UNLIMITED

MINISTRY OF TECHNOLOGY

DIRECTORATE OF MATERIALS RESEARCH AND DEVELOPMENT

INVESTIGATION INTO THE USE OF REINFORCED PLASTICS IN THE WESSEX HELICOPTER TO PREVENT CORROSION.

N. L. Bottrell
(Westland Aircraft Limited)

JULY 1967

UNCLASSIFIED

27

D Mat Report No. 148

D Mat Ref ZB/12/025

July, 1967

MINISTRY OF TECHNOLOGY

DIRECTORATE OF MATERIALS RESEARCH
AND DEVELOPMENT

INVESTIGATION INTO THE USE OF REINFORCED PLASTICS IN THE WESSEX HELICOPTER TO PREVENT CORROSION

N.L. BOTTRELL
(Westland Aircraft Limited)

JULY, 1967

FOREWORD

This report describes the work carried out by Westland Aircraft Ltd., under Contract KK/M/74/CB.25(a), dated 5.11.63, for the Directorate of Materials Research and Development, Ministry of Technology. The work was administered by Mat 7 under the direction of AD Mat (NM)

SUMMARY

Magnesium is used extensively in the Westland Wessex helicopter for transmission castings and in the skin-stringer constructed fuselage; in practice, defects due to the corrosion of magnesium occur. The present work shows that replacement of magnesium by a glass fabric reinforced resin composite can solve corrosion problems in the case of the tail gearbox fairing.

Three tail gearbox fairings were built; two were required to compare stiffness and impact resistance with the metal counterparts and the third was required to establish that adequate resistance to simulated aerodynamic leads was obtained. The tests were performed satisfactorily and the properties measured gave good agreement with those of the metal components.

The use of reinforced plastic for the cabin door proved unsatisfactory because of the excessive thinning of the skin necessitated by weight considerations; the component then had inadequate impact resistance.

A design study of the proposed replacement of the engine nose door by a reinforced plastic component showed that this could be done with advantage, both with sandwich and with skin-stringer types of construction; certain essential metallic components would be retained, but aluminium and titanium alloys would be used in place of magnesium in order to minimise corrosion effects.

CONTENTS

FIGURES

1.0 INTRODUCTION

Magnesium metal, with its low weight, high strength stiffness properties, is a material which is used extensively in the Westland Wessex helicopter for transmission castings and in the skin-stringer constructed fuselage. Extensive Service utilization of these aircraft has shown that a corrosion hazard is present with this material. Accidental damage, misuse, or normal wear and tear in service removes the carefully applied and essential organic protection. This permits moisture to come into contact with the unprotected metal, thereby promoting corrosion which, if not contained, reduce the structural efficiency of the component.

The majority of the corrosion experienced under Service conditions is mostly confined to the exterior surfaces of the aircraft in areas where intensive examination is required, such as the gearbox fairing, or where components require frequent manipulation, such as doors or covers. The gearboxes and associated transmission components do not suffer the same extent of corrosion as there is inevitably a film of oil contained on the surface due to spillage during servicing of the component. This is found to be beneficial and a very successful corrosion preventive.

Because defects due to corrosion of the magnesium in the airframe were occurring frequently on Naval Wessex aircraft, the Company was requested to investigate the possibility of replacing certain components with other commercially available materials or composites. The structures fabricated from these other materials wereto have similar structural properties to the existing magnesium components and under no circumstances was a weight penalty to be incurred.

A survey of the available commercial structural materials indicated that the only possible replacement for magnesium would be a glass fabric reinforced resin composite. Even this material would not possess the same stiffness-for-weight properties as magnesium. Consequently, it was decided that, where comparable stiffness was required, redesign, possibly incorporating a lightweight core, would enable a component with similar stiffness characteirstics to be fabricated.

It was agreed that the work would be aimed at obtaining basic information and design data relevant to producing both laminated and sandwich structures from resin pre-impregnated glass fibre cloth material. The equipment used would be that normally available. This included autoclaves, vacuum tables and, to cure the components, internally heated moulds or drapeable mats.

The pre-impregnated glass fabrics were considered to offer the following advantages when compared with the low-pressure hand lay-up methods.

(a) Better and cleaner processing

(b) Ready weight control

(c) Accurate resin/glass control

(d) Reduction in the variability of the properties of the resultant structure.

However, the early work revealed that at the maximum available pressure of 65 psi, good consolidation of the laminate was not obtained and the resulting physical properties were below the estimated values. Trouble was also experienced when manufacturing honeycomb sandwich structures; either the core collapsed under the curing condition or dimpling occurred on the laminate surface. Both these conditions were considered unsuitable for aircraft structure. Because of these experiences, the contract was extended to obtain the required data from specimens manufactured by the low-pressure hand lay-up technique. All test components were then manufactured in this manner.

Having established the necessary design data from the test programmes a redesign of the Wessex tail gearbox fairing and main cabin door was undertaken. Tools and assembly fixtures were manufactured to enable three prototypes of each component to be assembled for structural testing.

On satisfactory completion of testing of these two components, a design study of the engine nose door was undertaken. This was to establish if, by using the materials and processes evaluated in the Contract, a suitable door could be made without increasing the weight as compared with the original structure. An essential requirement of the redesigned component was interchangeability with existing attachments and mating surfaces.

2.0. PROGRAMME

2.1. Laminating systems. Laboratory and stress evaluation of known epoxy resin pre-impregnated glass fabrics and suitable low-pressure polyester-resin-glass fabric systems in respect of:-

a) Suitability to form void-free double curvature structures up to 20 swg (0·036 in.) thick.

b) Resistance to known aircraft fluids, moisture, salt spray, and actinic degradation; together with reduction of stiffness engendered by these environments.

c) Cure cycle in respect of autoclave working for the pre-impregnated systems.

d) Compatibility with metal edge-members such as clamps and hinges etc.

