 lb/in^2) without failure. It finally failed under an internal pressure of 12½ lb/in^2 through a section unaffected by the gunfire damage.

2.213 Contribution by Mr. C.H. Fortin of the Plastic Age Corporation

Mr. C.H. Fortin showed a colour film of firing trials against a full-scale Northrop F7U canopy which impressively supported the claims made by earlier speakers for pre-stretched material. In these trials the canopy was attacked from a broadside position so that the missile went in one side and out the other side of the transparency. The tests were made at ambient temperature in the open air.

The first attack was made with an internal pressure of 6 lb/in^2 in the canopy and caused only clean punctures of the transparency. These punctures were not repaired but were covered with transparent adhesive tape to restore the pressure seal and in this way the attack was repeated three more times on the same specimen at 6 lb/in^2 and once at 9 lb/in^2 internal pressure without causing failure. The specimen finally failed at the sixth attack which was made at 15 lb/in^2.

It was stated in answer to a question on this group of papers that no firing trials have been made against actual canopies at low temperatures. However, $dW/_{dA}$ does not change appreciably with decrease of temperature and therefore there is no reason to expect a marked change in shatter characteristics.

2.214 Contribution by Mr. John G. Stansbury, Swedlow Plastics Company

Mr. Stansbury said that the Swedlow Plastics Company had found the Rohm and Haas 'warm-forming' process the best of several processes they had tried. When stretched material is heated it tends to revert to its unstretched state, and the essential feature of the 'warm forming' process is that the material is heated to a lower temperature than usual so that this tendency is minimised. This temperature is necessarily below the best forming temperature but this does not appear to cause serious damage to the material.

Before adopting the 'warm-forming' process Swedlow tried restraining stretched sheets in a rigid frame so that they could be heated to the optimum temperature for shaping. This approach failed because the tendency for the sheet to revert to its original dimensions was so strong that the material tore away from the frame while being heated. They also tried stretching the material uni-axially in the flat state and then stretching in the perpendicular direction during shaping but the properties of material treated in this way were highly directional.

Mr. Stansbury said that only 15% to 20% of material bi-axially stretched in the flat state was suitable for shaping into canopies and it seemed preferable that the stretching should be done by the material suppliers rather than the shapers.

Several formed components were exhibited by the speakers in this group and these showed the excellent optical properties that can be obtained. The exhibits included half-scale models made from Plexiglas II, Plexiglas 55 and Gafite, and a full-scale F84 canopy made from Plexiglas 55. It was noticeable that none of these was of the rear-view bubble type which suggests that the combined stretching and forming process does not lend itself to forming deeply-drawn shapes. However, in answer to a question on this point, Mr. Robert S. Ames said there was no technical difficulty and that the shapes exhibited simply reflect current trends in canopy design.

2.22 Toughness testing of Hot Stretched Acrylics

Mr. J.A. Kies of the Mechanics Division of the Naval Research Laboratory presented this paper, which reviewed work sponsored by the Bureau of Aeronautics.

The determination of the work per unit area for crack propagation, $dW/_{dA}$, is based on the assumption that when sudden rupture occurs the relation $-dE_s = dW$ holds, dE_s being the change in stored elastic energy. To justify this it was demonstrated that only a very small percentage of the total energy required for fast fracture could be transmitted by the grips of the testing machine. For a 6 in. wide centrally notched specimen, at fracture velocities of 1,000-1,500 ft/sec the time for fracturing is about 1/5 of a millisecond, during which the grips travel 3.3×10^{-7} in. at 0.1 in./min. For a load of 5,000 lb the energy transmitted to the specimen would be 1.7×10^{-3} in. lb. But at a typical value of $dW/dA = 30$ in.lb/sq in. the total energy required would be about 37.5 in.lb, which is greater by a factor of about 22,000.

In calculating $dE_s/_{dA}$ the further assumption is made that no permanent set occurs during fracture. In recent work on an aluminium alloy the expression $dW/_{dA} = (\pi\sigma^2 x)/2E$, where σ is the tensile stress, x the crack length and E Young's modulus, does not hold accurately for fast ductile fracture. An additional term $F d\ell_p/dA$, where F is the load and $d\ell_p$ the permanent elongation, gives a more generalised expression. In the work on acrylics large test pieces are used so that the average stress on the holding area has been lowered to such levels that permanent set has been insignificant. Caution, however, needs to be exercised in the use of small specimens.

Recent experiments on hot stretched acrylic sheet have shown that warm forming can be done successfully without serious loss of toughness. Values of $dW/_{dA}$ can be obtained reliably on specimens in the range from 2 in. x 2 in. to 10 in. x 10 in. as shown in Table V.

Table V

Effect of Specimen Size on Measured Values of dW/dA

Size of Specimen in. × in.	No. of Specimens	σ	$-dE_s/dA$
2 × 2	8	4090	21.7
3 × 33	10	3340	21.2
6 × 6	10	2880	22.3
10 × 10	10	2760	21.2

Birefringence tests on stretched acrylics have been extremely useful in confirming determinations of dW/dA. Suggested levels of birefringence which can be expected for various levels of dW/dA are shown in Table VI.

Table VI

Birefringence of Stretched Materials

Material Specification	dW/dA in.lb/sq in.	Birefringence Fringes/in. thickness
MIL-P-6886A General purpose acrylic	25	4-8
MIL-P-8184	25	19
MIL-P-5425A Heat resistant acrylic	25	13

Considerable attention has been given to the applicability of the dW/dA values in determining the strength of a structure such as a canopy containing cracks. Previous comparisons have been between materials having about the same values for Young's modulus so that the strength under cracking conditions was simply proportional to $(dW/dA)^{\frac{1}{2}}$. Now however PMCA and glass are included in the tests and with such materials of varying modulus the stress is proportional to $(E\,dW/dA)^{\frac{1}{2}}$ indicating the importance of high modulus values. Representative values of $E\,dW/dA$ are given in Table VII.

Table VII

Values of $E\,dW/dA$ for Three Materials

Material	$E\,dW/dA$ $lb^2/in^2 \times 10^{-6}$
Steel	3,000
24 ST Aluminium	4,000
MIL-P 5425 A acrylic	
Cast	1.5
Hot stretched	10

2.23 The Suitability of Polymer K for Monolithic Enclosures

This paper was presented by Mr. L.B. Norwood of North American Aviation Inc.

Polymer K (made by the Rohm and Haas Company of Philadelphia) is one of the newer heat resistant resins which North American have evaluated for possible use as canopy materials for supersonic fighter aircraft. Figures 5 to 8 give comparative strength data for Polymer K and Gafite (made by the General Aniline and Film Corporation of Easton, Pennsylvania). Comparative stress solvent crazing data for Polymer K, Gafite, Plexiglas 55 and Plexiglas 5105 in the weathered state are given in Fig.9.

Polymer K is very notch sensitive and extreme care is necessary to avoid failures in forming and subsequent cooling. Completely uniform clamping of the edges of the sheet during forming is particularly important. The forming technique must be designed to give the lowest possible level of residual stress because residual stresses cannot be relieved by annealing. Canopies made from Polymer K should be designed for free blowing and should be supported in their frames as freely floating membranes. Figs.10 and 11 give dimensional details of edge attachments which North American have investigated, and Figs.12 and 13 give strength data for these attachments at various soak temperatures and with temperature gradients through the thickness of the sheet. The temperature/Mach number relationships from which the temperature gradients were determined are shown in Fig.14. It is most important that notch effects should be excluded from the edge attachments and all cut edges should be sanded and polished to a transparent finish. Synthetic fabrics are best for edge attachments and hot-set Dacron has given the best results to date. Good cemented joints are difficult to produce but Epon resins bond well if the surfaces are first lightly sanded.

2.24 Improvements in Sierracin 611 Polyester Material

Dr. E. Da Fano and Mr. D.G. Wilkins of the Sierracin Corporation gave the main paper, and Mr. C. Lemons of Douglas Aircraft Co., gave details of a new forming technique.

The early part of the paper reviewed the properties of Sierracin 611, without giving new information. Using their laminating process a number of new configurations of unbalanced thicknesses and distribution of plies have been developed for the industry. Sheets from 0.05 to 0.625 in. thick are in use in laminates from $\frac{1}{8}$ to $1\frac{1}{2}$ in. total thickness. Advantages over symmetrical laminates are claimed, arising from the asymmetry of the conditions to which windows or canopies are subjected in service.

The empirical nature of the ASTM heat distortion point was emphasised, and its arbitrary character in comparing cross-linked materials with the linear acrylics was demonstrated. At higher strains or at longer times cross-linked products may prove much superior although rated lower on this particular test. Moreover inter-laboratory correlation on its results was poor.

The Sierracin Corporation are now producing 500,000 sq ft of the material per annum under much improved quality control. They have now developed a new heat resistant type Sierracin 850-X, some data on which are compared with the 611 polyester in Table VIII.

/Table VIII

Table VIII

Comparison of Properties of Sierracin Types 611 and 850 - X

Material		611	850-X
Tensile strength lb/sq in. × 10^3	60°F	12	-
	80°F	10-12	10
	100°F	8.5	-
	150°F	5.5	7
	200°F	-	4.5
	230°F	-	2.8
	250°F	-	2.5
Flexural strength lb/sq in. × 10^3	Plain	18-20	20
	notched	9	11
Izod impact strength ft/lb	plain	6.5-11.5	6-11
	notched	1.2	1
Heat distortion point °F		190-205	225-235

The new material has the same craze resistance as the old, is slightly better in appearance and in light stability, and probably has the same weathering properties. In each case the stress strain curve is linear, that of 850-X up to 250°F.

Formability tests have shown that with its higher softening point different techniques may be needed for the 850-X material. For improved formability partially cured material can be supplied.

Sierracin 611 has been coated with metals for electrical de-misting, and has been tinted green with varying depth of colour for other purposes. Facings of 611 material on glass are being tried as protection against impact damage.

A new development designated a "monogenic" laminate was described. Within a single sheet polymerised together layers of varying thickness and properties are combined for optimum performance. Each zone consists of a polyester of composition chosen to achieve the required properties. Promising results were claimed, but material has not yet been made available for commercial evaluation.

New forming techniques have been developed by the Douglas Aircraft Co. for the RB66 greenhouse canopy, comprising ten separate panels of compound curvatures. The pre-heated blank (laminate) rests on a rigid female jig and edge pressure is applied at a number of points by a series of clamps. A male jig clamped to the female and sufficiently flexible to assume its shape holds other edges immobile. Accurate control of contour is achieved with section templates.

2.25 Polarized Light Analysis of Annealed Plastic Parts

Mr. B.L. Manire of Northrop Aircraft Co. discussed their investigation of the acrylic windshield for the F89 and showed a number of slides to illustrate their conclusions. The factors affecting optically observable internal strains included the following:

(a) Variations in forming techniques. Production changes in tooling, forming and machining were introduced.

(b) Restrained or unrestrained annealing. Glass laminate edge attachments may cause frozen-in strains. Bending methods and materials and methods of attaching have been modified.

(c) The relation of strain relief to cold flow and to annealing was examined.

(d) A qualitative comparison of residual and static loading strains was made.

(e) The effects of edge viewed internal strains on pilot's vision was studied.

The general conclusion was drawn that annealing of all windshields according to specification MIL-P-6997 without regard to edge attachments and their effects was of questionable value.

2.3 Morning Session, 3rd March

2.31 The Assessment of Visual Distortion through Aircraft Transparencies

This paper was presented by Mr. John Lazo of the Naval Air Material Centre, Philadelphia.

Visually significant optical defects in aircraft transparencies can be detected by photographing a suitable target through the transparencies with a double-aperture camera located at the position of the pilot's eyes. N.A.M.C. use a ruled grid of 1 in. squares for the target, and optical defects are then revealed by splitting of the lines due to local duplication of the image. Criteria for interpreting these records have been set up by visual assessment of 25 windscreen quarterlights. These were mounted 125 ft above the ground on a roof overlooking an airfield and a number of selected pilots viewed the airfield through them and so ranked them in order of preference. Analysis of the ranking awarded by different pilots showed good concordance; and correlation between the numbers of split lines in the photographs and the pilots' order of preference showed that the photographic method can satisfactorily rank transparencies in order of subjective acceptability. A specification is being prepared which will call for photographic examination of all Navy transparencies. For this specification the acceptance criteria have been elaborated to cover both the severity of local distortion and the total area over which distortion is evident.

2.32 Problems Encountered in Transparent Areas of Jet Fighter Aircraft

Lt. Colonel Midkiff of the Wright Air Development Centre gave this lecture in a most able presentation which was the highlight of the conference.

Extreme operational conditions have influenced the optics, thermal or cabin pressure loads and the slope of windshields, but it is still imperative to be able to see adequately if a mission is to be successfully accomplished. Considering 2 aircraft approaching each other $1^1/3$ miles apart and each flying at 600 m.p.h. on a crash course, a pilot required 0.1 sec to see and 0.5 sec to recognise another aircraft. 1 sec is required for decision, 0.4 sec to react, 2 sec for aircraft response, a total of 4 sec in which time they will have crashed. The maximum visibility is 4 miles; hence good visibility through all transparent areas is essential.

Distortions, which are magnified by low angle mountings, interfere with the judgment of distance or of altitude (e.g. by distortion of horizons) and produce fatigue. Imperfections may prevent enemy aircraft being observed or may magnify the target so that the time to attack is misjudged.

Improved physical qualities required include non-shatterability, better heat resistance and improved rain repellancy. Bubbles or discoloration produced by thermal de-icing are objectionable, and a pilot may be blinded by light rain.

Considering obstructions to visibility it was stated that 3 in. wide canopy supports will hide a 35 ft wing span fighter at 1,200 ft distance or 1 sec before collision. Poor optics in rearward vision are particularly objectionable to the pilot. Reflections during night flying either from the ground, from instruments or from other aircraft when flying in formation can be tiresome. Polarisation by reflection has produced grey areas forward in the windshield of F100 at altitude.

Light transmission may be reduced by the angle of installation of the component. Central panels appear hazy when flying in sunshine and at night reduced visibility may be occasioned by lowered transmission.

In conclusion Lt. Col. Midkiff emphasised the following needs:

1. A better field of vision.
2. Better optical properties.
3. Improved transparent materials.
4. Increased liaison between airframe manufacturers, transparent materials vendors and the Air Force an essential.

2.33 The Properties of Glass for Aircraft Applications

This paper, read by one of the authors (F.G.J.B.), was largely based on R.A.E. Report No. Structures 167. It is reproduced as Appendix IV to the present report.

2.34 Some Observations on the Mechanical Properties of Glass

This paper was read by Dr. Edward Saibel of the Carnegie Institute of Technology.

Dr. Saibel said that he had nothing new to offer; his paper was entirely a review of existing knowledge. The paper included a discussion of the effects of rate and duration of loading on the strength of glass and of heat treatment on the internal stress distribution. For the most part the treatment was very elementary and the information given was all well known.

2.4 Afternoon Session 3rd March

2.41 Progress in the Low Temperature Preparation of Electrical Conductive Transparent Coatings

This paper was read by Dr. G.A. Dalin of the Balco Research Laboratories.

Conductive coatings on acrylic sheet can be prepared by sputtering cadmium in an oxygen containing atmosphere of a critical concentration. The operation is performed in filtered air in a room at a pressure of an atmosphere or above. Satisfactory adhesion is obtained by the use of an undercoat of silica or titanium dioxide applied in the form of solution at normal temperatures. The principal factors determining the quality of the cadmium oxide coating are the partial pressures of oxygen and inert gas, the electrical current, the duration of the discharge, the surface temperature of the acrylic and the history of the cathode. The maximum temperature permitted by the plastic substrate is used. Plexiglas 1, 2 and 55, Lucite, Sierracin and glass have been treated.

Resistivities as low as 100 ohms per square have been achieved and down to 20 ohms per square in the case of glass. Transparency up to 80 per cent transmission is obtainable. Film uniformity judged by interference colour is good. The largest piece treated so far is 6 in. square. A negative temperature coefficient of resistance is observed.

In reply to a question on the possibility of treating a complete fighter canopy, Dr. Dalin stated that a flat surface was the initial objective. He believed they could go further, and were preparing for the sputtering of curved visors.

2.42 Progress in the Development of Transparent, Electrically Conducting Films of Indium Oxide

Dr. E.H. Lougher of the Battelle Memorial Institute presented this paper.

Thin films of indium sputtered or evaporated on glass have been converted to the oxide at temperatures of 250-400°F. This may be done after laminating the glass if desired. Heating electrically to oxidise the film has frequently produced local hot spots. Both the evaporation and oxidation processes are very critical. The rate of evaporation must be low and the distance and pressure carefully controlled to avoid either mirror formation or non-adherence of the film. Resistivities of less than 500 ohms per square and light transmissions of 75 per cent have been obtained by oxidation at 250°F, but at 400°F better results were found with resistivities of 130 ohms per square and 80 per cent light transmission.

A photo effect has been observed in these films, and has been attributed to sorption and desorption of atmospheric gases. When a film is illuminated, the resistance slowly falls to a minimum value. Storage in the dark over 5 days or more causes a rise to a value 1.5-3 times the minimum. The effect of such storage is shown in Table IX and that of alternate exposures to light and darkness in Fig.19. Some properties of typical films are given in Table X.

/Table IX

Table IX

Resistance Increase of Indium Oxide Films During Storage in the Dark

Film Number	Minimum(1) Resistance, ohms per square	Increase(2) in Resistance After One Day in Dark, per cent	Increase in Resistance After 5 Days in Dark, per cent
9507-40A	516	54	184
-48	464	44	190
-25	1015	40	-
-46	419	31	118
-43	461	26	80
-45	550	23	67
-42A	257	20	62
-29	501	16	-
-66A	592	31	75
-70	220	16	35
-70A	224	15	41
-66	373	11	18

(1) These are the lowest resistances attained in the first light cycle.

(2) Averages for 3 to 5 cycles.

Table X

Properties of Typical Indium Oxide Films

Film Number	Oxidation Temperature °F	Minimum Resistance,(1) ohms per square	Transmission of White Light per cent
Evaporated Films			
9507-29	250	500	70
-45	"	550	80
-31	"	650	75
-42	"	260	75
-43	"	460	75
-66A	300	592	80
-70A	"	225	75
-80A	"	330	75
-90	"	155	72
-90A	400	175	72
-95	"	130	80
-95A	"	250	78
Sputtered Films			
3-11-1	250	470	75
3-11-2	"	390	75
I-115	"	450 (600)(2)	(72)(2)
I-121	"	390 (430)(2)	(62)(2)

(1) Minimum resistances are after first light cycle for evaporated films and in vacuum for sputtered films.

(2) Numbers in parentheses are values obtained after additional conversion at low pressure.

2.43 Some Observations on the Problem of Fabricating Flat Heat-resisting Windshields of Superior Optical Quality

This paper was presented by Mr. R.G. Whittemore of the Pittsburgh Plate Glass Company.

Mr. Whittemore discussed the effects of surface grinding and polishing of laminated tempered glass panels on the distribution of internal stress in the glass. Tests have been made on laminated specimens having a facing of 3/16 in. nominal thickness laminated through a vinal interlayer to a backing of ¾ in. nominal thickness. The tests covered all combinations of three different interlayer thicknesses and three different degrees of facing lamina temper. Glass was ground from the outer surface of the facing lamina and measurements of the stress distribution across the thickness of the glass were made with the apparatus shown in Fig.20, and the results of the stress measurements are given in Figs.21 and 22. Measurements were also made of the curvature of the ground facing lamina after removal from the vinal interlayer and backing; one such result is given in Fig.22.

Removal of 30% or more of the thickness of the facing reduced the surface compressive stress to zero or less, whatever the temper of the glass or the thickness of the vinal interlayer. If less than 20% of the facing thickness must be removed to obtain the required optical properties, a high degree of temper is preferable for the facing lamina, because in this case the surface compressive stress remaining after grinding increases with increase of temper. It is undesirable to remove more than 20% of the thickness of facing laminae of any thickness, but if this is unavoidable the glass should be only lightly tempered. These conclusions follow from the curves shown in Fig.21. Glass often breaks from a free edge and the condition of the edges after grinding, therefore, is important. For lightly tempered glass it is likely that the edges still retain some compressive stress even after 40% of the thickness has been ground away. It is possible that the material at the bottoms of surface fissures may be in tension although the ground surface is in compression and this could possibly cause failures. This risk does not seem very serious, however, and can probably best be assessed by service trials of ground panels.

Highly-tempered glass has a strong tendency to curl due to unbalance of the internal stresses after grinding. This may cause de-lamination at the edges of a panel but this defect is not thought to be dangerous.

No 'Nesa' panels have been reground and no thermal shock tests have been made of reground panels. Thermal shock tests of glasses before regrinding have shown that annealed plate glass will withstand an instantaneous temperature difference between its two faces of about 100°F. The corresponding figures for semi-tempered and fully-tempered glass are 300°F and 400°to 500°F respectively.

During the discussion of this paper Mr. R.A. Gaiser of Libbey-Owens-Ford stated that about 1,500 'Electrapane' panels had been reground after lamination and that their service behaviour had been satisfactory.

2.44 Review of Materials Laboratory Programme

Captain J.F. Wilcox of the Materials Laboratory, Wright Air Development Centre reviewed progress on the following contracts and projects:

(a) Production of acrylic polysiloxane interlayer, and development of interlayers useful up to 400°F. None yet promising.

(b) Goodyear work on gunsight domes has been completed: Part II of the report will shortly be available.

(c) Rohm and Haas continuing to study the gunfire characteristics of laminates and stretched sheet.

(d) The Armour Foundation report 55/24 on thermal shock will shortly be available. The rates of shock and of temperature drop are critical. A survey of the glass field is planned.

(e) The Aeromedical Laboratory require the development of a visor for high altitude pressure suits.

(f) The Aircraft Laboratory are to determine the feasibility of a one-piece windshield from the optical aspect.

(g) Aircraft and Material Laboratories are to pressure test stretched material canopies.

(h) The Equipment Laboratory report 53/99 Part I is an analytical study of work done on engineering design factors for laminated windshields. Part II will report on testing.

In general comment interlayers for glass are regarded as most important, but those for plastics less critical than was earlier the case. The need for new high temperature plastics was again emphasised.

3 Additional Information Obtained from Discussions Before and After the Conference

3.1 Transparent Plastics

Unmodified acrylic materials are rapidly being superseded by materials of higher softening point such as 'Plexiglas 55', 'Polymer K' and 'Gafite' (polymethyl-α-chloracrylate made by G.A.F.).

Plexiglas 55 has been used for several types of fighter canopy which are now in service - including that for the North American F.100 - and is also being used for civil aircraft windows. Plexiglas 55 is less susceptible to crazing than unmodified acrylics and the defect rate for civil aircraft windows made from this material has been much less than for the acrylic windows they have displaced.

Gafite is now being manufactured on a large scale and will undoubtedly be widely adopted. The physical properties of Gafite, and its defects, are similar to those of Resin C produced by I.C.I. before work ceased on their P.M.C.A. pilot plant. The second order transition temperature is about 135°C. Gafite can be stretched in the same way as acrylic materials and in the stretched state has similar high resistance to shatter. The whole cost of development has been borne by the manufacturers as a commercial risk and the material is said to be very expensive.

Polymer K is still being evaluated but will probably be adopted by North American at least. The notch sensitivity of this material is a big disadvantage which must be weighed very carefully against the advantage of the high softening point.

Rohm and Haas are developing a new transparent plastic which should be available in experimental quantities in 1956. They were not prepared to give any information about the physical properties of this material but said that if it were not substantially better than existing competitive materials there would be no commercial incentive to produce it. This suggests a softening point of at least 150°C.

Plexiglas 1A, II and 55 are all available as laminates with polyvinyl butyral interlayers. Polymer K and Gafite can be laminated satisfactorily and L.O.F. are considering marketing these materials in laminated form. Interest in laminated materials seems to have lessened considerably as a result of the striking progress made with biaxially stretched materials; the latter offer practically the same advantages as laminated materials for considerably less weight and design complication.

L.O.F. and Du Pont have collaborated to increase the bubbling temperature of polyvinyl butyral; as a result the Du Pont material now being used by L.O.F. can withstand one hour's heating at 300°F when laminated between plastic facing sheets. With this interlayer bubbling is no longer a serious limitation on the shaping of aircraft canopies. L.O.F. use polyvinyl butyral containing 25% of plasticiser in preference to the 37% plasticised grade normally supplied commercially. The preferred plasticiser is dibutyl sebacate. Monsanto have also improved the high temperature behaviour of their polyvinyl butyral and samples of a grade having similar properties to the Du Pont material have been submitted for approval to W.A.D.C.

A lot of effort is going into the development of biaxially stretched materials and at least two major shaping companies (Swedlow and Goodyear) can make canopies of stretched material. Stretching increases the strength of the material (one isolated test of Gafite gave an ultimate tensile strength of 42,000 lb/in^2) and the ductility; it also increases the crazing resistance. These advantages are obtained at the expense of the second order transition temperature which is reduced about 5° to 10°C by stretching and shaping in one operation and rather more by pre-stretching and 'warm-forming'. This may be a serious disadvantage for supersonic aircraft. There is a tendency to bolt stretched materials directly into metal framework and to dispense with reinforced edges. This seems a retrograde step which might well lead to unforeseen service troubles.

Very little glass laminate is now used for reinforcing canopy edge attachments. Most manufacturers use Orlon (polyacrylonitrile) laminate, but Nylon and hot-set Dacron are also used fairly extensively. This development is in line with current recommended practice in the U.K. Orlon is preferred for its excellent weathering properties and for its low yield strength when laminated which promotes good load sharing in bolted attachments.

American fabricating processes for transparent plastics are distinguished by the very great care taken to control each operation and to avoid unnecessary damage to the plastic. As a result of this Swedlow, for example, employ less than 3% of their canopy shop labour force on resurfacing and polishing. Typical precautions taken by Swedlow include draping all edges of the mould with clean mould cloth before offering up the hot sheet and before withdrawing the blank from the mould. This prevents direct contact between the mould and the visual search areas of the finished component. On removal from the mould the entire blank is masked with cheese cloth which is pressed into a freshly-sprayed coat of 'Spraylac' and then given a second sprayed coat of the same material. To prevent solvent penetration of this protective coating during subsequent cementing processes the blank is then given a sprayed coating of glycerol-plasticised glue; all masking tapes used during cementing are also impregnated with this material. Before any cementing is done additional cellophane sheaths are attached to the shaping by masking tape. These sheaths are arranged to flare out rapidly from their lines of attachment to form wide skirts which keep cement droppings well away from the masking material on the plastic surface. The floor under each cementing jig is covered with brown paper which collects all cement droppings and which is replaced by clean paper after each operation. This reduces the concentration of solvent vapour in the atmosphere and avoids the use of drip trays which may interfere with free access to the jig.

Reactive cements are used exclusively in preference to solvent cements of the 'Tensol 6' type. For acrylic components Swedlow use a solution of acrylic polymer is monomer which is catalysed by the addition of 0.1% dimethyl aniline and 1% benzoyl peroxide. This cement is mixed to an initial viscosity of 3,500 centipoises or less; this is sufficient to permit its use in convenient conical bags of transparent plastic film similar to those used by bakers for applying sugar icing. In one pint batches this cement has a pot life of 40 to 60 minutes at 70°F and it gels so rapidly on setting that no special control of pot life is necessary. The cement is entirely prepared by a member of the laboratory staff attached to the canopy shop who makes regular periodic checks to ensure that the required pot life and setting characteristics are maintained. It is essential that the monomer used for this cement is free from inhibitor; up to 1% of hydroquinone can be tolerated but the pot life then varies strongly with temperature.

3.2 Glass Transparencies

Although some thought is being given to special glasses for high temperature applications all the projects discussed, with one exception, are designed to use heat-treated commercial plate glass. The exception is the Republic F.103, the forward - and sideways-looking transparencies of which are expected to reach temperatures of 800°F (427°C) and 600°F (316°C), respectively. Both these temperatures are higher than that at which heat-treated soda - lime - silica glass begins to lose strength due to relaxation of internal stresses. Forward vision from the F.103 will be provided by a periscope looking through a small pyramidal dome of pure fused silica. Direct vision sideways, forwards and downwards, will be provided by two small domed windows of 96% silica glass beside the pilot's head. This glass is being supplied by Owens Corning and has a coefficient of thermal expansion equal to 3.2×10^{-6} per degree Centigrade.

North American are thinking of using load-bearing panels of heat-treated commercial plate glass faced with thin non load-bearing laminae of annealed low-expansion glass. In this way they hope to combine high strength with good resistance to thermal shock. The interlayer used to attach the facing laminae will need to be fairly thick and very flexible over a wide range of temperatures to minimise stresses due to differential expansion of the two types of glass and will have to be more stable than polyvinyl butyral at high temperatures.

Professor E. Orowan of the Department of Mechanical Engineering, M.I.T., has developed an optical instrument for measuring the surface stress in heat-treated glass. This instrument compares the critical angle which is found for light polarised in the plane of the glass surfaces with that for light polarized in the normal plane. The difference of these angles is a measure of the difference of the stresses in the two planes of measurement and this is equal to the stress in the plane of the surface because the stress normal to the surface is zero. The refractive indices of the glass, and therefore the critical angles, are affected by the thermal history of the glass but this effect is the same for both measurements and does not affect their difference. The instrument is self-contained, small and portable and is suitable as an inspection tool. It consists of a source of parallel polarized light, an approximately rectangular prism through which the light is directed at nearly grazing incidence to the glass surface, and a viewing telescope in which the separation of two dark areas is read directly against a calibrated graticule. This separation is a function of the difference of refractive indices and therefore of the stress in the glass surface. The prism has a refractive index slightly greater than that of the glass under examination and rests on a film of contact liquid having the same refractive index as itself. The sensitivity of the instrument can be varied by changing either the geometry of the prism or its refractive index; the accuracy of the arrangement in use at the time of the visit was said to be better than ±3% for commercial plate glass and ±1% for optically polished glass. The greater accuracy for the latter material is due to the superior surface finish. At the time of the visit the instrument was dismantled and was not seen in use. Professor Orowan said that some recalibration was necessary after which a full report would be published. A copy of this report will be made available to the M.O.S.

It seems likely that the Dow Corning silicone interlayer material is further advanced than the paper given by Mr. K.E. Polmanteer at the A.I.A. - W.A.D.C. conference would suggest; production of glass panels laminated with this material may well be possible within a year. The silicone is not seen as a direct replacement for polyvinyl butyral; a conventional extended-edge interlayer of the silicone material would need to have roughly twice the thickness of the corresponding p.v.b. interlayer to give the same optimum impact resistance. The silicone has obvious applications, however, as a means of attaching thin facing laminae to load-bearing panels and this would make possible the use of flush-fitting glazing bars without the undesirable complication of bevelled or rebated edges for the load-bearing panel. Its use with reinforced edges of the types suggested in R.A.E. Technical Note No. Chem.1228 is also a possibility.

The improved polyvinyl butyral interlayer mentioned in para.3.1 is not used for laminating glass. Glass is laminated at a high temperature and, although bubbling of the interlayer is prevented by the application of a high pressure, improved material which has been treated in this way has the same bubbling temperature under normal conditions as the standard material.

Some manufacturers still use appreciably lower strength factors for their laminated glass windows than those specified for British military aircraft. This leads to flight failures of the panels concerned but the design philosophy accepts this risk on the grounds that the interlayer prevents catastrophic blow-outs. The glass failure rate for one aircraft was stated to be such that units stationed overseas have had difficulty in obtaining sufficient spares.

3.3 Radomes and Plastic Structures

Most of the radomes now in production embody glass-cloth honeycomb cores but some use is still made of cores foamed in place. Radomes for equipment which is sensitive to directional errors are made from solid glass-cloth laminate; such radomes are made on accurate male tools and machined all over their outer surfaces to maintain the required thickness tolerance. Gun laying radomes at high angles of incidence have not been satisfactorily achieved, and the problem of the pointed ogive remained unsolved according to Goodyear. Only experimental double sandwiches have been made by them.

There have been flight failures of radomes both in and out of rain. Tests of the F86 have shown that, when properly applied, the neoprene coating gives protection for about one hour's flight in heavy rain; the failures in rain therefore were probably due to defective coatings. However, there is a possibility that impact of rain drops on the unsupported areas of skin over the centres of the honeycomb cells may cause local skin failures which reduce the efficiency of the neoprene coating and thus open up the way for rapid disintegration. In view of the interest now being shown in honeycomb cored radomes for British aircraft this possibility should receive further consideration. Sub-standard workmanship by a sub-contractor was thought to be the main cause of one failure which was discussed in detail, but the designing firm are reviewing their strength requirements and will probably insist on larger strength margins for future radomes. The component in question is a large chin-type radome similar to those fitted to the British V-class bombers. Several firms design for a reserve factor of 1.5 but their structural tests are often not taken beyond a reserve factor of 1.0 and some firms are satisfied if the component fails under this load. The design calculations are based on very thorough material tests over the full range of expected temperatures and adequate allowances are made for stress concentration. However, failure at 100% seems just as likely to be due to errors of strength estimation as to the use of material which is at the lower end of the strength distribution and the practice described does not seem to make sufficient allowance for the scatter of strength which is found for plastic structures.

There have been cases of water penetration into the cells of honeycomb-cored radome but this trouble has been confined to radomes having skins which were not void-free. Goodyear report that inspection for void freedom is still by visual examination and systematic tapping. They reported some experience of radomes deteriorating electrically under conditions of high humidity and temperature. In extreme cases some delamination was observed when 114 finish was used on the glass. These results paralleled those obtained at R.A.E. in the laboratory. There is some concern about the possible effects of upward thermal shock on plastic structures which contain water either absorbed in the laminate or trapped in voids or in core cells.

Opinion seems to be divided on the relative merits of continuous and batch cleaning the glass cloth prior to surface treatment. L.O.F. say that batch cleaning is the more consistent but Boeing think the opposite.

L.O.F. have a finish for glass fibres which is applicable at the roving stage. In general, however, they are not enthusiastic about the use of finishes in place of weaving size. Their experience has convinced them that contamination between the weaving and laminating stages is very difficult to avoid and that the best possible properties are not, therefore, achieved in the finished product.

L.O.F. say that Garan, V.T.S. and the Bjorksten finishes are all effectively the same thing, and differ only in the method of application. Garan is applied by an hydrolysis reaction the only by-product of which is ethyl alcohol. Both the others give acid by-products which are much more difficult to remove by washing. In Dr. Ryan's opinion there is little to choose between the V.T.S. finishes and Volan for use with epoxy, triallyl-cyanurate or phenolic resins.

The N.O.L., White Oak, Maryland are working on improved finishes for glass fibres. The basis of their latest finish (NOL 24) is said to be allyl-trichlorosilane which is reacted with resorcinol under heat in an inert atmosphere. The reaction products are dissolved in xylene at $\frac{1}{2}$% concentration for application to the glass. This finish has given flexure strengths greater than 100,000 lb/in^2 with 181 cloth. Laminates made with epoxy resins lost only 5%-10% of their dry strength after 2 hours boiling. Phenolic resin specimens have actually gained strength as a result of this treatment.

Bu.Aer. (AE-44) have a contract NOas 55-213-C "Development of High Modulus Glass Fibre for Plastics Reinforcement" with the Imperial Glass Corporation of Bellaire, Ohio. The aim of this work is a fibre having a Young's Modulus of 20 x 10^6 lb/in^2. To date a figure of 14 x 10^6 lb/in^2 has been achieved in experimental mixes.

One or two firms mentioned difficulties experienced with triallylcyanurate (TAC) and silicone laminating resins. The curing process for the former type is strongly exothermic and the temperature rise in thick sections may be sufficient to cause blistering due to evolution of volatiles or even charring of the laminate. This makes it difficult to achieve laboratory strength properties under practical conditions. High shrinkage, crazing and porosity were also mentioned. Partial control of crazing has been achieved by the use of a flexible alkyd crosslinked with TAC. At temperatures of the order of 700°F silicone laminates became thermoplastic and sagged under their own weight after a few minutes exposure.

Phenolic resins are preferred for heat resistance and were stated by Goodyear to have been used in thin-walled radomes. They do not feel that either these or the epoxy resins are electrically good enough although both find some users.

4 Discussion and Conclusions

The conference and subsequent discussions revealed relatively little that was new in material development. Cross-linked acrylics and polymethyl chloracrylate remain the principal canopy materials and are superseding the straight unmodified acrylics. Developments in the transparent polyesters were unimpressive. With one exception (see 3.2) heat treated commercial plate is the glass used for high temperature applications. Work on conductive coatings was of interest, though comparison with work in this country suggests that the proposed systems offer little potential advantage over the protected gold films when used on glass.