2.2. Sandwich construction. Laboratory evaluation of relative effectiveness of paper honeycomb compared with glass fibre honeycomb, metal honeycomb, or rigid foams, when used to reinforce thin fibre-glass structure with respect to:-

a) Stiffness/weight ratio when bonded to the optimum glass reinforced plastic skin as evaluated in 2.1.

b) Ability to resist environmental changes and retain structural integrity.

2.3. Tail gearbox fairing. Manufacture of tools to produce glass reinforced plastic gearbox fairing (WS16.20.64132) at same or lower weight as existing structure.

Manufacture of three interchangeable tail gearbox fairings for structural testing and for comparison with existing metal structures in respect of:-

a) Resistance to impact damage.

b) Tear off strength of attachment.

c) Aerodynamic loads.

2.4. Cabin door. Manufacture of tools and assembly of three interchangeable Wessex cabin doors, using honeycomb or expanded material stiffening. The doors to be the same or lower weight (18 lb - area 18 ft^2) as existing structures and meet existing technical requirements for emergency release.

Test for:-

a) Stiffness.
b) Impact resistance.
c) Long term dimensional stability.

Work to be dependent on the evaluation of sandwich construction (para. 2.2.) and a design study. Design data, available from the plastic fuselage contract being operated at the Hayes Division, can be incorporated.

2.5. Engine nose door. Design study for suitability of manufacture from plastic. The study to include consideration of aerodynamics, weight reduction, improved buoyancy, and improvement to the engine air intake. Interchangeability with existing hinges and latches to be essential.

3.0. WORK CARRIED OUT AND RESULTS

3.1. Materials

3.1.1. Epoxy resin pre-impregnated glass fabrics. "Marglass 1069" was chosen from the then available epoxy resin pre-impregnated glass fabric systems. The fabric (S/150E to BS. S3396, finished with amino-silane) has good physical properties in the warp and weft, good drape and formability characteristics, low moisture pick-up in the cured laminate, and a six month shelf life at 21°C in the uncured condition. The impregnating resin is an epoxy (Novalac).

3.1.2. Polyester glass fabric low-pressure laminating system. The fabric is identical to that used in the epoxy pre-impregnated system, but the finish employed is a methacrylate silane (Marglass P.734). The associated resin system is Scott Bader's Marco Resin 28D, Catalyst H, and Accelerator E, released to DTD.5537, Class MC.

3.2. Moulding techniques. Forming excercises were carried out on the epoxy pre-impregnated fabrics to establish the suitability of fabricating void-free skinning and structure at thicknesses down to 0·032 in. These showed that the material was capable of being formed over double curvatures and hemispherical shapes of 6 in. diameter, but, under the maximum curing pressure of 65 psi obtainable in the autoclave, voids were still present in the moulding, irrespective of shape or size.

All combinations and methods of applying the vacuum and pneumatic-autoclave pressures available in the experimental equipment were performed without substantially affecting the volume of voiding. This lack of success necessitated a comparison of the effects of various moulding pressures and laminates. Test laminates, made in a platen press at pressures of 25, 50, 75 and 100 psi, were evaluated for their properties. The results indicated that a moulding pressure of 100 psi was required to manufacture void-free laminates with good mechanical properties. In the tensile test a drop in ratio was noticed between moulding pressures of 25 and 75 psi. The cross-breaking strength, however, showed the expected gradual rise with increase in pressure.

Tests were repeated on laminates manufactured identically from the same batch of material after it had aged for nine months. The cross-breaking strength properties showed a similar increase in strength with an increase in moulding pressure up to 75 psi, but at 100 psi a 10% drop in the tensile strength was noted.

Further tests were made on laminates fabricated from the same batch of material after 10 to 12 months ageing. The properties examined gave lower values than those originally obtained and scatter had increased. The scatter might have been masking the expected pattern of results and no definite conclusion was drawn from the results obtained. To complete the investigation satisfactorily, it was felt that it would be desirable to evaluate laminates moulded at pressures of 125 and 150 psi.

With the polyester resin laminating system, void-free laminates can be fabricated readily using the well established technique detailed in DTD.5537, App.7. The drape and forming properties of the system are dependent on the make-up of the fabric and this can be chosen to suit the required shape. For the manufacture of components the laminate was laid-up under vacuum.

3.2.1. Curing of laminates and shapings. The pre-impregnated system was fully cured by initial press curing at 160 ± 5°C for 30 minutes and post curing in the jigged position at 180 ± 5°C for two hours. Jigging was found necessary during the post-cure period, even on flat laminates, to prevent distortion of the component.

The low-pressure laminating system was post cured, after room temperature moulding, for two hours at 80°C to obtain a constant cure condition as indicated by a consistent Barcol hardness value. No measurable distortion was observed after the post-cure operation.

3.3. Resistance of laminates to aircraft contaminants. An environmental test programme for epoxy pre-impregnated and polyester systems was initiated to evaluate some of the basic physical properties of the laminates, and thereby establish data for design and process control.

The results indicated that neither the epoxy nor polyester systems were adversely affected by a 1000-hour total immersion in the various contaminants, including water-containing liquids and conditions of high humidity. A 10000-hour exposure test on the epoxy-impregnated system showed that water-containing environments could reduce tensile and cross-breaking strengths by up to 35%.

3.4. Fatigue testing.

3.4.1. Tensile. The specimens were prepared in accordance with R.A.E. TECH. NOTE CHEM.1376,Fig.1, Type C. The results showed that the fatigue limit, both for an epoxy system and a polyester system, was in the order of 35% to 40% of the ultimate tensile strength.

3.4.2. Resonance. Each specimen was a 1 in. wide, $\frac{1}{2}$ in. long, single-lap joint bonded with EC.2216 adhesive and having 4 in. arms in 0·050 in. thick material on either side of the joint. The specimens were vibrated in free bending and the mode of failure in all specimens was de-lamination of the laminate at a position between the test fixture and the inner edge of the bonded joint.