The interest in rubbery interlayer materials for plastics has diminished, but for glass the silicone development appears to constitute a major advance. Considerable effort has gone into the development of stretched acrylic structures which offer the same advantages as the laminated type without several of the disadvantages. The concepts of N.R.L. on crack propagation have reached a point where useful criteria of material behaviour can be applied practically, the stretched acrylics illustrated such an application.

The needs of the Air Forces in relation to optical transparencies for high speed aircraft were well stressed at the conference. The important work of N.A.M.C. on visual distortion showed the detailed consideration which is being given to some of these requirements.

For glass fibre laminates the most important development would appear to be that of glass fibre of improved stiffness. Work on glass finishes suitable for use with several types of resin was described. Honeycomb structures find, in general, preference over foam sandwiches for radomes. Difficulties with resins prepared for the best high temperature performance were briefly discussed.

REFERENCES

No.	Author	Title etc.	
1	Fyall, A.A. and Strain, R.N.C.	RAE Report No. Chem.502 (See contribution by Russell, E.W.)	(1955)
2	Church, M.G.	Inorganic Macromolecules Unpublished M.O.S. Paper, Ref. 7/Plastics/491	(1955)
3	Russell, E.W.	RAE Tech Note Chem.1247	(1955)
4	Church, M.G.	Polymethyl-α-chloracrylate Unpublished M.O.S. Paper Ref. 7/Plastics/240	(1955)
5	Holland, A.J. and Turner, W.E.S.	J. Soc. Glass Tech, 24, 46 - 57	(1949)
6	Brown F.G.J. and Ellis, J.	RAE Report No. Structures 167	(1954)
7	Murgatroyd, J.B. and Sykes, R.F.R.	Nature, 156, 176	(1945)

Attached:

Drgs. Nos. CH.2246-2259 and 2264
Negs. Nos. 123,701 - 123,705
Detachable Abstract Cards

Advance Distribution:

CA
RCA
DC(A)
DGTD(A)
PDSR(A)
PDARD
DARD
DD(RAF)A
D(RAF)B
D(RAF)F
D(RN)A
DAC
D Mat RD (Air)
AD Mat RD (Air)   Action Copy
ADR Structures
ADSR Records
AD/ARD (Research)
AD MXRD
TPA3/TIB   170
AID Harefield CINM   2
Dr. Wright Joint Services RD Committee on Plastics   30

Director RAE
DDRAE(A)
Aero Dept.
Naval Air Dept
Metallurgy Dept
ME Dept
IAM
RAE Library
RAE Bedford Library
Pats 1/RAE
Radio Dept
GW Dept
Elect Eng Dept
IAP
RRE

APPENDIX I

ATTENDANCE

at

JOINT A.I.A. - W.A.D.C. TRANSPARENT MATERIALS CONFERENCE

Engineers Club of Dayton - Dayton, Ohio

2 - 3 March 1955

1	Aircraft Industries Association 610 Shoreham Building Washington 5, D.C.	V. G. Mellquist Assistant Director Technical Service
2	American Window Glass Company 4375 Old William Penn Highway Turtle Creek, Pennsylvania	Fred W. Mowrey Chief Research Chemist
3	Balco Research Laboratories 49 Edison Place Newark, New Jersey	George A. Dalin Assistant Technical Director
4	Boeing Airplane Company Seattle Division Seattle, Washington	L. J. Workman Research Engineer
5	Boeing Airplane Company Wichita Division Wichita, Kansas	Carwin C. Smith Process Engineer
6	Bjorksten Research Laboratories 232 W. Gorham Street Madison, Wisconsin	Dr. Johan Bjorksten President
7	British Ministry of Supply London, England	Dr. M.G. Church
8	British Joint Services Mission 1800 K Street N.W. Washington, D.C.	N.K. Walker
9	Bureau of Aeronautics Department of the Navy Washington 25, D.C.	Philip M. Goodwin Head Non-Metallic Materials Section
10	Carbide & Carbon Chemistry Co. Research Department South Charleston, W. Virginia	Russell Van Cleve Research Engineer
11	Cessna Aircraft Co. Prospect Wichita, Kansas	Web W. Moore Assistant Project Engineer
12	Chance Vought Aircraft P.O. Box 5907 Dallas, Texas	Henry W. Kleindienst Supervisor, Non-Metallic Materials

13	Convair Fort Worth Division Fort Worth, Texas	Carl E. Sisler Sr. Design Engineer
14	Convair San Diego Division San Diego, California	W.R. Lee - Sr. Design Engineer E. Schiff - Test Engineer
15	Corning Glass Works Walnut Street Corning, New York	W.W. Shaver Manager Atomic Energy Department R.H. Mariner - Sales Manager Standard Production
16	Crystal Glass and Plastics Ltd. 130 Queen's Oway E. Toronto, Canada	Howard Yates Manager
17	Debell and Richardson Hazardville, Connecticut	John M. De Bell President
18	Douglas Aircraft Co. El Segundo, California	Henry Hummel Design Specialist
19	Douglas Aircraft Co. Long Beach, California	Mel Root Designer
20	Douglas Aircraft Co. Sante Monica, California	Carl Lemons - Plastics Engineer H.C. Watts - Process Engineer
21	Douglas Aircraft Co. Tulsa, Oklahoma	H.C. Watts - Process Engineer
22	Dow Corning Corporation Midland, Michigan	Keith Polmanteer - Research Physicist F.J. Campbell - Research Engineer
23	E.I. DuPont 10th Market Street Wilmington, Delaware	Charles H. Concklin - Sales Technician
24	E.I. DuPont DeNemours 13000 W. Seven Mile Road Detroit, Michigan	Robert T. Currin District Representative
25	Eastern Air Lines P.O. Box 787 Miami 48, Florida	George E. Hanff Project Engineer
26	French Air Attache Office S.N.C.A.S.O. Washington, D.C.	T. Cornillon
27	General Aniline & Film Corporation 435 Hudson Street New York, New York	Jesse Werner - Director of Commercial Development R.L. Demmerle - Commercial Development Department J.E. Harrington

28	General Aniline & Film Corporation Easton, Pennsylvania	J.W. Lang - Director of Research Dr. H.D. Anspon - Research Fellow J.M. Wilkinson - Research Manager
29	Glenn L. Martin Company Baltimore, Maryland	Herman Hollerith - Materials Engineer J.H. Flesher - Design Specialist
30	Goodyear Aircraft Corporation Akron, Ohio	R.S. Ames - Manager, Canopy and Laminates Fred W. Dover - Staff Representative R.W. Dunmire - Assistant Manager Canopies and Laminates C.R. Frownfelter - Development Engineer
31	Goodyear Aircraft Corporation 3059 Lake Road Cuyahoga Falls, Ohio	R.A. Burkley Development Engineer
32	Goodyear Aircraft Corporation 260 Cordelia Road North Canton, Ohio	Harold J. Sickafoose Canopy Engineer
33	Goodyear Aircraft Corporation Litchfield Park, Arizona	Ted Smithers Engineer
34	Goodyear Aircraft Corporation Dayton, Ohio	H.H. McIntosh - Manager Dayton Office C.E. Stark - Staff Representative
35	Grumman Aircraft Engineering Corporation Bethpage, New York	Robert M. Carbee Design Engineer
36	Kawner Company 3rd Street Plant Nile, Michigan	R.H. Horning - Assistant, General Manager and Sales Manager W.E. Murray - Chief Engineer Clayton O. Stevens - Senior Engineer Chemist Joseph Lelucas - Project Engineer
37	Kelly Air Force Base, Texas	Orlando L. Belcher Plastic Foreman
38	SAAMA Kelly Air Force Base, Texas	Don Turner - Chief UR Branch E.E. Huggins - Aircraft Fuselage and Airframe Specialist M.Z. Massey - Engineering Standards

39	Libbey-Owens-Ford-Glass Co. 1701 E. Broadway Toledo, Ohio	G.B. Watkins - Director of Research J.D. Ryan - Assistant Research Director P.T. Mattimoe - Research Department R.A. Garsir - Assistant Director Research G.M. Sollenberger - Manager Aircraft Sales David R. Grove - Engineer J.J. Hofmann - Research Department H.G. Orser - Manager Special Glass Manufacturers
40	Libbey-Owens-Ford-Glass Co, Brackenridge, Pennsylvania	D.W. Barkley - Research and Development Steve Harwig - Engineer W.H. Colbert - Pres Liberty Mirror Division J.C. Ogle, Jr., Production Manager
41	Libbey-Owens-Ford-Glass Co. 901 3rd National Buildings Dayton, Ohio	W.A. Zentis - Manager Dayton Office R.Z. Graham - Industrial Representative
42	Lockheed Aircraft Corporation Burbank, California	L.F. Bonza - Research Engineer
43	Lockheed Aircraft Corporation Marietta, Georgia	C.V. LeCraw Materials and Process Engineer
44	Luria-Cournaud Incorporated Havard Grace, Maryland	T.P. Norton - Projects Manager
45	Minnesota Mining and Manufacturing Co. 900 Fauquier Street St. Paul, Minnesota	Byron F. Murphey Physicist
46	Modern Plastics 2850 NW 40th Avenue Miami 42, Florida	George H. Light Aircraft Sales Manager
47	Monsanto Chemical Co. Monsanto Avenue Springfield, Massachusetts	J.S. Nelson - Research Department Edward Lacey - Technical Service Manager
48	McDonnell Aircraft Corporation P.O. Box 516 St. Louis, Missouri	C. Fuqua - Stress Group Supervisor I.L. Tubb - Process Engineer
49	National Bureau of Standards Washington 25, D.C.	Irvin Wolock - Organic Plastics Section G.M. Kline
50	Navy-NAS Alameda Overhaul & Repair Dept. Aero. Eng. Group Alameda, California	Gordon F. Bourne Materials Engineer

51	Naval Air Material Center Building 76, 5th Floor Philadelphia 12, Pennsylvania	Charles A. Cassola Plastics Technologist
52	Naval Research Laboratory Washington, D.C.	J.A. Kies - Physicist R.L. Kahler - Physicist H.L. Smith - Physicist
53	North American Aviation, Inc. East 5th Avenue	R.O. Baines - Supervisor Plastics J.E. McComber - Research Engineer J.L. Kaufman - Research Engineer R.E. Sanders - Research Engineer
54	North American Aviation, Inc. L.A. International Airport Los Angeles 45, California	L.B. Norwood Senior Research Engineer
55	Northrop Aircraft, Inc. Northrop Field Hawthorne, California	Blair L. Manire Process Engineer
56	Pan American Airways 36 St. Airport Miami, Florida	Berton Low Chemist
57	Phoenix Trimming Co. 2000 No. Racine Chicago, Illinois	Russell J. Neff Assistant to President
58	Pittsburgh Plate Glass Co. 1 Gateway Center	Edward Saibel A. Whittemore - Technical Representative R.G. Whittemore - Manager Production Development Department A.V. Johnson - Technical Representative L.A. Keim - Technical Representative
59	Pittsburgh Plate Glass Co. Creighton, Pennsylvania	B.J. Dennison - Assistant Director Research R.F. Raymond - Assistant Head, Chemistry Department
60	Plastic Age Co. 649 Arroyo Avenue San Fernando, California	Chet Fortin Sales Manager
61	Preston Laboratories Box 149 Butler, Pennsylvania	F.W. Preston Director
62	Republic Aviation Corporation Farmingdale, New York	D.G. Reid - Assistant Chief Research Engineer E. Voelker - Experimental

63	Rex Corporation West Acton, Massachusetts	J.J. Houriham Jr., - Division Manager G. Schewer
64	Rohm & Haas Company 5657 Wilshire Boulevard Los Angeles, California	D. Kline - Sales Engineer
65	Rohm & Haas Company 1206 Evergreen Road Morrisville, Pennsylvania	J.R. Hiltner - Research Supervisor
66	Rohm & Haas Company Bristol, Pennsylvania	W.F. Bartoe - Chief Physicist O.L. Pierson - Laboratory Head J.J. Gouza - Physicist
67	Rohm & Haas Company Philadelphia, Pennsylvania	N.G. Wedemeyer - Assistant Sales Manager J.F. Woodman - Technical Sales W.K. Stemple - Technical Sales Engineer Walter G. Lee - Sales
68	Royal Aircraft Establishment, Farnborough, Hants, England	E.W. Russell - Chemistry Department
69	Royal Aircraft Establishment, Farnborough, Hants, England	F.G.J. Brown - Structures Department
70	Safetee Glass Company 4717 Steuta Avenue Philadelphia, Pennsylvania	A.G. Worrall - Director Research M.J. Johnson - Sales
71	Scheidl Manufacturing Company Great Neck Road Copiague, L.I., New York	James E. Reidy - Engineer
72	Shawinigan Resins Corporation 644 Monsanto Avenue	A.N. MacDonald - Research Chemist
73	Sierracin Corporation 1121 Isabel Street Burbank, California	R.C. Armstrong - President D.G. Wilkings - Vice President E. DeFano - Research Director J.E. Slatky - Field Engineer
74	Standard Bent Glass Company Butler, Pennsylvania	A. H. Schottland - Manager
75	Swedlow Plastics Company 6986 Bandini Boulevard Los Angeles 22, California	J.P. Endicott - Vice President J.G. Stansbury - Technical Manager
76	Swedlow Plastics Company 394 North Meridian Road Youngstown, Ohio	Van Asmus Bunting Contracts Manager
77	U.S. Navy Aero Medical Laboratory Philadelphia, Pennsylvania	John Lazo - Physicist

78	Uniscience, Incorporation Hatboro, Pennsylvania	Dr. John H. Glaser President
79	United Air Lines Mills Field San Francisco, California	George D. Wible - Chemical Engineer

WRIGHT AIR DEVELOPMENT CENTER, Wright-Patterson AFB, Ohio

W.F. Barth	
L.J. Breidenbach	WCRTR-4
Lt. A.D. Brown, Jr.	
John R. Cannon	WCRTY-2
David M. Goddington, Lt.	WCRTR-4
Lt. James R. Collier	ARL
Joseph W. Evans	
Dr. R.N. Evans	WCRTR-2
Harold C. Glover	Aero Medical Laboratory
Leon J. Kosofsky	Aerial Reconnaissance Laboratory, WADC
Lt. R. Mandel	WCRTR-4
Harry Merkle	AMC
A.B. Nutt	WCLSJ
Stanley A. Szawlewicz	WCRTY-2
R.T. Schwartz	WCRTR
Lt. Donald Schmidt	WCRTR-4
E.J. Roselli	WCRTR-4
M.R. Whitmore	WCRT
F.J. Wilcox, Captain	WCRTR-4
Robert E. Wittman	WCRTR-4
E.D. Wright	WCRTR-4

Attendance on 3rd March 1955

1	Battelle Memorial Institute 505 King Avenue Columbus, Ohio	Earl R. Olson - Assistant Division, Chief E.H. Layer - Principal Physicist P. Schall E.H. Lougher - Principal Chemist W.A. Hedden - Ceramist
2	Corning Glass Works Corning, New York	George H. Southworth Product Engineer
3	National Bureau of Standards Washington, D.C.	C.H. Hahner Chief, Glass Section
4	William Lawry Company Seven Smith Street Merrich, New York	William Lawry
5	Swedlow Plastics Company 394 North Meridian Youngstown, Ohio	William W. Chapman Contracts Representative

Wright Air Development Center:

1	R.L. Clodfelter	WCLEM
2	Major Alvis J. Sheard	
3	W.R. Koch	WCR
4	Major R.T. Flanagan	WCR
5	Arthur E. Morse	
6	John Grammer	WCLS
7	Lt. Col. Richard L. Midkiff	WCSF

APPENDIX II

AGENDA

JOINT AIA-WADC CONFERENCE

TRANSPARENT MATERIALS FOR AIRCRAFT ENCLOSURES

2 - 3 MARCH 1955

ENGINEERS CLUB, DAYTON, OHIO

CHAIRMAN - COLONEL JOHN V. HEARN, JR.

2 March 1955 Morning Session

Discussion Leader - Mr. Carl Lemons, Douglas Aircraft, Santa Monica.

0900 Opening Remarks - Mr. V.G. Mellquist, AIA

Introduction - Colonel John V. Hearn, Jr., Chief, Materials Laboratory, WADC

0915 Orientation - Captain F.J. Wilcox, Materials Laboratory, WADC

0930 Progress in the Development of High Temperature Interlayer Material. Mr. K. E. Polmanteer, Dow-Corning Corporation

1015 Break

1030 Progress in the Development of Polymethyl Alpha Chloroacrylate. Dr. J.M. Wilkinson, Jr., General Aniline and Film Corporation

1115 Discussion of Methods of Determining High Temperature Properties of Plastics. Mr. W.F. Bartoe, Rohm and Haas Company

1135 Lunch

Note: 1. All material to be discussed is unclassified.