3.5. Compatibility of joints and metal edge-members. A single lap joint was the principal type for this work. Therefore, jointing and edge compatability tests were directed towards obtaining a suitable adhesive wet-assembly technique, using anti-peel rivets at the edge of the joint. The best system observed was that employing a flexible epoxy adhesive 3M.2216, a $\frac{1}{8}$ in. dia. controlled closing rivet, and a $\frac{3}{8}$ in. standard rivet burr located on the reinforced plastic facing.

Best practical results were obtained when the adhesive was used as a jointing compound and applied to the cut edges of drilled holes and the mating faces of the plastic, metal and burrs. Tensile testing, at gauges of 0·032 in., always produced a failure in the aluminium or plastic sheet, but peeling of the joint was satisfactorily resisted by the rivet and burr.

3.6. Compatibility of joints in reinforced plastics. The replacements for the two chosen magnesium components required lap joints to be made between the reinforced plastic skinning and the ribs etc. As the stiffness of the structure was of the utmost importance, it was desirable to modify the joint. This was achieved by wet assembly of the joint with a strong adhesive having a low modulus. Five adhesive systems and three types of rivets were evaluated to determine their suitability.

3. 6.1. Evaluation of adhesive systems suitable for bonding polyester-glass in the construction of high strength structures.

The following systems were tested:-

a) Scotchweld EC.2216, Parts A and B.

b) Araldite AY.111 + Hardener 111 + 100% Slate filler.

c) Araldite MY.750 + X.83/219 + 951 Hardener.

d) Double Bond Putty, Parts A and B.

e) Bostik 39GA.114, Parts 1 and 2 (polymide cured epoxy resin).

Test pieces were prepared using 10-ply polyester glass laminates moulded under vacuum pressure. The ½ in. overlapping edge of each laminate was abraded using 300-grit carborundum paper, then both surfaces were wetted with the appropriate adhesive. The ½ in. overlap was maintained by means of a suitable jig, the top plate being loaded to give a dead-weight load of 3 psi throughout the joint. The adhesive was allowed to cure for 16 hours, then the assembly was removed from the jig and stoved for 3 hours at 60°C. After cooling the assembly was band-sawn in 1 in. widths and the outer ½ in. to ¾ in. of the bonded laminate discarded. A further 24 hours was allowed to elapse before evaluating the specimens. From the results it was decided that the Scotchweld EC.2216 B/A adhesive would be used on all jointing in the fabrication of components.

3. 6.2. Evaluation of adhesive bonded riveted joints. Two types of rivet were considered: the solid rivet, formed by impact loading, and the hollow rivet, formed by controlled expansion of the shank.

The solid rivet was considered to be of little value when jointing reinforced plastics. Damage was invariably experienced on the rivet surround, due to uncontrolled striking.

Hollow rivets substantially eliminated damage to the reinforced plastic. The rivets evaluated were of three types:-

a) Tucker - Closed by pulling a shaped mandrel through the core with an air-operated gun or hand-operated lazy tongs. The rivet is made blind by shearing the mandrel in the core.

b) Chobert - Closed by an enlarged mandrel which expands the tail and shank when drawn through the rivet by an air-operated gun. The closure action is rapid and a small amount of crushing occurs in the reinforced plastic around the shank. This is repaired by the application of an adhesive during wet assembly. The rivet is not self-sealing.

c) Huck - Similar to the Tucker, but the closure speed can be controlled by the gun. The mandrel is sheared automatically at the end of its travel and seals the rivet core.

The test specimens were $\frac{1}{2}$ in. overlap joints in 0·050 in. thick polyester laminates, riveted at 1 in. pitches. The holes were pre-drilled and the specimens wet assembled with adhesive EC.2216. Dome-head rivets were used, and some rivets were fitted either with burrs under the head or with burrs under both the head and the tail.

After curing for seven days at room temperature the specimens were cut to produce $\frac{1}{2}$ in. x 1 in. joints with a rivet located centrally. Each joint was loaded in tension to determine its load carrying capacity and the effect on the form of the rivet.

The decision resulting from the tests was to recommend Huck CKL fasteners with the appropriate rivet burrs on the tail for the manufacture of lap joints.

3.7. The effect of various contaminants on riveted and plain EC.2216 bonded joints.

Evaluation of the properties of riveted adhesive bonded lap joints led to the examination of the effect of normal aircraft contaminants, not only on these joints, but also on non-riveted specimens.

The contaminants were:- DTD.585, D.Eng.R.D.2487, D.Eng.R.D.2494, BS. S1595 (isopropyl alcohol), distilled water, 100% R.H. at 70°C, salt spray at 20°C, Skydrol 530A, and natural weathering.

Both the riveted and non-riveted specimens were $\frac{1}{2}$ in. x 1 in. single overlap joints of 0·035 in. thick glass reinforced plastic material. The rivet used in the riveted specimens was located centrally in the joint and was a Huck CKL with a rivet burr on the tail.

Six specimens were evaluated in tension from each conditioning. The results indicated that, generally, despite the contaminant, the effect of the rivet was to improve the shear strength of the joint. It was observed that water-containing environments had the most serious effect on both the laminate and the adhesive system used.

As little was known of the resonant fatigue properties of reinforced plastic laminates, especially when riveted, some of the 1 in. x $\frac{1}{2}$ in. joint specimens were vibrated in free bending. The mode of failure in all specimens was de-lamination of the laminate positioned between the test fixture and the inner edge of the joint.

3.8. Foam-filled honeycomb cores. Before the Contract was modified to include polyester low-pressure techniques, an integral sandwich construction comprising a paper or resinated paper honeycomb core and pre-impregnated fabric facings was considered.

Initial evaluation showed that, at the maximum permissible density to retain the same overall weight as a magnesium structure of 4 lb/ft^3, the core would collapse under moulding pressures at temperatures below the curing temperature. When the density of the core was increased sufficiently to resist collapse, the core weight became too great to be of value. Skin dimpling between hexagons also occurred. This defect was considered intolerable for structural components and its eradication, by matched die processing, uneconomical.

To reduce the dimpling and to improve core strength, a polyurethane foam filling was bonded to the walls of the honeycomb. The resultant composite had an inconsistent density due to the foam being restricted by the core shape and by the premature collapse of the foam as it made contact with the cell walls. The experiment was terminated at this stage as it was felt that the material would be of little or no value to the purpose of the contract.

3.9. Construction of the glass reinforced plastic tail gearbox fairing. The tail gearbox fairing, chosen to be the first for replacement of the existing magnesium components, was considered ideal as the operational stress levels in the skinning were relatively low and the shape and construction difficult. The construction in glass reinforced plastic followed that of the metal structure. Modifications made were due to the method of fabrication, or were made to take advantage of moulding techniques.

Bulkheads were fabricated by vacuum assisted moulding on tooling identical to that used for the metal components. Lightening holes to the existing design, but reinforced with a glass laminated lip, gave, for equal weights, the stiffest section and were the easiest shape to mould.

The front bulkhead was reinforced on the rear face with two vertical top-hat sections. These included cores of ½ in. thick expanded PVC which were moulded into the laminate and left in situ. This method increased the stiffness without an undue weight penalty, was simple, and reduced tooling costs.

The outer skin was moulded in two parts. The mouldings incorporated louvred rear air vents which, replacing expanded metal sections, provided a stronger section and enhanced the appearance of the rear end.

The top access panel was moulded in one piece as compared with two parts required for the metal structure. Reinforcing around the aperture in the top was provided by rectangular cut-outs having generous angle lipping with additional edge layers of glass fabric. The large cut-out in the port side was reinforced with four additional glass laminate surrounds, giving a thicker and stiffer section. The laminates were staggered at $\frac{1}{4}$ in. pitches to spread the load.

Attachment of the access panel was by screws fitted with rubber washers and screwed into rivnuts secured to the main structure. Rivnuts were employed in order to eliminate additional riveting, to provide tapped bushed holes, and for ease of replacement. Steel screws were recommended for use with the rivnuts. The Expandamet panels were permanently attached by rivets.

It was possible to assemble the components with simple jigging, using an adhesive system designed for glass reinforced plastic structures and suitable rivets with rivet burrs on the tails. The mating of the moulded components gave good location and assisted in the method of manufacture. The riveting provided a clamping and location effect, desirable during the cure of the adhesive, and fulfilled an anti-peel function in the bonded joints.

3.10. Testing the tail gearbox fairing

3.10.1. Simulated aerodynamic loading. The calculated factored aerodynamic loading experienced by the component in the most severe flying attitude of the aircraft formed the basis of the test work. The static loads and the points at which they were applied are indicated in fig.1.

For the test, the component was suspended in a rectangular frame in a manner similar to that in which it is fixed on the aircraft. It was, however, inverted to enable the loads applied to pull on the surfaces.

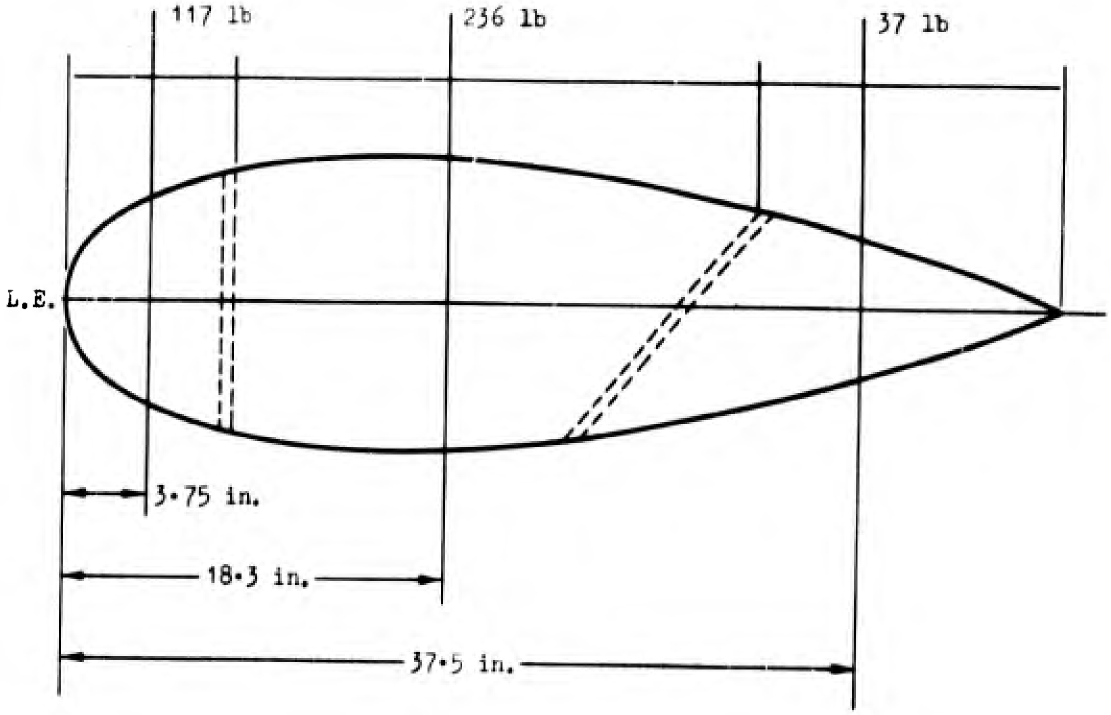
Pressure pads were located on the underside and on the inside face at the top of the component at the positions indicated (fig.1). The two pads in line were connected to a single-load strut. The struts were designed so that the load could be applied in three ways:-

a) With both the top and bottom faces sharing the applied load.
b) With the top face supporting the total load.
c) With the bottom face supporting the total load.