2. Discussion leaders will allow questions from the floor following each presentation as time allows.

2 March 1955 Afternoon Session

Discussion Leader - Mr. L.J. Breidenbach, Materials Laboratory, WADC

1300 Progress in the Development of stretched Transparent Plastic Material

1. Dr. O.L. Pierson, Rohm and Haas Company
2. 2 Mr. R.S. Ames, Goodyear Aircraft Corporation
   Mr. C.R. Frownfelter, " "
3. Mr. C.H. Fortin, Plastic Age Corporation
4. Mr. J.G. Stansbury, Swedlow Plastic Company

1415 Discussion of above presentation

1445 Break

1500 Toughness Testing of Hot Stretched Acrylics
Mr. J.A. Kies, Naval Research Laboratory

1530 The suitability of Polymer K for Manolithic Enclosures,
Mr. L.B. Norwood, North American Aviation

1600 Improvements in Sierracin 611 Polyester Material, Mr. D.G. Wilkins,
Dr. E. Da Fano, Sierracin Corporation

1630 Polarized Light Analysis of Annealed Plastic Parts, Mr. B.L. Manire
Northrop Aircraft

1700 Adjournment

3 March 1955 Morning Session

Discussion Leader Dr. J.D. Ryan, Libbey-Owens-Ford Glass Company

0900 The Assessment of Visual Distortion Through Aircraft Transparencies
Mr. John Lazo, Naval Air Material Center

0945 Problems Encountered in Transparent Areas of Jet Fighter Aircraft
Lt. Colonel Midkiff, WCSF, Wright Air Development Center

1015 Break

1030 The Properties of Glass for Aircraft Applications
Mr. F.G.J. Brown, Royal Aircraft Establishment

1100 Some Observations on the Mechanical Properties of Glass, Dr. Edward
Saibel, Carnegie Institute of Technology

1130 Lunch

3 March 1955 Afternoon Session

Discussion Leader - Captain F.J. Wilcox, Materials Laboratory, WADC
Reported in WADCTR 53 - 378

1300 Progress in the Low - Temperature Preparation of Electrical Conductive
Transparent Coatings, Dr. G.A. Dalin, Balco Research Laboratories

1330 Progress in the Development of Transparent, Electrically Conducting
Film of Indium Oxide. Dr. E.H. Lougher, Battelle Memorial Institute

1400 Improved Optics in Thermal Shock Resisting Glass Panels,
Mr. R.G. Whittemore, Pittsburgh Plate Glass Company

1430 Review of Materials Laboratory Programs, Capt. F.J. Wilcox
Materials Laboratory, WADC

1500 Break

1515 Open Discussion

1700 Adjournment

Note: 1. All material to be discussed is unclassified

2. Discussion leaders will allow questions from the floor as time will allow.

Report No. Chem. 504
Structures 194

APPENDIX III

EFFECTS OF STRETCHING ACRYLIC PLASTICS

by

O. L. Pierson

The Rohm and Haas Company, Philadelphia, Pennsylvania

The effects of stretching acrylic plastics have been investigated under WADC Contract AF 33(616)-489. Both biaxial and multiaxial methods of stretching, defined at the Fifth Transparent Materials Conference, were employed for this investigation. As illustrated in Fig.2, these have equal stretch in all directions for multiaxial, and either equal or unequal stretch in two directions for the biaxial method of stretching.

The properties of biaxially-stretched material were equal or superior to multiaxially-stretched material. Since biaxial stretching has greater freedom of selection of stretching conditions and the process can be more accurately controlled, it is recommended that it be used in future investigation.

Stretched acrylic plastic materials are considerably better than unstretched materials in resistance to crazing, impact strength, and notch sensitivity properties. They are equivalent to unstretched materials in optical properties and dimensional stability. They are inferior to unstretched materials in abrasion resistance.

Three types of stretched acrylic materials were investigated under this contract; viz.,

MIL-P-5425A, stretched at 120°C (248°F)
MIL-P-6886A, stretched at 135°C (275°F)
MIL-P-8184, stretched at 135°C (275°F)

The rate of biaxial stretching used for this contract was the maximum $2\frac{1}{2}$ in. per minute attainable for the size sheet. The time required to stretch to the full 22 in. x 22 in. biaxially stretched sheet was 3 to 6 minutes from the start of the machine crosshead motion.

The stretched MIL-P-8184 material had the best combination of properties in comparison with the MIL-P-6886A and MIL-P-5425A materials. Biaxially stretched MIL-P-8184 material with 100% stretch Direction A, and less than 100% stretch Direction B, appeared to have some advantages over biaxially stretched material with equal stretch in both directions, when tested with the long axis of the test specimen parallel to Direction A; and, therefore, subjected to stress in that direction. The Izod (unnotched) impact strength of the unaged MIL-P-6886A material, stretched 100% Direction A, 50% Direction B, was 15.5 ft lb per in. width, as compared to 8.5 ft lb per in. width for equal stretch (100%) Direction A and Direction B. Any advantage to be gained from unequal stretch in two directions would depend upon orientation for applied stress in the direction of greatest stretch. For practical reasons, it may be more desirable to stretch the material equally in two directions.

The effects of ageing, either outdoors or indoors at 23°C (73°F) and at 50°C (122°F), on the physical properties of stretched materials were investigated under this contract. The relative improvements in the properties of stretched materials were maintained to a large degree after six months ageing under any of these conditions. The change in properties with ageing of the stretched materials, especially the more craze-resistant MIL-P-8184 material, was generally less than for unstretched material. Of the three ageing conditions, outdoor ageing had the greatest effect upon property changes. All stretched materials were much less resistant to stress-solvent crazing after outdoor ageing. However, the crazing resistance of outdoor aged, stretched materials was considerably better than unstretched materials, either aged or unaged.

The stretched MIL-P-8184 material showed the least change in properties of any material after six months outdoor ageing. Impact strength was affected less than crazing resistance by various conditions of ageing for all three materials. The data show higher impact strength for higher percent stretch in all outdoor aged materials, and no great difference in impact strength between any of the outdoor aged materials stretched the same amount. Six months ageing produced little change in the notch sensitivity of the stretched acrylic plastic materials. Notch sensitivity was improved by stretching, and high percent stretch resulted in better retention of flexural strength after ageing biaxially stretched material. All stretched materials showed satisfactory dimensional stability after six months ageing under the three conditions. Thermal relaxation properties were affected by the heat-resistant qualities of the three materials and by the percent stretch in the direction of measurement. The temperatures at which the materials started to thermally relax were as follows:

MIL-P-6886A	70°C (158°F)
MIL-P-5425A	90-100°C (194-212°F)
MIL-P-8184	100-110°C (212-230°F)

The contract covered the investigation of properties of acrylic plastic stretched under single conditions of stretching for both biaxially and multiaxially stretched materials. The stretching conditions were based on previous experience and were arbitrarily selected to give the best results based on limited information. It is now proposed that these investigations be expended to study the effects of some of the variables in the stretching procedure on the properties of stretched acrylic plastic.

Preliminary to possible investigation of the stretching variables, we have some data on MIL-P-5425A material that may be of interest in connection with a future programme suggested by WADC. The material was biaxially stretched at different temperatures and at two rates of stretching; viz., 5/8 in. per minute and 2½ in. per minute. The stretched material was evaluated by means of Izod (unnotched) impact strength, stress-solvent crazing resistance and for crack propogation properties in accordance with the procedure given in Naval Research Laboratory Memorandum Report No. 372. The MIL-P-5425A material was biaxially stretched 40, 73, and 100% in 0.2 in. final thickness.

Within the limits of the rates of stretching that were used, the properties of the stretched MIL-P-5425A material did not appear to be affected significantly in any of these tests. This confirmed earlier observations for similar rates of stretching which showed little effect on the properties as the result of variation in stretching speed. Stretching rates higher than 2½ in. per minute have not yet been investigated.

Stretching temperatures of 120°C (248°F), 135°C (275°F), and 150°C (302°F) were used for this investigation. Data on the effects of stretching temperature upon the properties of stretched acrylic plastic are incomplete and only partial data on MIL-P-5425A material are available to present at this time. The data on MIL-P-5425A material show definite trends in variations in the specific properties with temperature, but these trends are not always in the direction of improvement with increase in temperature. It may, therefore, be necessary to choose a stretching temperature, different for each material, that will produce the best combination of desired properties in the stretched material. The results of the evaluation of the MIL-P-5425A stretched material are as follows:

Effects of Stretching Temperature on Resistance to Crack Propogation

The method developed at the Naval Research Laboratory, under the sponsorship of the Bureau of Aeronautics, for evaluation of the shatter resistance of stretched acrylics, measures the work, "W" or dW/dA expressed as inch pounds per square inch, consumed per unit area of fracture, including both surfaces, at the point of instability of fracture. The effect of stretching temperature on the dW/dA values is shown in Fig.3.

These data on flat test specimens show maximum dW/dA values at less than 100% stretch, and the maximum occurs at higher degrees of stretch with increase in temperature. There is a slight increase in dW/dA maximum value with increase in temperature. The effect of holding the material at warm forming temperature for 110 minutes is also shown in Fig.3. This resulted in more uniform dW/dA values with increase in percent stretch, and higher values for material stretched 100% at the lower stretching temperatures.

Effect of Stretching Temperature on Izod (unnotched) Impact Strength

Izod (unnotched) impact strength increases with increase in percent stretch. This does not appear to be significantly affected by stretching temperature within the range investigated; viz., 120°C (248°F) to 150°C (302°F). There is considerable scatter in the test results at high degrees of stretch as shown in Fig.4. Tests were conducted on 0.2 in. thick by 0.5 in. width specimens mounted flatwise.

Effect of Stretching Temperature on Stress-Solvent Crazing Resistance

Stress-solvent crazing resistance of the stretched MIL-P-5425A material increases with increase in percent stretch. The effect of the stretching temperature on the stress-solvent crazing resistance with isopropyl alcohol is shown in Fig.3. There is some reduction in the stress-solvent crazing resistance with increase in stretching temperature, but the difference is not great for the range of temperatures that was used.

Report No. Chem. 504
Structures 194

APPENDIX IV

The Properties of Glass for Aircraft Applications

by

F. G. J. Brown
Structures Department, Royal Aircraft Establishment

The object of the work I want to describe to you was to find ways of increasing the allowable working stress for the glass used in British aircraft. For tempered glass this stress is at present about 4,500 lb/in^2; it is not specified explicitly in our design requirements but is implicit in a test factor of 3.0 on aircraft ultimate loads which must be demonstrated by destructive tests of typical panels. The original aim of the work was to save weight. In the meantime, however, studies of the transparency problem for aircraft flying at high supersonic speeds have shown that it may be impossible to satisfy our present requirements with glass of the quality now used, and this has increased the importance of the results we have obtained.

In the course of this talk I shall show you some curves based on these results. These curves and the conclusions I shall draw from them apply to British tempered glasses and they may not apply with equal force to the materials used in the United States. However, the methods themselves are quite general and I hope that they will be of value to you.

The peculiar difficulty presented by the supersonic aircraft is illustrated by Figure 15 which shows the peak stress in the windshield of a hypothetical aircraft during deceleration from Mach 2.5 to subsonic speed in approximately 1 minute. The stress is plotted as a function of glass thickness and, for ordinary soda-lime glass, has a minimum value somewhat greater than the allowable working stress for the material. The particular case illustrated is a marginal one and an 11% increase of allowable stress would make it possible to use ordinary tempered soda-lime glass, but the required improvement increases with increase of either speed or deceleration.

The windshield could be made of pure fuzed silica as shown by the lower curve in Figure 15, but this material is comparatively weak, and the minimum thickness necessary to withstand the maximum pressure load in the case under discussion is about 1 in. as compared with less than ½ in. which would be satisfactory in soda-lime glass. Evidently development of the more familiar material would pay a large weight dividend and we are convinced that this is possible.

In tempered glass we have a material which owes its apparent strength partly to residual compressive stresses which must be overcome before tension can develop in its surfaces and partly to the true intrinsic strength of the glass. Both the residual compressive stress and the intrinsic strength vary from one specimen to another; and the intrinsic strength also depends upon the rate of loading. The statistical distribution of apparent strength for tempered glass can be found quite simply by bursting tests of typical panels under any chosen rate of loading. To determine the distribution of sustained loading strength, however, is a difficult experimental problem and generalization of the results is practically impossible without accurate measurements of the residual compressive stress in the surfaces of each specimen. For these reasons we chose a theoretical approach using the sustained loading data for annealed sheet glass reported by Holland and Turner in the Journal of the Society of Glass Technology for 1944[5]. These covered tests of some 1,200 specimens, 400 of them under uniformly increasing load and the remainder under sustained loads ranging from 30% to 100% of the average breaking load for the first 400.

It was first necessary to put these data into a form suitable for handling by statistical methods, and we did this by expressing the applied load as a fraction of the strength which the strongest specimen broken in a given time interval would have shown if it had been broken under rapid uniformly increasing loading. This rapid loading strength, which we called the 'initial strength' of the specimen, can only be found statistically because we can only break each specimen once. Fortunately Holland and Turners' control specimens provided the necessary information about the population from which the sustained loading specimens were drawn.

The results of this analysis are shown in Fig.16. The figure printed beside each point gives the fraction of the average breaking load for the control specimens which produced the corresponding failure. The radius of the circle surrounding each point shows the reliability of the estimate and the probability that the point should lie above or below the circle is less than 1 in 20.

The curves drawn through the points for each loading level define the maximum ratio which the applied load can bear to the initial strengths of particular specimens if these specimens are to have a chosen minimum endurance. Intuitively we expected all the points to group about a single curve but as you can see the points for each loading level fall on a separate curve. These curves show that weak specimens fail earlier than strong specimens even when all are loaded to the same proportion of their initial strengths which suggests that even shorter endurances would be found for specimens which initially are very weak. To check this we estimated the position of one point on the endurance curve for specimens loaded to 30% of the average breaking load for the control specimens. In fact, there were no failures in 1,000 hours under these conditions in Holland and Turner's experiments and the estimate rests on the conservative assumption that the weakest specimen was at the point of failure when the experiment ended. This point is shown in Fig.16 and lies very close to the 40% curve. From this we concluded that the 30% curve, if it exists at all, must be practically an extrapolation of the 40% curve in the direction of increasing endurance, and that the tangent curve to the probable error circles shown in this illustration can be used safely to predict minimum endurances at least up to 1,000 hours. Moreover, the flatness of this tangent curve for long endurances suggests strongly that we are unlikely to introduce big errors by extrapolating it to endurances more than 1,000 hours. We can therefore express the maximum allowable stress for a particular specimen of annealed glass in the form

$$f_m = K f_i \qquad (1)$$

where K is a coefficient depending upon the endurance required and f_i is the initial strength of the specimen. The corresponding equation for tempered glass is

$$f_m = f_c + K f_i \qquad (2)$$

this is obtained from equation (1) by adding a term f_c representing the residual compressive stress in the surfaces of the glass. Since f_c is difficult to measure accurately it is convenient to express it as the difference of the intrinsic and apparent strengths whose distributions can be found experimentally. With this substitution the maximum allowable stress for tempered glass can be written

$$f_m = f_a - (1 - K) f_i \qquad (3)$$

where f_a is the apparent strength of the tempered glass.

Due to random variations of thickness the stress induced by identical loads in otherwise identical specimens will vary from one specimen to another. The wider the variation of thickness the lower will be the safe design stress; and better control of thickness is a possible way of increasing allowable stresses. To a first approximation the applied stress will vary as $(\overline{T}/t)^2$ where $\overline{T}$ is the nominal thickness and t is the actual thickness of the glass. However, it is much more convenient to consider the applied stress constant and to use a fictitious maximum allowable stress defined by

$$\begin{aligned} f'_m &= f_m (t/\overline{T})^2 \\ &= (f_a - (1-K) f_i)(t/\overline{T})^2 \qquad (4) \end{aligned}$$

Starting from equation (4) we can find the distribution of the fictitious maximum allowable stress in terms of K and the mean values and coefficients of variation of the other variables. Knowing this we can estimate the strengths of specimens of any chosen probability, and by giving any one of the parameters a range of values we can examine its effect on the allowable working strength of the glass at any probability level. The statistical method is fully described in Ref.6 and I shall only give typical results.

The stresses found in this way are associated with a definite risk of failure and would normally be used with a factor of safety. In choosing this factor we can put the sustained loading effect to good use because some experiments reported by Murgatroyd and Sykes[7] in Nature for 1945 showed that the strength which glass exhibits under rapidly applied loading is not measurably changed when the material is first subjected to a sustained load just too small to cause failure. Every specimen which does not break under the applied stress, therefore, has an inherent safety factor equal to the quotient of its initial strength by its sustained loading strength. It follows that all such specimens will have safety factors at least equal to the design safety factor if the allowable working stress is reduced in the ratio which the inherent factor bears to the design factor.

Figs.17 and 18 show curves obtained in this way for a tempered glass having an average apparent strength of 25,000 lb/in^2. The approximate stress permitted by the current British strength requirements is shown in both illustrations for comparison. The design safety factor assumed is 1.5 in both cases. Fig.17 compares the effects of random thickness variations with those of random variations of apparent strength. The range given to each parameter is one we think likely to occur in normal production. The variation of apparent strength has much the stronger effect on the permissible stress for the material; the benefits of close control of thickness would be relatively small but still worth having, particularly for thin glasses for which the proportional variation of thickness is greatest.

The opinion we have arrived at by analysis of some 400 tests of tempered glass panels is that major variations of apparent strength are largely due to failure to reproduce exactly the heating and cooling conditions for batches of the same article processed in different runs through the furnace. We have found broad agreement with this opinion in discussion with representatives of our glass industry. The best hope of achieving the large increase of allowable strength which this slide shows is possible, therefore, lies in improving control over the tempering process. Our discussions with the glass industry have revealed several promising lines of attack on this problem and we are on the point of placing contracts for further study of these.

Fig.18 compares the effects of the same random variations of apparent strength with those of the sustained loading coefficient K. The variation of apparent strength again has by far the stronger effect on the permissible stress. In round figures the values given to K correspond with endurances of 10 seconds, 10 minutes and 10,000 hours. Alternatively we can think of these curves as illustrating the advantages of glasses which are chemically more stable than the soda-lime-silicates and therefore less susceptible to sustained loading effects.

I have tried to show that, so far as static strength and thermal shock resistance are concerned there is a lot of stretch left in tempered soda-lime glasses. Practically their only serious shortcoming is a tendency to lose temper at temperatures around 550°F. I mentioned at the beginning of this talk that there may be serious weight penalties for the use of low expansion glasses which by their very nature are likely to be weak materials. Moreover, unknown stresses such as those due to assembly are relatively more important for weak materials than for strong ones and the increased thickness associated with use of low expansion glasses may increase the magnitude of these stresses. This suggests that a glass having physical properties broadly similar to those of the soda-lime glasses, but a higher softening point, might have a very useful future for aircraft operating at very high boundary layer temperatures and we consider this well worth further investigation.

In conclusion I would like to say how very much Mr. E.W. Russell, Dr. M. G. Church and I appreciate the honour you have done us by inviting us to attend this conference and present this paper. I must also acknowledge my indebtedness to the Chief Scientist of the British Ministry of Supply for permission to present it and to the Controller of Her Brittanic Majesty's Stationery Office for permission to use the Crown copyright illustrations. I would also like to acknowledge the help received from colleagues, and particularly from my co-author John Ellis, in preparation of the R.A.E. Report on which this paper is based.

FIG.1.