At total loads of 390 lb (simulating 150 knots) and 780 lb, no effects were observed. When the total load was increased to 1170 lb the stiffening member on the front bulkhead buckled slightly and the rear angle bulkhead tore at a point adjacent to the two open edges on the underside of the fairing.

TAIL ROTOR GEARBOX FAIRING IN FIBRE GLASS

AERODYNAMIC LOADING SIMULATION
(150 KNOTS)



1. LOADS SHOWN AND TOTAL LOADS, TO BE EQUALLY DISTRIBUTED BETWEEN UPPER AND LOWER SURFACES.

2. THE LOADS SHOULD BE DISTRIBUTED OVER THE AREAS INDICATED MAINTAINING THE LOAD CENTROIDS AT THE POSITIONS GIVEN.

Position			
Forward	Central	Aft	Total
Load (lbs)			
117	236	37	390
234	472	74	780
351	708	111	1170
468	944	148	1560
525	1162	166	1835

Loading glass reinforced plastic tail gearbox fairing

Figure 1

At a total load of 1560 lb the length of the tear increased to 3 in., the front stiffening member buckled further, and the undersurface indented $\frac{1}{2}$ in. at the centre. Under a total load of 1835 lb the tear extended to 4 in. when fouling with the structure prevented further tearing. Buckling of the front stiffener continued and indentation at the centre of the undersurface increased to 1 in.

At this stage, the shot bags used to apply the loads were rubbing the structure, and the loading trays were incapable of receiving further bags. The support frame was also seen to be buckling.

A total load of 1852 lb was then transferred to the underface of the component. The effect was to produce further indentations in the mid-section surface. Transference of the load to the upper surface resulted in the return of the underside to its original shape. The detachable door, now supporting a load of 1162 lb, was seen to hold firm, suggesting that the method of attachment was adequate. The remainder of the component showed no visible signs of further deterioration.

The component was left in this stage of loading for 14 days. No further deterioration in the component was observed within this period.

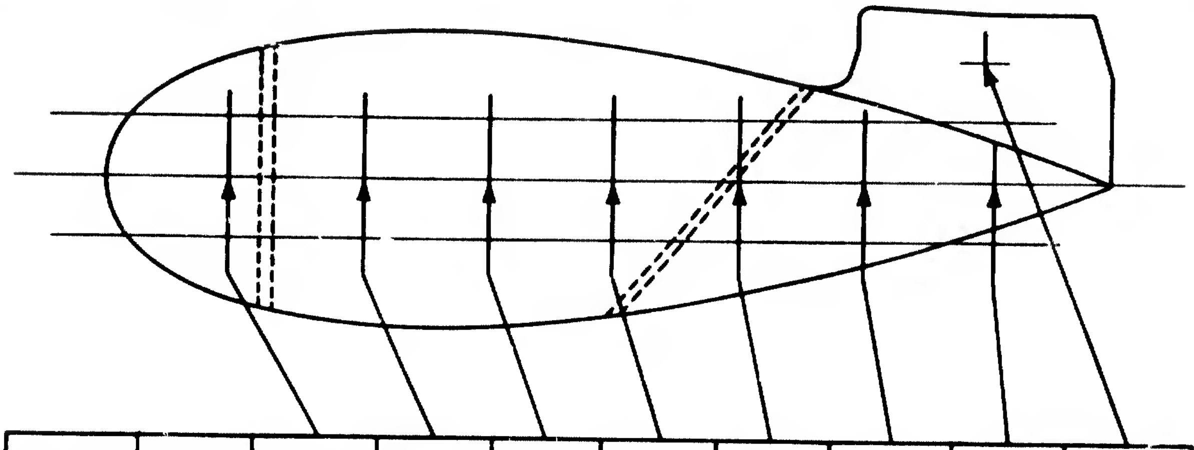
A metal structure, given an identical load test, sustained slight tearing of the rear angled bulkhead and permanent distortion of the skin at a total load of 1560 lb.

3.10.2. Impact resistance. A simple pendulum type impact tester was used to establish the impact resistance of a glass reinforced plastic structure and a similar metal structure. The pendulum had a 3 ft arm and the striker head was either a 1 in. or a 2 in. dia. steel hemisphere. The load at impact was varied by load additions to the striker.

The glass reinforced plastic structure suffered crazing of the resin in the area of contact and, under heavy loads, slight de-lamination occurred. At no stage in the test did the glass reinforced plastic rupture, and any damage incurred in the test was considered repairable by conventional methods.

The metal structure sustained permanent deformation in some areas with the 1 in. dia. striker at $\frac{1}{4}$ ft lb impact load. The same areas were penetrated and the metal broken at an impact load of $5\frac{1}{4}$ ft lb. At loads of 4 ft lb, the support rib on the centre section of the removable door buckled.

3.10.3. Torsional stiffness. An attempt was made to compare the torsional stiffness of the glass reinforced plastic fairing with that of the metal structure.