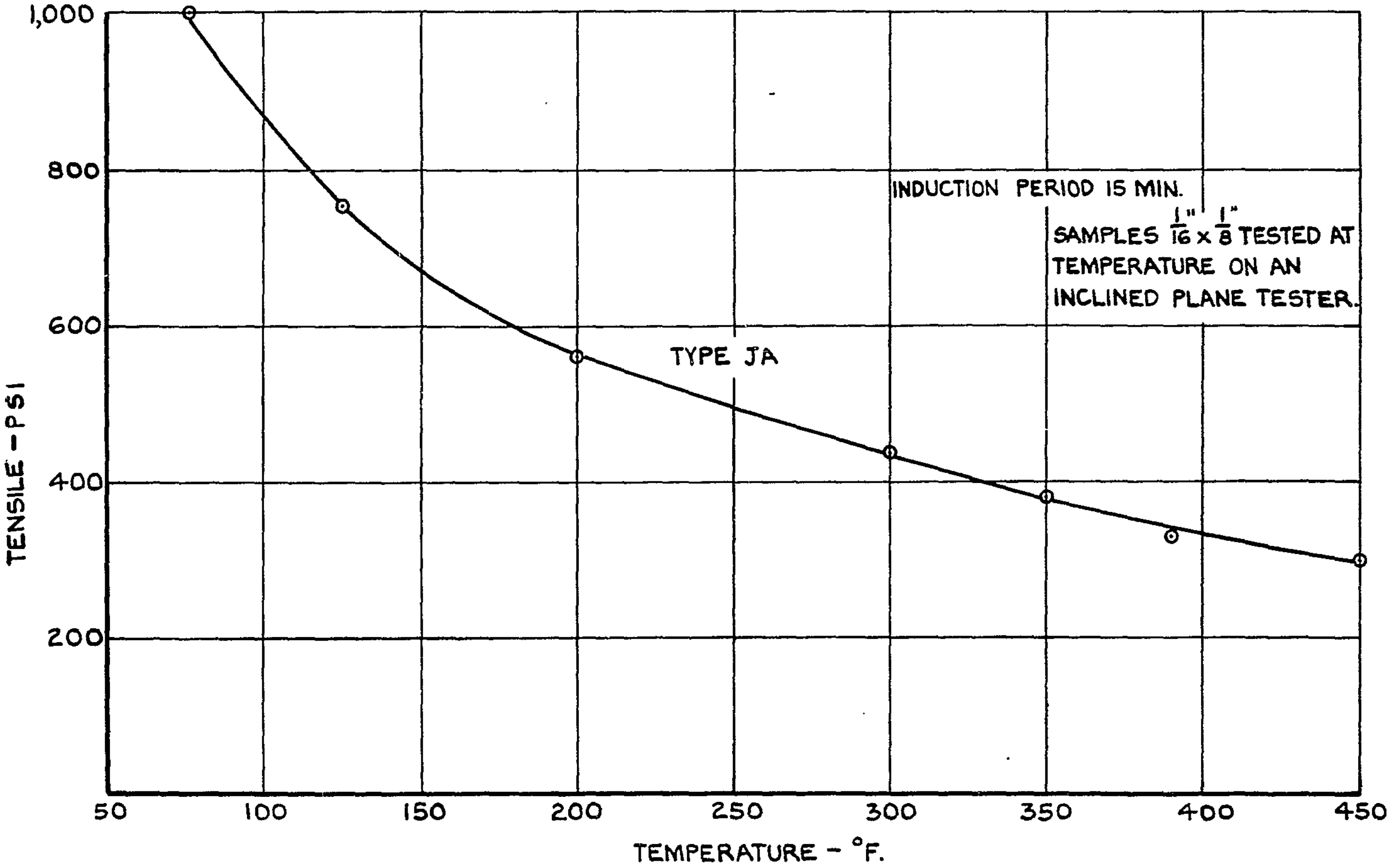
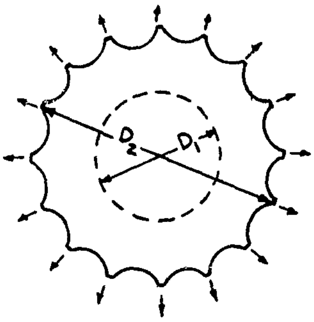


FIG.1. TENSILE STRENGTH OF TYPE JA MATERIAL AT VARIOUS TEMPERATURES.

2247.

FIG. 2.

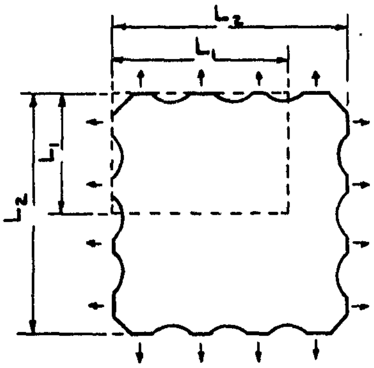


MULTIAXIAL

% STRETCH = $100\ (T_o/T_F - 1)$

T_o = ORIGINAL THICKNESS OF SHEET

T_F = FINAL THICKNESS OF SHEET



BIAXIAL

% STRETCH = $100\ (L_2/L_1 - 1)$

L_1 = ORIGINAL LENGTH OF SHEET

L_2 = FINAL LENGTH OF SHEET

FIG. 2. BIAXIAL AND MULTIAXIAL STRETCHING.

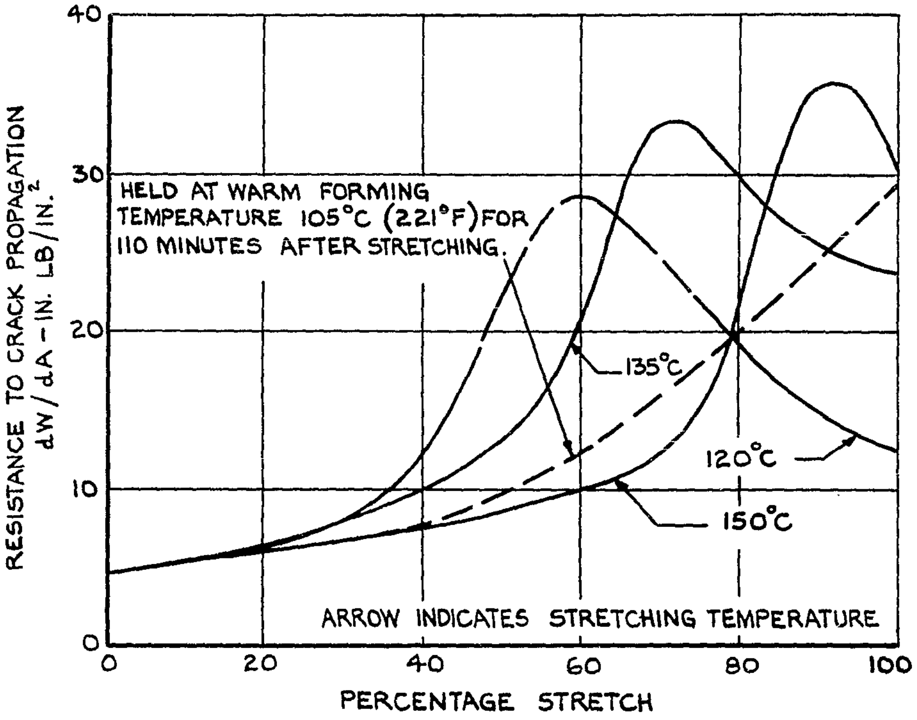


FIG.3. EFFECT OF STRETCHING TEMPERATURE ON RESISTANCE TO CRACK PROPAGATION.

FIG.4.

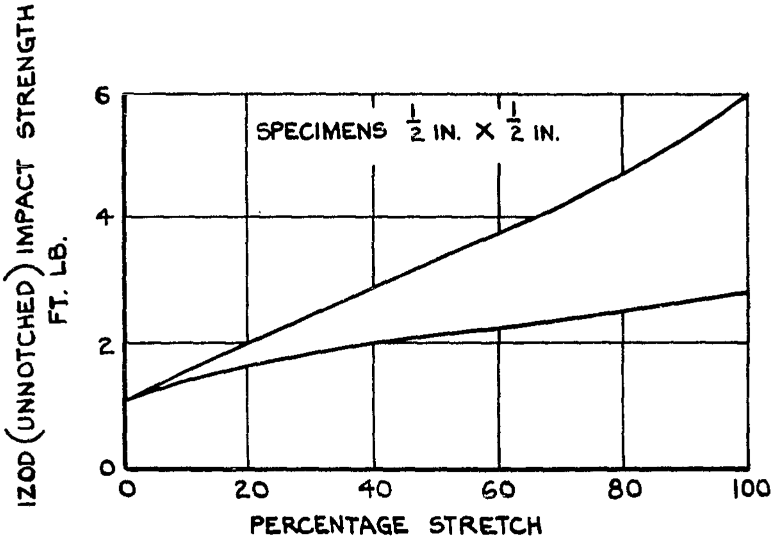


FIG.4. EFFECT OF STRETCHING TEMPERATURE ON IZOD (UNNOTCHED) IMPACT STRENGTH.

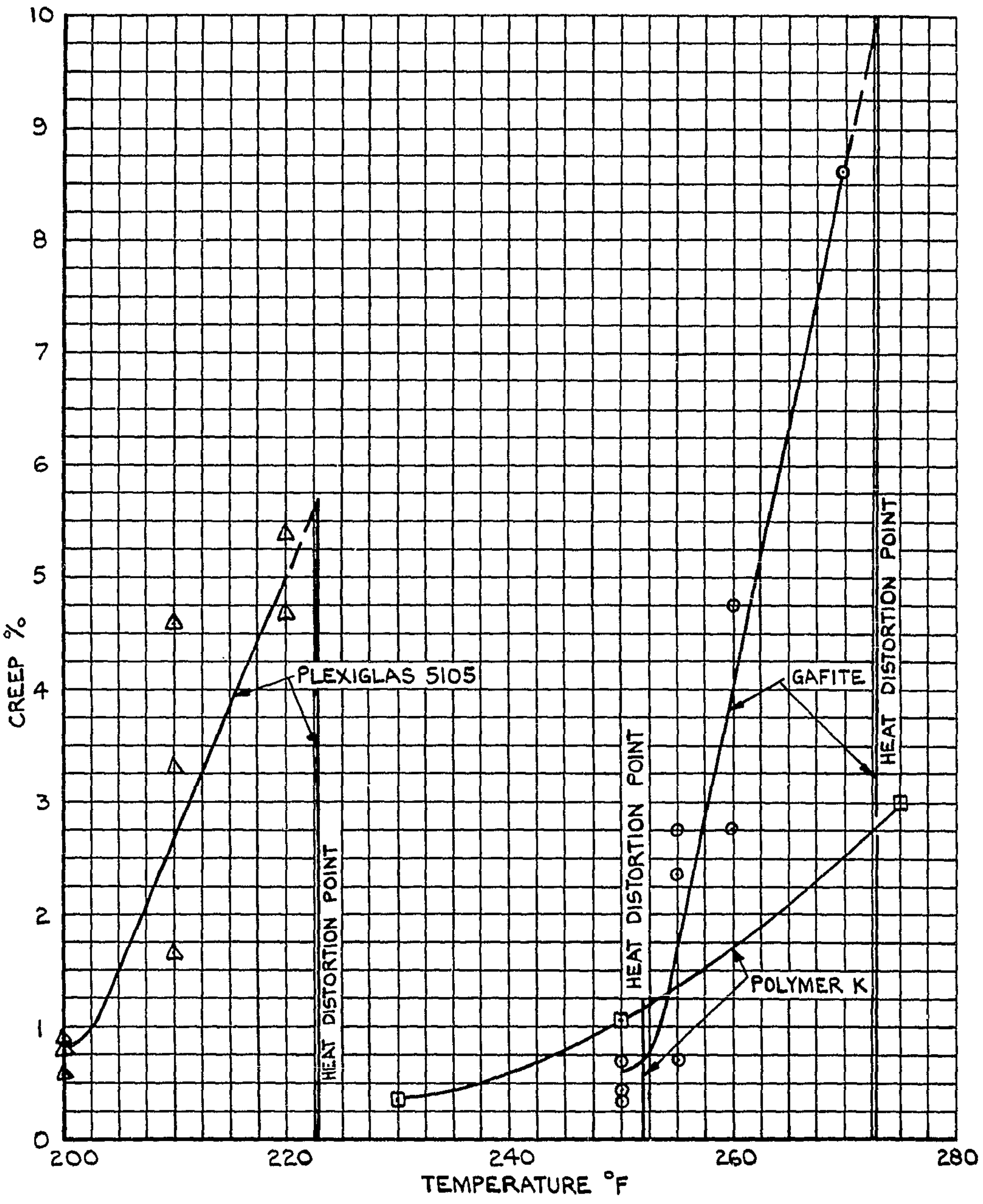


FIG.5. CYCLIC TENSILE CREEP VS. HEAT DISTORTION POINT OF POLYMER K, PLEXIGLAS 5105 & GAFITE.

FIG. 6.

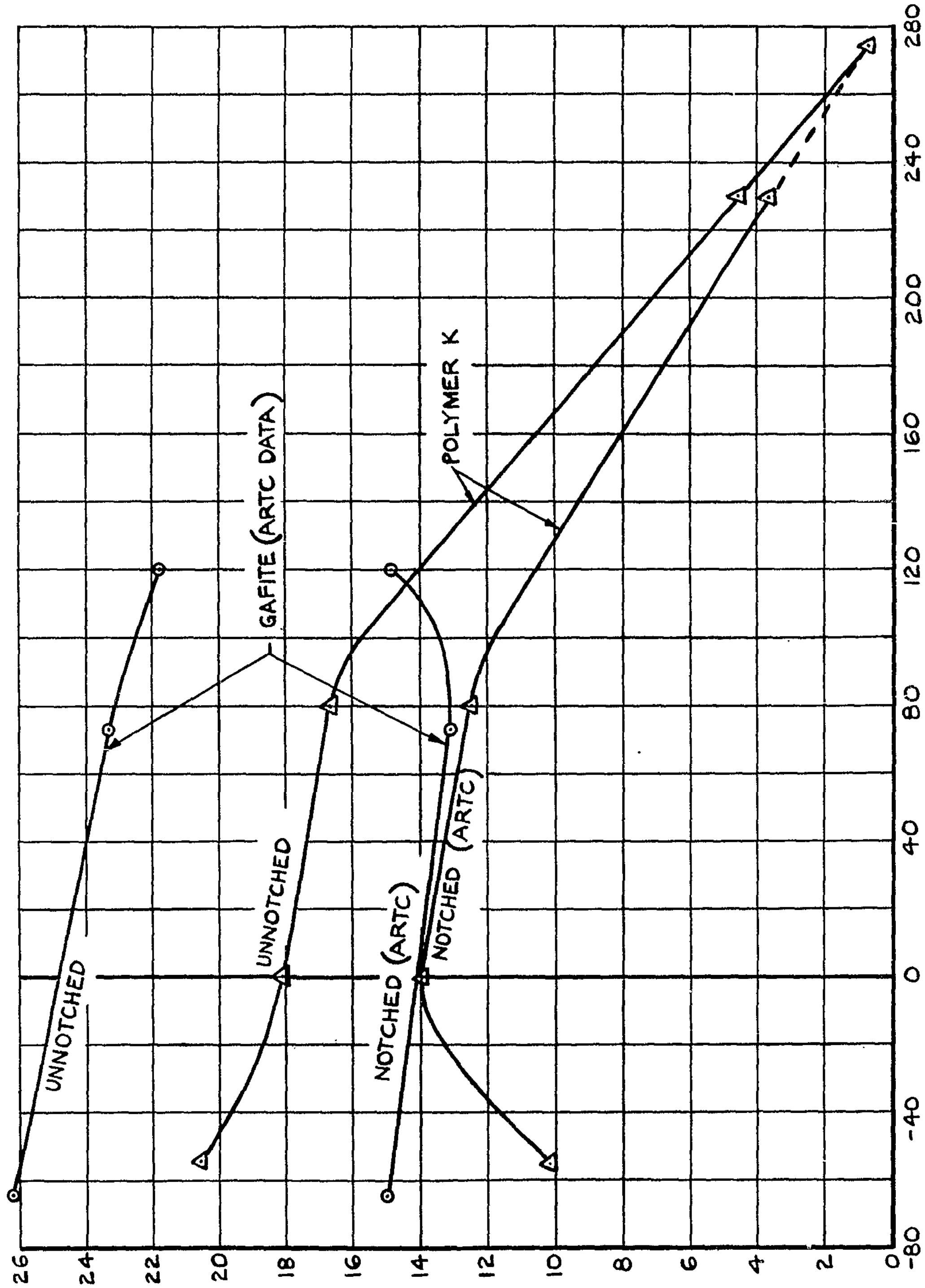


FIG. 6. FLEXURAL STRENGTHS VS. TEMPERATURE OF POLYMER K & GAFITE.

FIG.7.

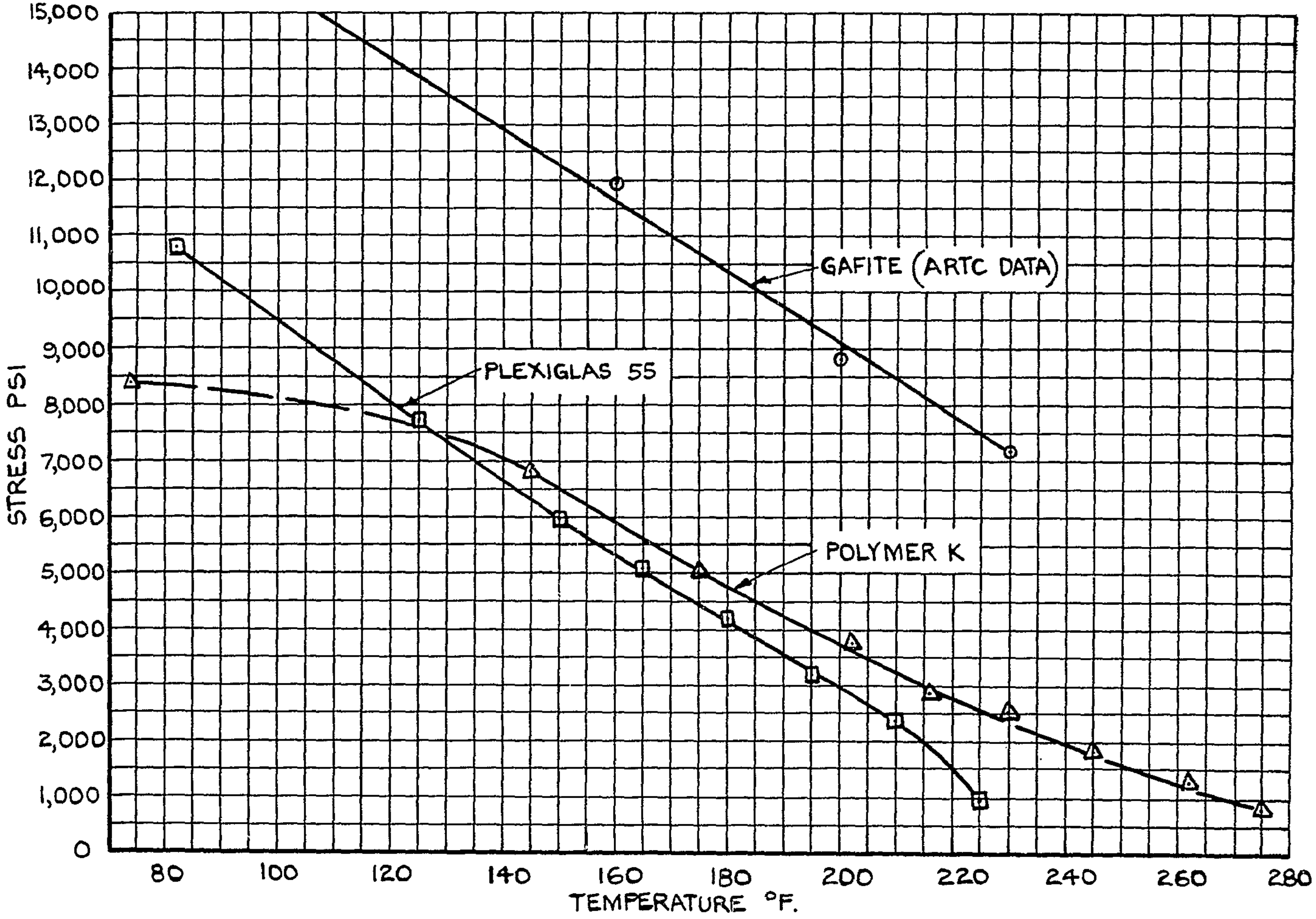


FIG. 7. TENSILE STRENGTH OF POLYMER K VS. PLEXIGLAS 55 & GAFITE – AT ELEVATED TEMPERATURES.

2253.

FIG.8.

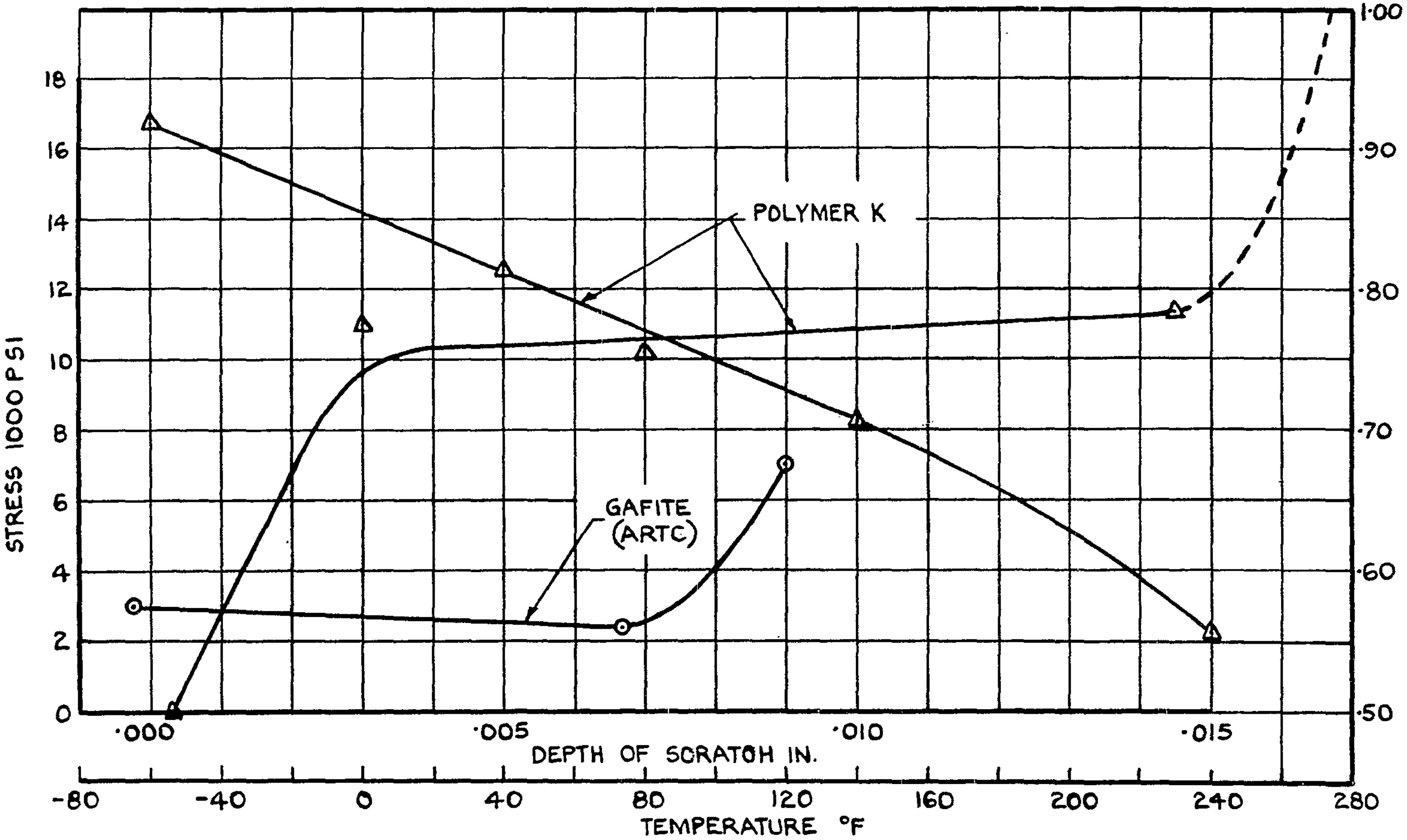


FIG.8. NOTCH EFFECTS ON FLEXURAL STRENGTH OF POLYMER K & GAFITE.

FIG 9.

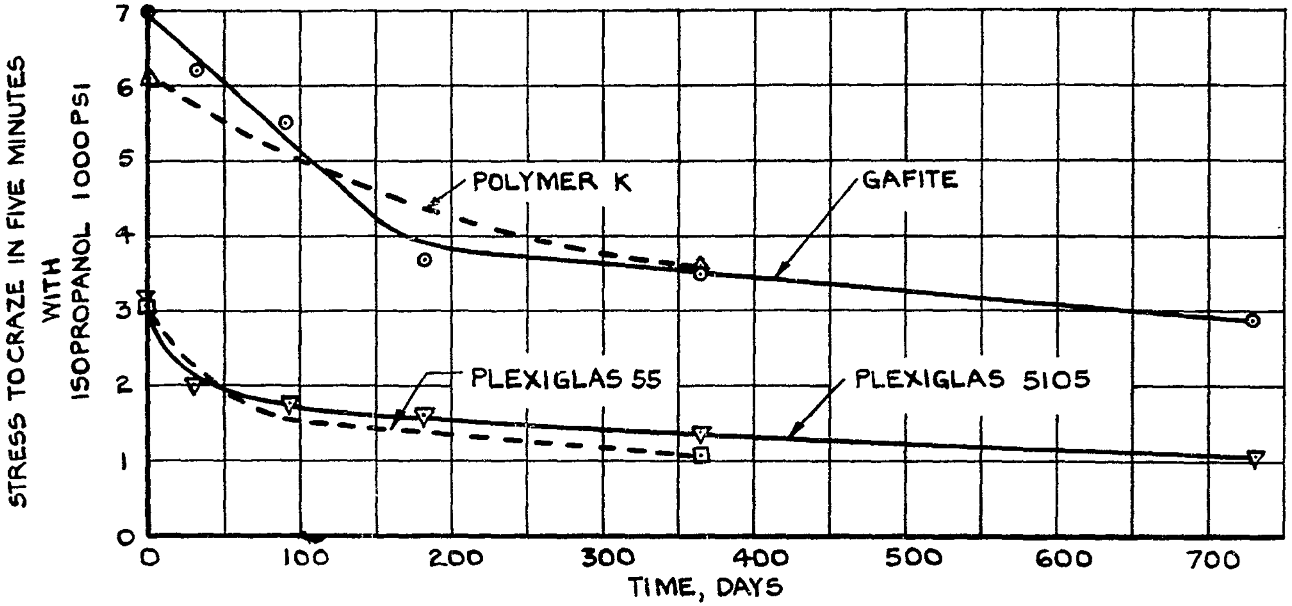


FIG.9. STRESS TO CRAZE VS. OUTSIDE WEATHERING OF POLYMER K, PLEXIGLAS 55 & GAFITE.

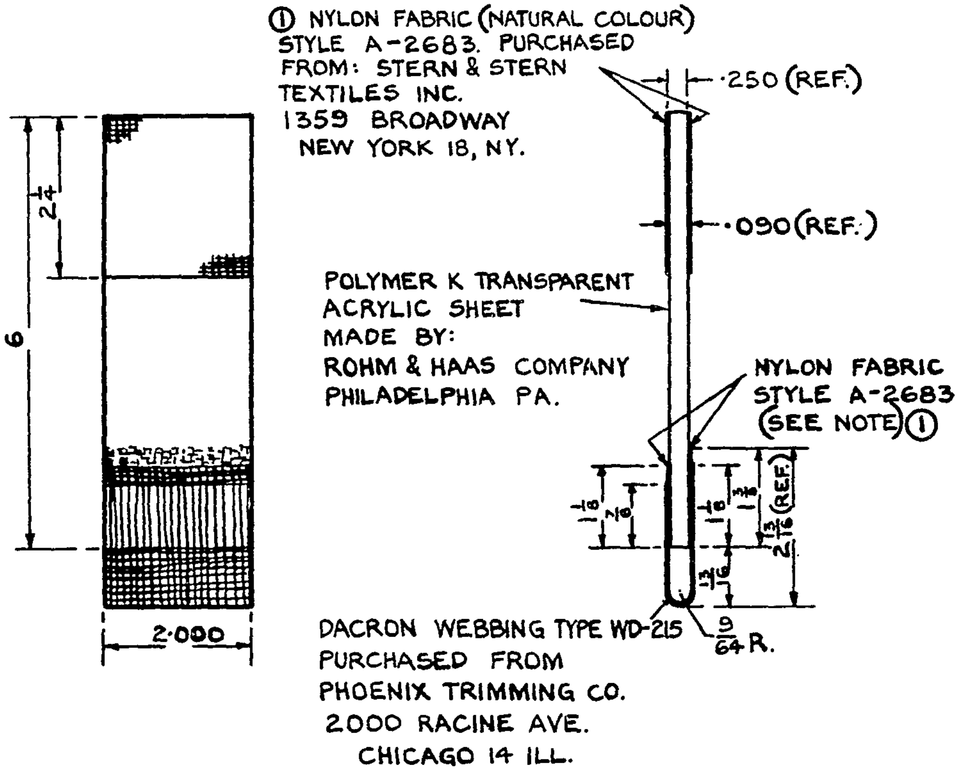


FIG. 10. NORTH AMERICAN AVIATION INC. TYPE I EDGE ATTACHMENT SPECIMEN.

FIG. 11.

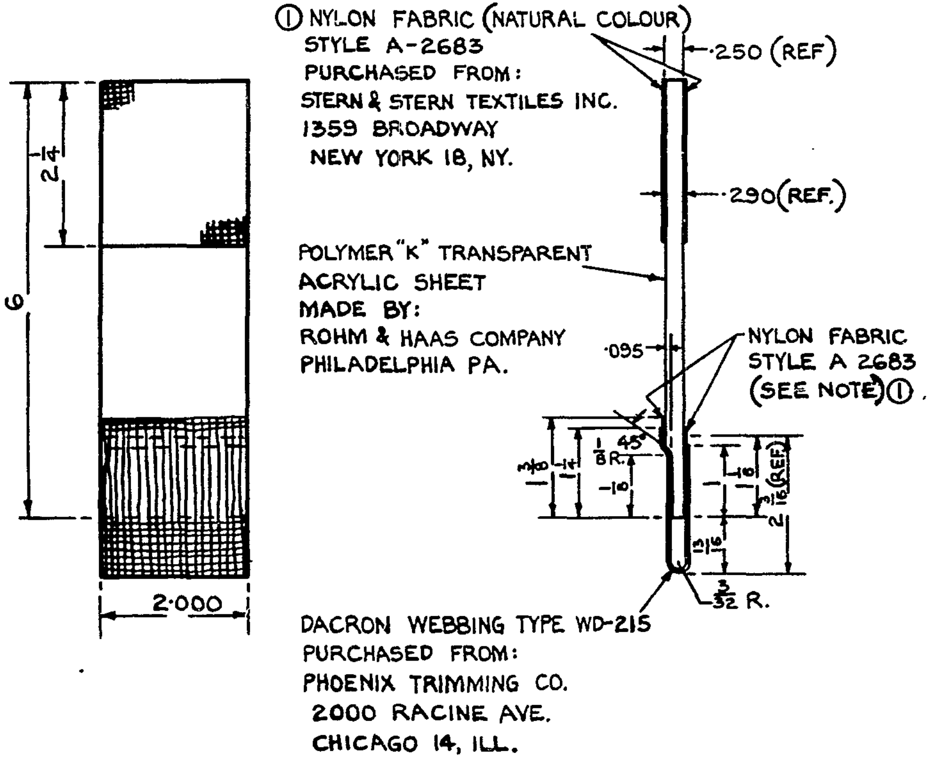


FIG. 11. NORTH AMERICAN AVIATION INC. TYPE II EDGE ATTACHMENT SPECIMEN WITH ROUTED OFFSET.

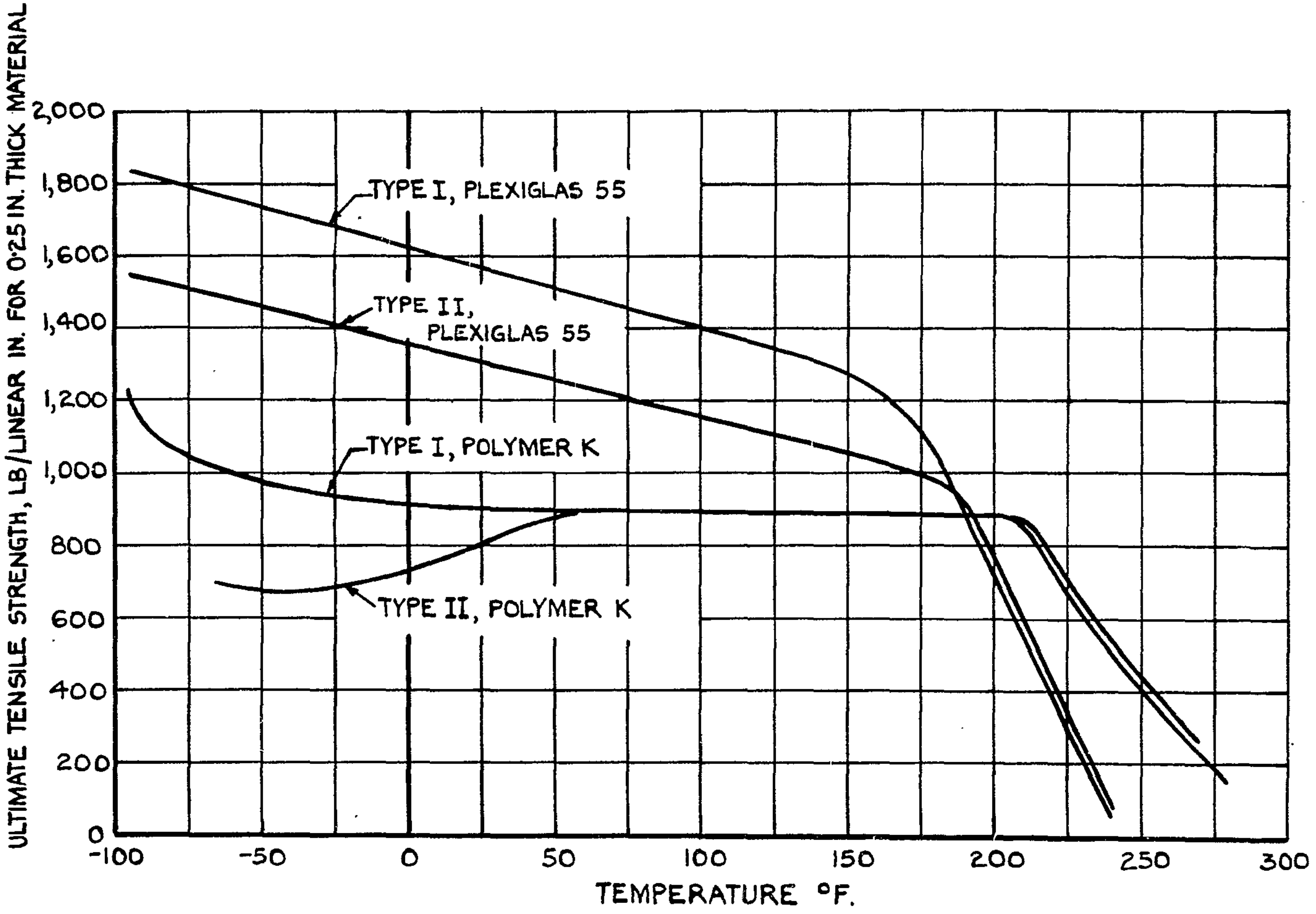


FIG.12. TENSILE STRENGTH OF EDGE ATTACHMENTS VS. TEMPERATURE.

CH. 2258.

FIG.13.