Ft. lbs	Arc ft.	S.T.N.1		S.T.N.2		S.T.N.3		S.T.N.4		S.T.N.5		S.T.N.6		S.T.N.7	S.T.N.8	
¾	1	B	A	A	A	A	A	A	A	A	A	Wire	A	Grill	A	A
"	2	B	A	A	A	A	A	B	A	A	A		A		A	A
"	3	C	B	B	A	B	A	C	A	A	A		A		A	A
3	1	C	C	B	A	C	A	C	A	A	B		A		B	A
"	2	C	D	C	A	C	A	C	A	A	B		A		C	A
"	3	C	E	C	A	C	A	C	A	A	C		A		C	A
6	1	C	E	C	A	C	A	C	A	A	C		A		C	A
"	2	C	E	C	A	C	A	C	A	A	D		B		C	A
"	3	C	E	C	A	C	A	C	A	A	E		C		C	A
9	1	C	E	C	A	C	A	C	A	B	E		C		C	A
"	2	C	E	C	A	C	A	C	A	B	E		C		C	A
"	3	C	E	C	A	C	A	C	A	E	E		C		C	A
12	1	C	E	C	A	C	A	C	A	E	E		C		E	B
"	2	C	E	C	A	C	A	C	A	E	E		D		E	C
"	3	C	E	C	A	E	A	C	A	E	E		E		E	C
15	1	C	E	C	B	E	A	C	A	E	E		E		E	C
"	2	C	E	C	C	E	B	C	B	E	E		E		E	D
"	3	D	E	E	D	E	C	C	C	E	E		E		E	E

Key for magnesium structure

A = No damage sustained
B = Slight dent
C = Increase in depth and area dent
D = Skin pieced
E = Structural failure

Key for glass reinforced plastic structure

A = No damage sustained
B = Slight bruising
C = Increase in area of bruising
D = Delamination
E = Increase in area of delamination

Observations of impact loading along the centrelines of the structures. Damage incurred was typical of that sustained on the line four inches above and below centre.

Observations of impact loading on tail gearbox fairings

Figure 2

The component undergoing test was attached to a support fixture by the two angle stringers that attach the fairing to the aircraft skin. Torsional movement was applied on the neutral axis through beams fixed to the fore and aft bulkheads. Deformation against various loadings was measured, but, due to problems inherent in the test set-up, accurate deflection measurements for comparing the stiffness of the components could not be recorded.

The glass reinforced plastic deformed more readily, but recovered completely when the load was released. That the original datum in the measuring system was never recovered indicated that the test set-up and the structure were too flexible, despite repeated loadings designed to stabilize the structure.

The work done, however, indicated that the metal component was stiffer, but again not tolerant of permanent distortion.

3.11. Redesign and manufacture of plastic cabin door. The cabin door was considered a suitable component for sandwich construction, as it was required to be 1 in. thick, be stiff and have good dimensional stability. The design changes were from a 0·024 in. thick skin and 0·020 in. thick horizontal and stringer frame-work to a 1 in. thick, $\frac{1}{4}$ cell, 0·001 in. foil, soft aluminium core with a reinforced plastic edge member and a 0·012 in. thick facing skin. Constructional details are shown on drawing WB5.10.17819.

3.12. Testing cabin door

3.12.1. Stiffness. The door was set up in a horizontal position with the outside face upwards. The underside edges, inclusive of the contoured edges, were supported by the test fixture.

Dial gauges were positioned $\frac{1}{4}$ width distant from the vertical side edges, and $\frac{1}{2}$ length distant from the horizontal edges. A total of 200 lb was applied at the intersection of the door diagonals in 10 lb increments. Deflection was recorded at each 10 lb application.

The reinforced plastic component was found to be of comparable stiffness to the metal structure, but sustained a slight permanent set.

3.12.2. Impact resistance. The test fixture was identical to that used for the stiffness test. A simple 3 ft moment pendulum with a 2 in. dia. steel striker and capable of being applied through 1, 2 and 3 ft arcs was used. The loads applied were increased in increments of 1 lb until the component failed or assessable damage had been inflicted.

Damage to the metal component was minor, the most severe being permanent indentations of $\frac{1}{2}$ in. to $\frac{3}{4}$ in. dia. combined with slight surface cracking of the material.

Damage to the glass reinforced plastic honeycomb-structure under similar loadings was severe in the impacted area. Crushing of the honeycomb was observed, and was generally associated with permanent dishing, crazing of the laminate and, in some tests, a small split in the laminate at the centre of impact.

The most disturbing failure of the honeycomb-to-facing joint was an adhesion failure. This occurred on the impact face, was the width of the impact, and extended to the nearest edge member. The failure was considered due to compressive and shear loads acting simultaneously on the bond and imparting very high shock peeling loads to the thin facing skin.

3.13. Design study of engine nose door. The main problem of the Wessex engine door, other than corrosion, is separation of particulate matter from the engine intake air. To overcome this problem it is considered essential to incorporate in the glass reinforced plastic door a momentum separation device that has already been successfully built and tested. A second function of the device, due to the heat transfer properties of the aluminium alloy used in its construction, is to assist in de-icing the intake. An aluminium door, however, is expensive to produce and, of the alternative materials, plastic is preferable to magnesium. As the de-icing facility is limited to certain types of operation (which are a low percentage of aircraft utilization) the provision of a non-corrodible plastic door having particle momentum separation only is considered necessary.

The design study shows that, while the basic shape of the momentum - separation door must be maintained, changes to non-metallic materials in certain areas are advantageous in preventing corrosion and in weight and cost saving. The proposed structure would utilize two basic types of plastic structure, one a skin-stringer-frame structure, the other a laminate-faced, rigid polyurethane foam sandwich. Where existing metals are retained, plastic to metal jointing techniques would be necessary.

The air intake aperture of the metal door is considered necessary for retention in the plastic door because it has proved successful in the installation tests and that to change it might reduce the efficiency of the momentum separation device. The existing metal component is a stiff, welded tube assembly which, in the plastic configuration, it is intended to overwrap with a plastic laminate in order to retain the shape and stiffness. The tube would be retained around approximately 1 in. of the rim of the intake, and the facing laminate would run out into the adjacent structure, which is designed to be single curvature.