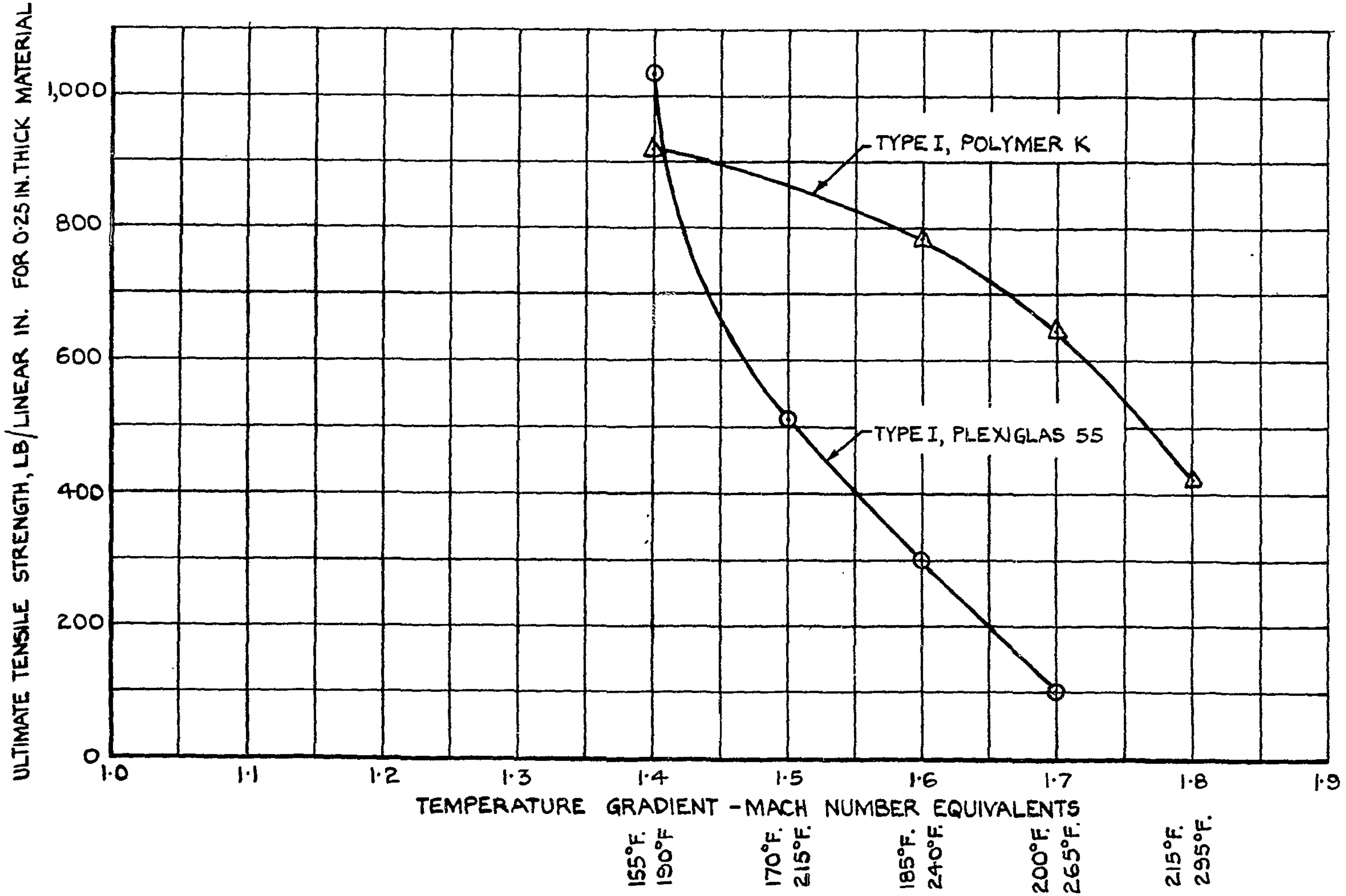


FIG.13. TENSILE STRENGTH OF EDGE ATTACHMENTS VS. TEMPERATURE GRADIENT AT MACH NUMBER.

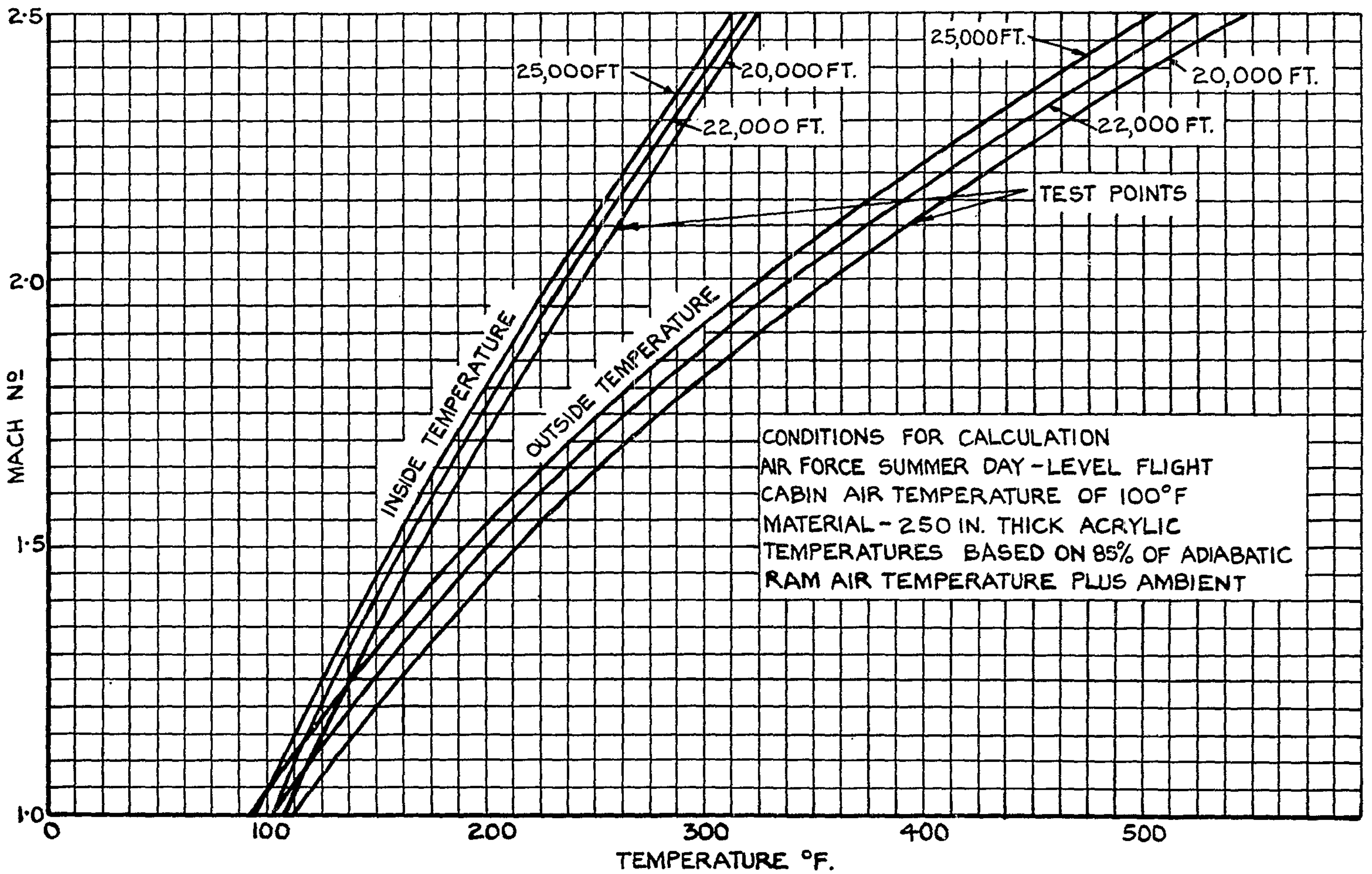
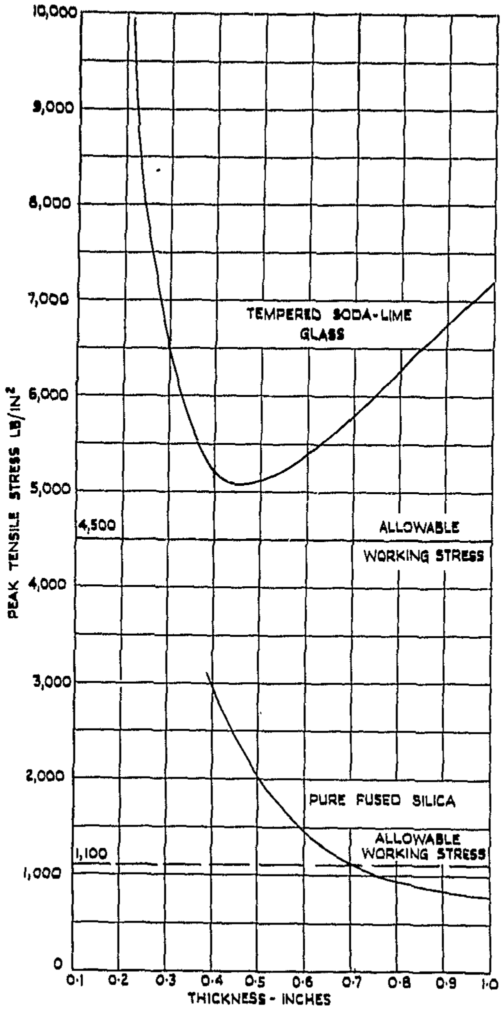
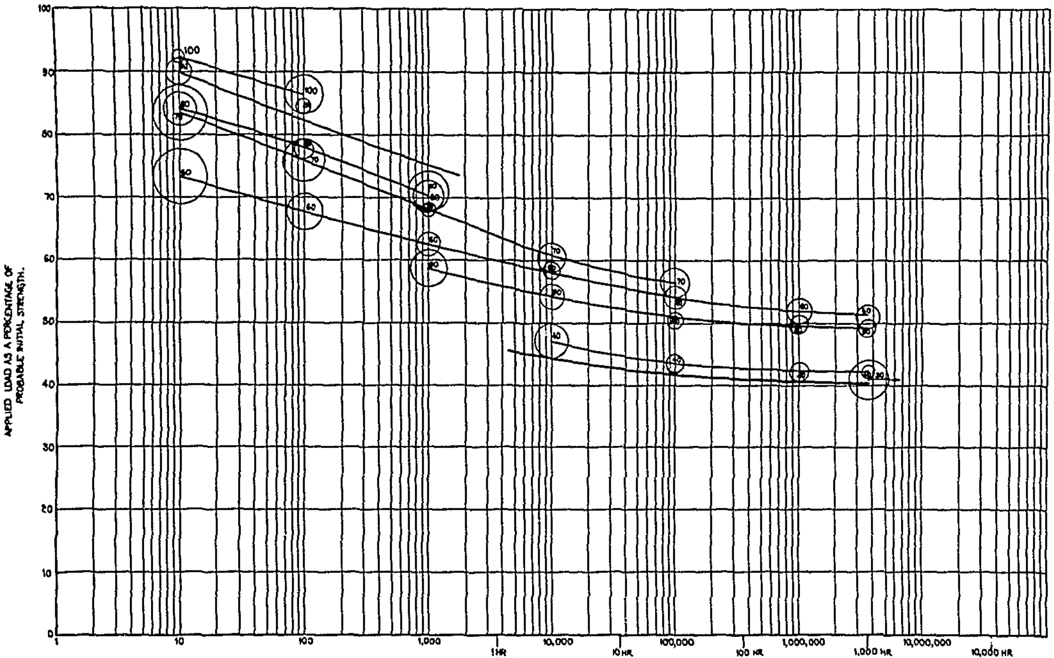


FIG.14. CANOPY SURFACE TEMPERATURES VS. MACH NUMBER FOR HIGH SPEED AIRCRAFT.



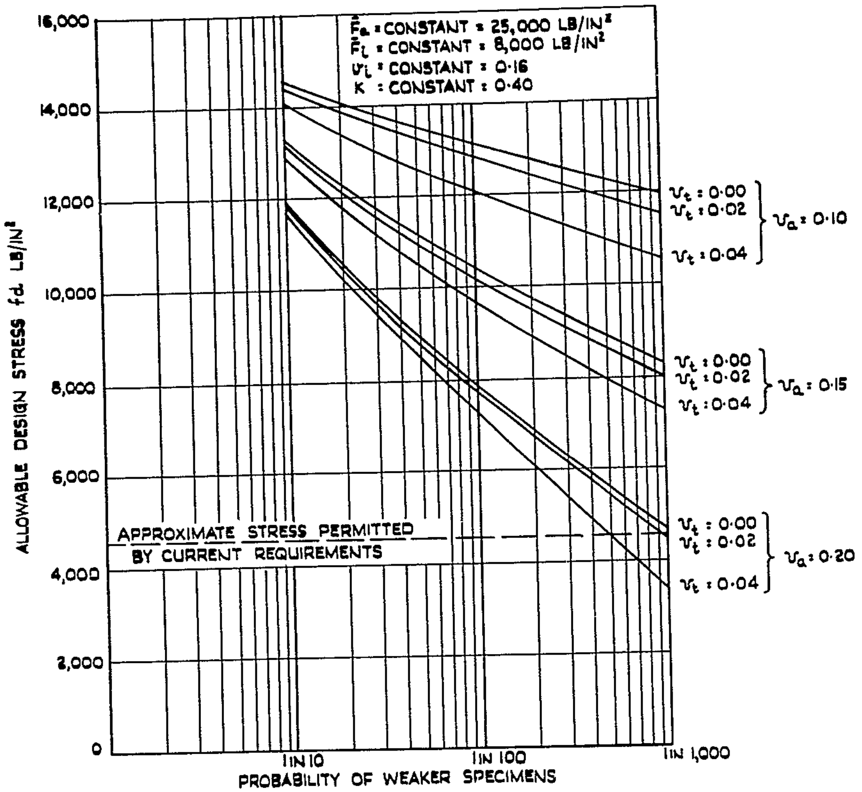
VARIATION OF PEAK TENSILE STRESS ON OUTER SURFACE OF WINDSHIELD DURING DECELERATION FROM M 2·5 AT 39,000 FT.

FIG. 15



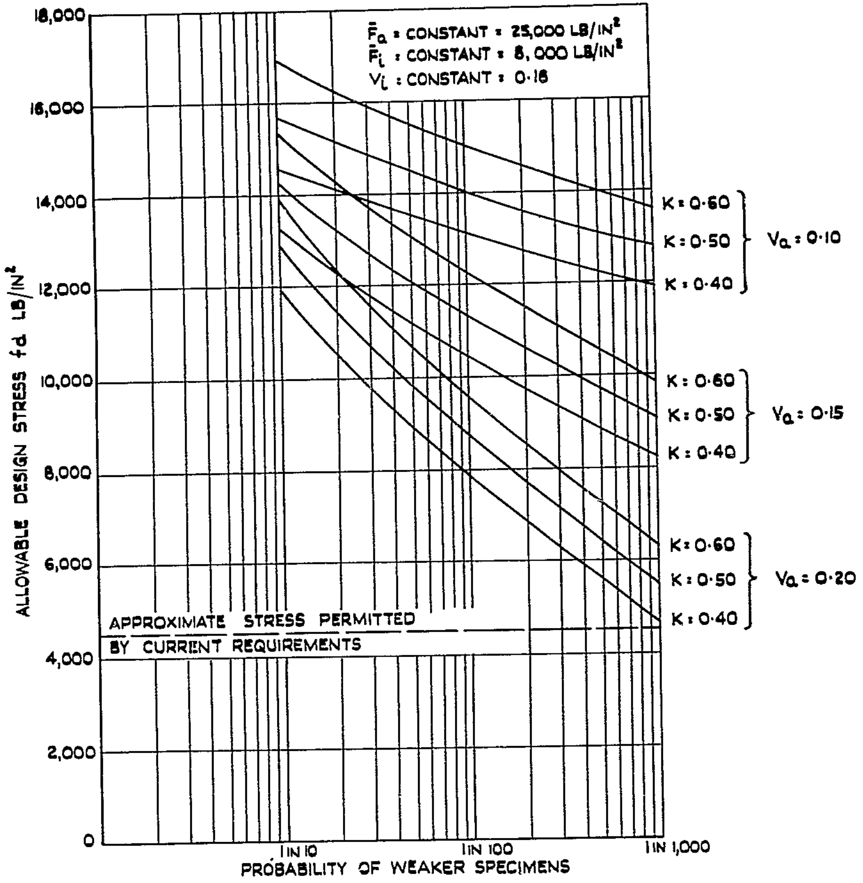
THE STRESS WHICH WILL JUST CAUSE DELAYED FAILURE OF ANNEALED GLASS EXPRESSED AS A FRACTION OF THE PROBABLE INITIAL STRENGTH.

FIG. 16



COMPARISON OF THE EFFECTS OF RANDOM VARIATIONS OF THICKNESS & APPARENT STRENGTH ON THE ALLOWABLE WORKING STRESS FOR TEMPERED GLASS.

FIG.17



COMPARISON OF THE EFFECTS OF THE SUSTAINED LOADING COEFFICIENT AND OF RANDOM VARIATIONS OF APPARENT STRENGTH ON THE ALLOWABLE WORKING STRESS FOR TEMPERED GLASS.

FIG.18

FIG.19.

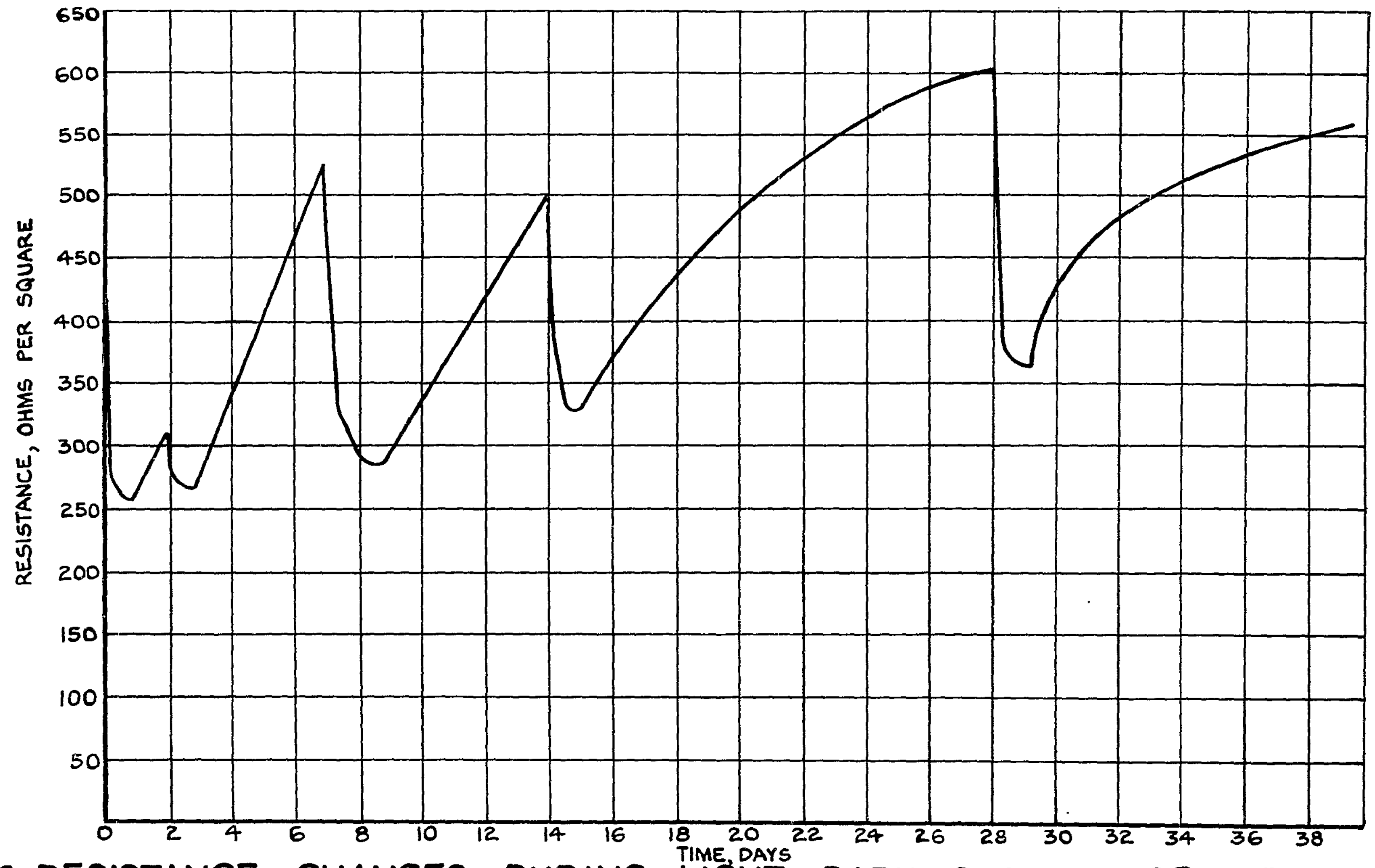


FIG.19. RESISTANCE CHANGES DURING LIGHT-DARK CYCLING OF INDIUM OXIDE FILMS.

FIG.20

RAE 123703 55

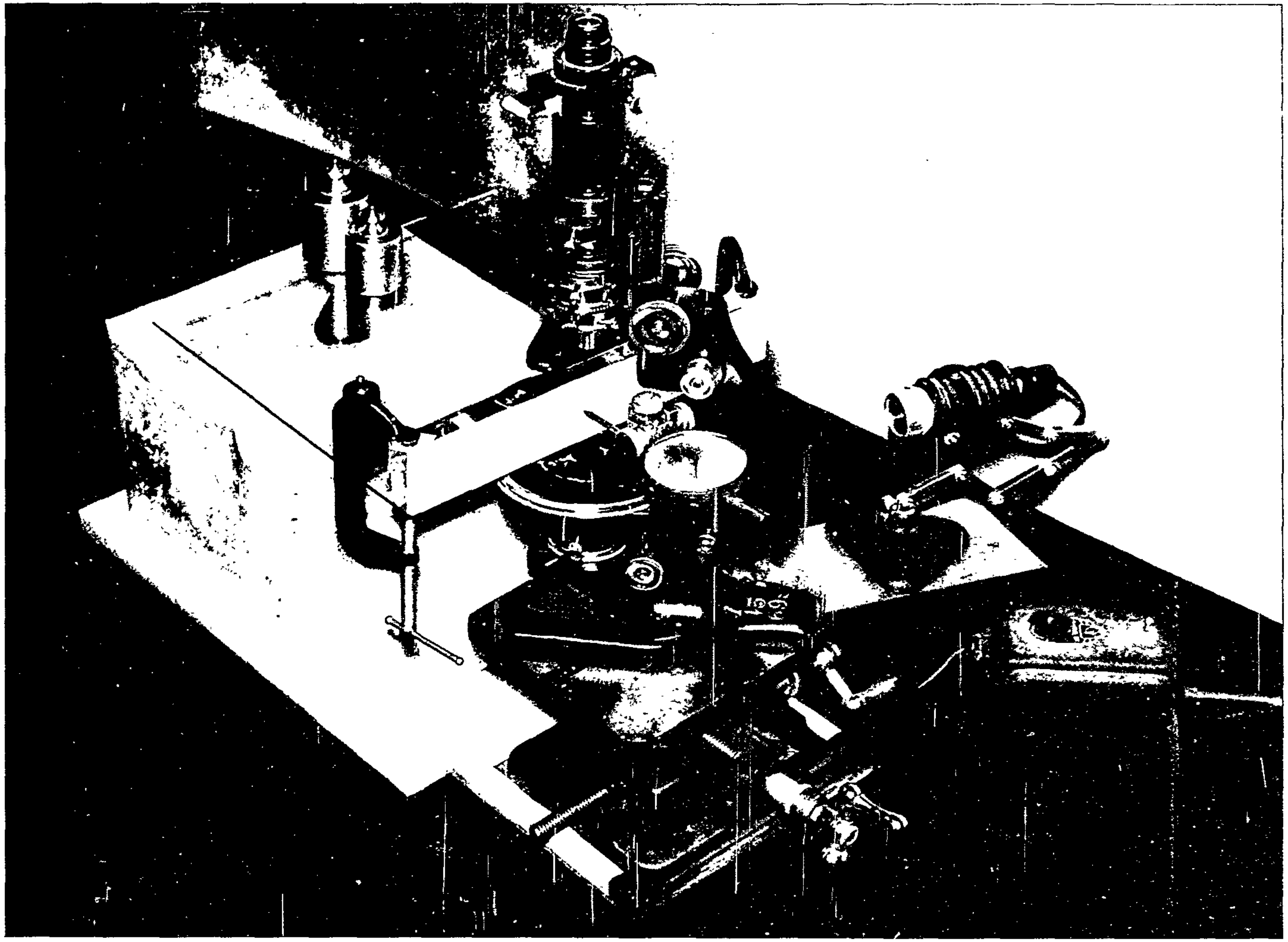


FIG.20 Arrangement For Measuring Stress Distribution Across Thickness of Glass Strips.

R: CHEM. 504
STRUCTURES 194
FIG.21

RAE: 123705 | 55

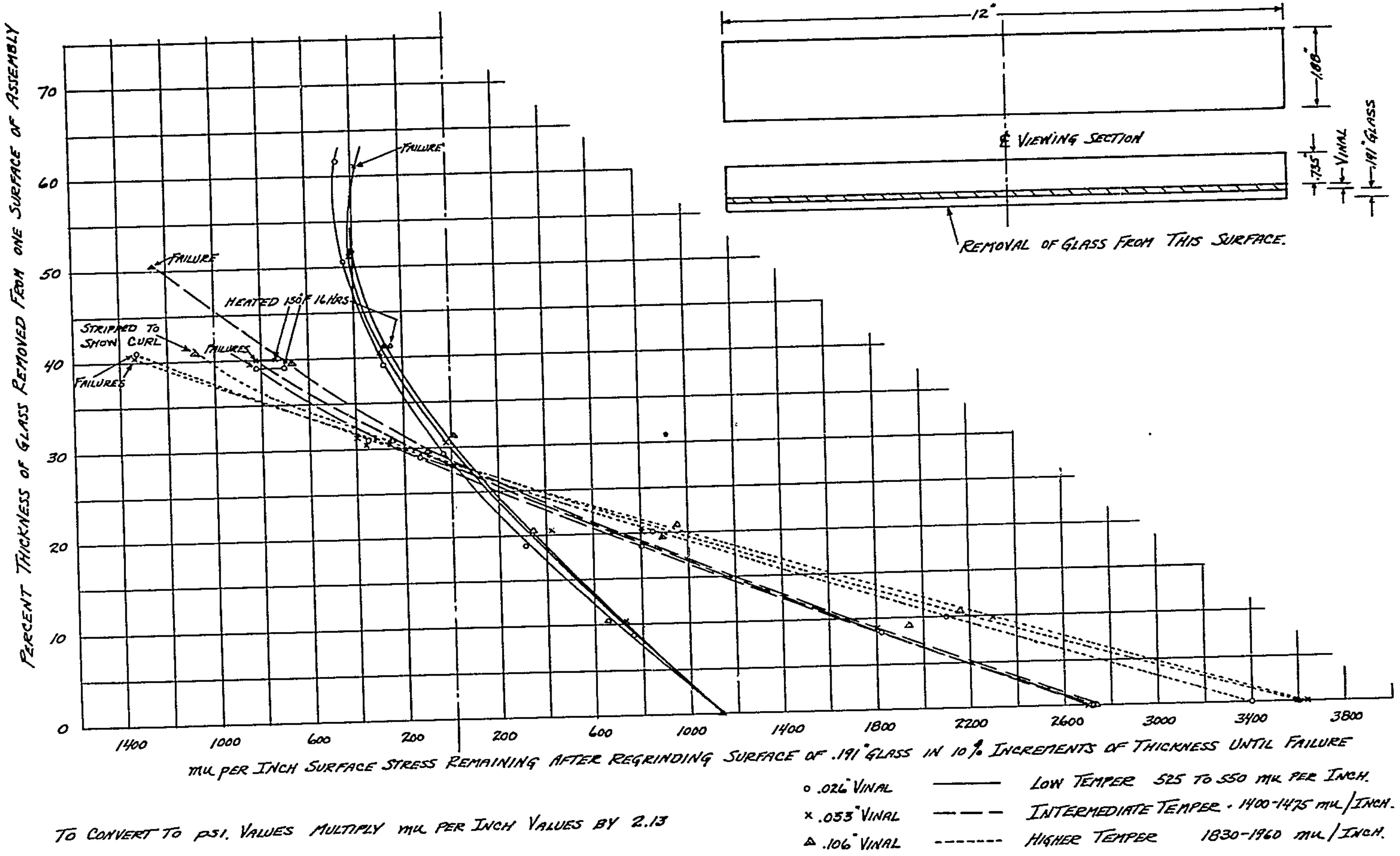


FIG.21. REGRINDING OF TEMPERED GLASS SURFACES IN LAMINATED ASSEMBLIES
RESEARCH LABORATORY, PITTSBURGH PLATE GLASS Co., CREIGHTON, PA.

FIG.22

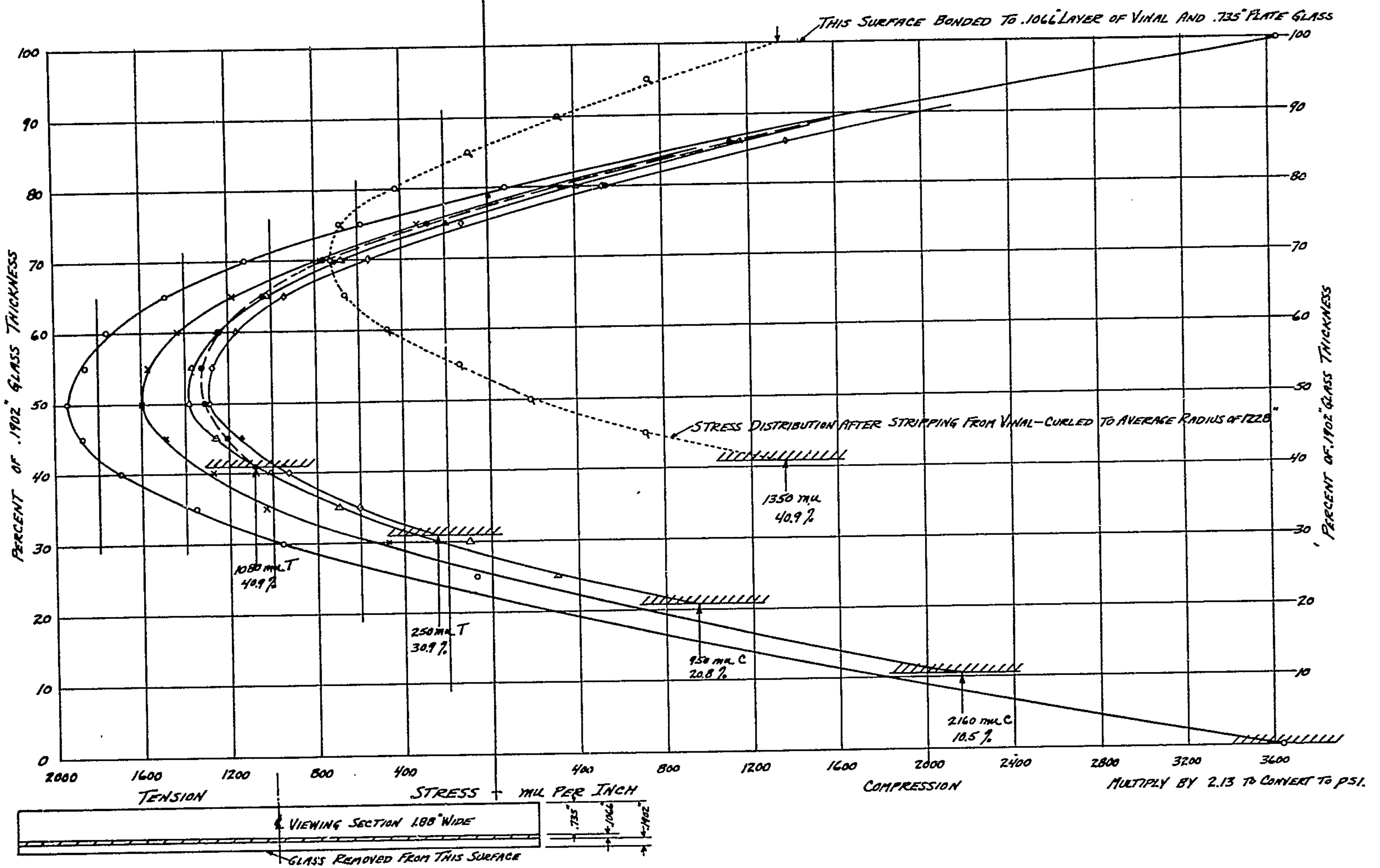


FIG.22. STRESS DISTRIBUTION THROUGH THICKNESS OF LAMINATED GLASS GRINDING FROM ONE SURFACE
RESEARCH LABORATORY, PITTSBURGH PLATE GLASS Co., CREIGHTON, PA.

DETACHABLE ABSTRACT CARDS

These abstract cards are inserted in RAE Reports and Technical Notes for the convenience of Librarians and others who need to maintain an Information Index.

Detached cards are subject to the same Security Regulations as the parent document, and a record of their location should be made on the inside of the back cover of the parent document.

SECRET-DISCREET

Royal Aircraft Est. Report No. Chem.504 06.076(73):
Structures 194 629.13.012.13
1956.1
Brown, F.G.J. and Russell, E.W.

REPORT ON A VISIT TO THE U.S.A. TO ATTEND THE SIXTH ANNUAL A.I.A. - W.A.D.C. CONFERENCE ON TRANSPARENT MATERIALS AND TO DISCUSS PROBLEMS RELATING TO AIRCRAFT TRANSPARENCIES

This report is an account of a visit by the authors to the U.S.A. to attend the Sixth Annual A.I.A. - W.A.D.C. Conference on Transparent Materials and to discuss problems of common interest to the U.K. and the U.S.A. in the field of aircraft transparencies.

SECRET-DISCREET

SECRET-DISCREET

Royal Aircraft Est. Report No. Chem.504 06.076(73):
Structures 194 629.13.012.13
1956.1
Brown, F.G.J. and Russell, E.W.

REPORT ON A VISIT TO THE U.S.A. TO ATTEND THE SIXTH ANNUAL A.I.A. - W.A.D.C. CONFERENCE ON TRANSPARENT MATERIALS AND TO DISCUSS PROBLEMS RELATING TO AIRCRAFT TRANSPARENCIES

This report is an account of a visit by the authors to the U.S.A. to attend the Sixth Annual A.I.A. - W.A.D.C. Conference on Transparent Materials and to discuss problems of common interest to the U.K. and the U.S.A. in the field of aircraft transparencies.

SECRET-DISCREET

SECRET-DISCREET

Royal Aircraft Est. Report No. Chem. 504 06.076(73):
Structures 194 629.13.012.13
1956.1
Brown, F.G.J. and Russell, E.W.

REPORT ON A VISIT TO THE U.S.A. TO ATTEND THE SIXTH ANNUAL A.I.A. - W.A.D.C. CONFERENCE ON TRANSPARENT MATERIALS AND TO DISCUSS PROBLEMS RELATING TO AIRCRAFT TRANSPARENCIES

This report is an account of a visit by the authors to the U.S.A. to attend the Sixth Annual A.I.A. - W.A.D.C. Conference on Transparent Materials and to discuss problems of common interest to the U.K. and the U.S.A. in the field of aircraft transparencies.

SECRET-DISCREET

[dstl]

Information Centre
Knowledge Services
[dstl] *Porton Down,*
Salisbury
Wilts
SP4 0JQ
22060-6218
Tel: 01980-613753
Fax 01980-613970

Defense Technical Information Center (DTIC)
8725 John J. Kingman Road, Suit 0944
Fort Belvoir, VA 22060-6218
U.S.A.

AD#: AD0093320

Date of Search: 12 Nov 2009

Record Summary: AVIA 6/20187
Title: Report on visit to USA to attend the 6th annual Aircraft Industries Association-Wright Aircraft Development Centre Conference on Transparent Materials and to discuss problems relating to aircraft transparencies (RAE REP CHEM 504)
Availability Open Document, Open Description, Normal Closure before FOI Act: 30 years
Former reference (Department): REPORTS STRUCT 194
Held by The National Archives, Kew

This document is now available at the National Archives, Kew, Surrey, United Kingdom.

DTIC has checked the National Archives Catalogue website (http://www.nationalarchives.gov.uk) and found the document is available and releasable to the public.

Access to UK public records is governed by statute, namely the Public Records Act, 1958, and the Public Records Act, 1967.
The document has been released under the 30 year rule.
(The vast majority of records selected for permanent preservation are made available to the public when they are 30 years old. This is commonly referred to as the 30 year rule and was established by the Public Records Act of 1967).

This document may be treated as UNLIMITED.