Impact resistance and smoothness are respectively the properties required for the forward facing area surrounding the intake and for the outer surface of the inner skin. The most suitable structure to combine these properties is a sandwich of rigid polyurethane of 4 to 6 lb/ft^3 density faced with polyester resin glass laminate. A simple manufacturing technique would be to use a single male mould to preform the foam core, lay-up the inner facing laminate, and to complete the assembly. The sandwich construction would run out at the edges into a complex double curvature. This is required to blend into the aircraft shape and to contain the airflow "duct" to the engine intakes; the duct is the inner skin of the component. Shape would also be controlled by the need to pick up existing hinges and fasteners.

The most suitable way to connect the regularly shaped duct to the double curvature external skins is to support both with variously shaped stringers which are themselves supported and positioned by horizontal frames. The frame and stringer details can be manufactured as single items and contribute to the integrity of the structure. Skin-to-frame stringer joints would be made using a cold cure epoxy resin adhesive. Large pitch riveting, using Huck rivets with rivet burrs on the shank, would be employed to reduce peel loadings in the joint.

Metal firewall and momentum separation walls would be retained to comply with design requirements. Their attachment to the plastic structure would be by cold cure adhesive bonding. Huck rivets with rivet burrs on the shank would be used at the plastic underfacing.

Existing metal attachment parts would be retained, and suitable stiffening of the laminate would be effected by the addition of suitably orientated thicknesses of glass fabric.

The design study shows that, when compared with an aluminium alloy door, the plastic door is expected to be weight-saving and of lower cost.

3.13.1. Principle of particle momentum separation. The airflow path from the intake to the engine is a simple down-draught chamber. An impact plate placed in the airflow path absorbs the energy of any particle that strikes it. The particle falls from the plate to a no-pressure airflow collection area; the cleaned air passes to the engine.

4.0. ADDITIONAL WORK

Although pre-impregnated fabrics were not used in this work, sufficient material was available to manufacture specimens to enable a small amount of work to be done on the tensile fatigue properties of the material.

The specimens were prepared as detailed in R.A.E. T.N. CHEM.1376, Fig.1, Type C. The results are given in Westland Aircraft Ltd. Report No. ML/31,872.

5.0. DISCUSSION OF RESULTS

5.1. Tensile strength

5.1.1. Epoxy pre-impregnated system. Room temperature control values in the order of 48000 psi were achieved in test laminates manufactured at 100 psi.

Specimens immersed in aircraft liquid contaminants showed losses of up to 15% in strength when the contaminant contained water. This effect was highlighted by the results of an immersion test in a water-methanol mixture. No deterioration was indicated at 1000 hours but a loss of approximately 20% occurred at 10000 hours. In distilled water, over the same period, the loss was 33% and,in 100% R.H. at 70°C,some 6·5%. External weathering was less severe, a drop of 12% being experienced.

5.1.2. Low pressure polyester laminating system. A room temperature control value of 53000 psi was achieved, but, on evaluation of the initial environmental specimens after 50 hours exposure, the control values were some 3500 to 7500 psi higher, indicating that the control laminates were exceptionally good.

The degree of variability of this type of composite material demonstrated by this occurrence was further indicated by other results. The material appeared to regain some of its lost properties on prolonged immersion in the test fluid. For example, when immersed in a water-methanol mixture for 50 hours,a 8·5% loss of strength was observed, which increased to 14% at 500 hours, and decreased to 8·5% at 1000 hours.

Distilled water has the expected effect of reducing the tensile strength. At 1000 hours a drop of 16% compared with the control value was observed.

The exposure test in 95 - 100% R.H. at 70% further indicated the effect of the variables encountered in this system. An unexpected improvement in strength occurred after 100 hours and was maintained for the remainder of the 1000 hours test.

5.2. Flexural strength

5.2.1. Epoxy pre-impregnated system. A room temperature control value of 71000 psi was observed. In the initial 500 hours of exposure in all fluids, a drop in strength was noted, which levelled off to a 10 to 18% loss, compared with the control value, over the remaining 500 hours.

At 10000 hours exposure, the effect of water was evident. The strength losses were 50% in distilled water, 35% in water - methanol mixture and 28% in 100% R.H. at 70°C. The effects of the other contaminants showed little change from those noted at 1000 hours.

5.2.2. Low pressure polyester laminating system. Conversely to the tensile specimens, the control value of 75200 psi was low when considering values obtained from immersion specimens at various states of exposure. The general trend of the tests, comparing the drop in strength from the 50 hours exposure period to the 1000 hours period, showed a reduction of up to 12% in material strength, depending on the environment.

An interesting result of the 100% R.H. at 70°C exposure test was an increase in strength at 100 hours and 500 hours with a minimal drop at 1000 hours.

5.3. Stiffness - epoxy pre-impregnated system. The stiffness value of the laminate has been taken from the load deflection curve of the flexural test specimens. There was no pattern of change of stiffness in the material after 1000 hours exposure in the various contaminants.

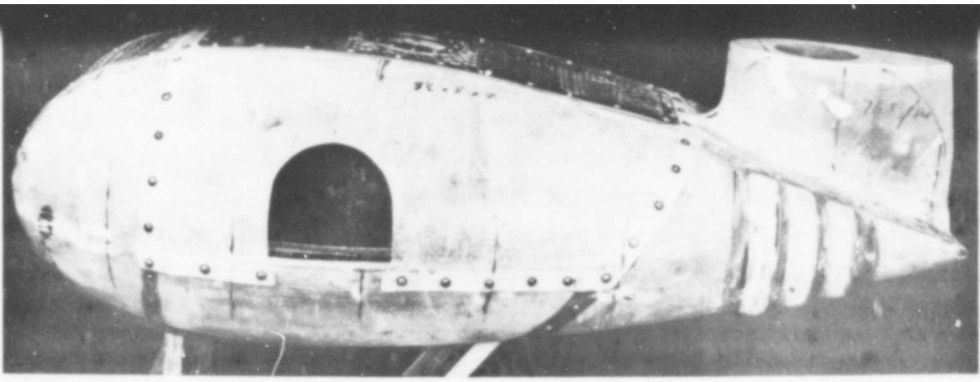
5.4. Replacement components - test specimens

5.4.1. Skin stringer construction - tail gearbox fairing. It was evident from the work done that for Class 3 skin-stringer structure, a simple replacement of glass reinforced plastic for magnesium could be effected without affecting performance. The replacement in some cases could save time and money by moulding multiple details in a unit construction. This was seen to be beneficial to the integrity of the resulting structure.

The riveted wet assembly method of jointing employed proved successful. In the impact and static load tests, both rapid and slow deformation of the joint occurred without any serious bond or joint failure. All failures observed started away from the appropriate joint.

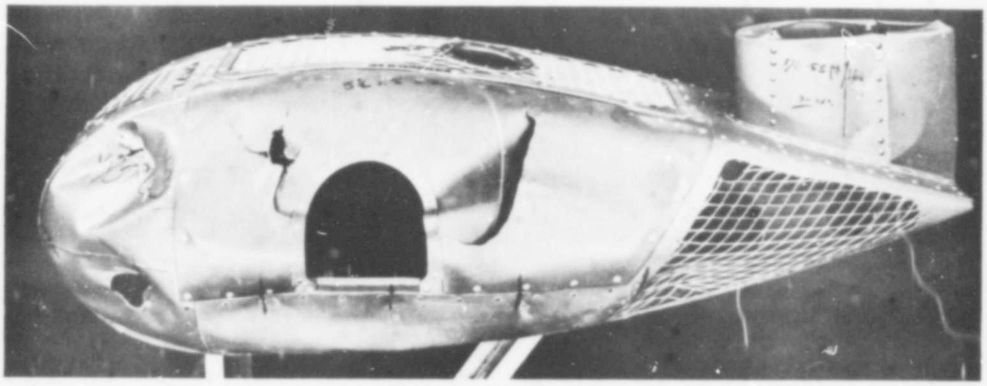
Static load testing showed that the rear angle bulkhead of the fairing is subject to tearing at high loadings. For the test, however, the fairing was in the free state and not riveted along the base to the pylon. If it had been so attached the tearing would have been less. It must not be overlooked that the method of construction would permit substantial local reinforcing of the bulkhead where tearing occurs, thereby eliminating the defect.

The impact test has clearly shown that a reinforced plastic component can withstand impact loads that severly damage a magnesium structure.



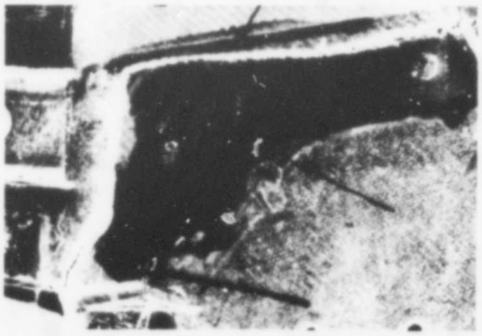
Glass reinforced plastic tail gearbox fairing after impact loading

Figure 3



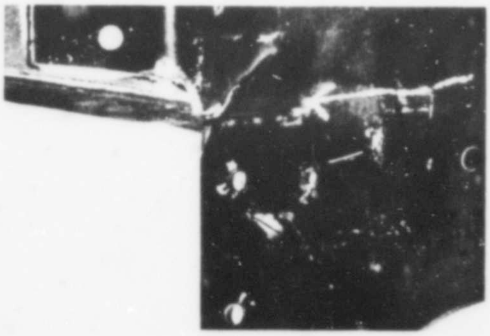
Magnesium tail gearbox fairing after impact loading

Figure 4



Damage to glass reinforced plastic gearbox fairing during static loading

Figure 5



Damage to magnesium gearbox fairing during static loading.

Figure 6

Impact damage to glass reinforced plastic cabin door.

Figure 7

Impact damage to magnesium cabin door.

Figure 8

This successful result was attributed to the construction of the component, where the positioning of bulkheads and stiffeners etc. did not permit large areas of lightly supported fibreglass skin. Consequently a structure with high uniform resilience was achieved. This property was also considered to have assisted in the recovery from deformation on the static load test.

A critical weight analysis was not carried out on the units built, but the specimens manufactured were within a few ounces of their metal counterparts. It is anticipated that a further component (to be fitted on an operational aircraft) will be built with the emphasis on weight control. The weight is confidently expected to be 10% less than the weight in metal of 9·25 lb. The weight of the three fairings completed to date were 9, 9·2 and 9·5 lb.

5.4.2. Honeycomb sandwich structures - cabin door. The results of the stiffness test showed the plastic door to be only a little less stiff than its metal counterpart. With only a slight increase in weight, the stiffness difference could be overcome by increasing the thickness of the honeycomb tail and/or facing skins. The results of the impact test showed the sandwich construction to be grossly inferior to the metal.

To obtain a similar weight as the metal (18 lb), the skin thickness of the plastic door was reduced to 0·012 in. At this thickness, the skin had little load carrying capabilities, and the weight control and the resin-to-glass ratio were variable. Production was difficult in that removal of the top ply of the laminate in preparation for adhesive bonding of the honeycomb induced severe crazing in the laminate and in the resin. This defect rendered the facing unsuitable. An alternative method of surface preparation, that of light sanding, was prone to damage the top ply of the fabric, reducing the load carrying capacity by as much as 25% in the effected area.

Because of these defects it was not considered a production proposition to face a honeycomb with a 0·012 in. thick skin. Failure under impact loading would be highly possible if it were used.

It was considered that for a facing skin for a component having a large surface area, i.e. in excess of 4 ft^2, a minimum thickness of 0·020 in. would be required.

6.0. RECOMMENDATIONS FOR FUTURE WORK

The design study of the Wessex nose door indicated that the existing door could be satisfactorily replaced with a plastic structure. It is recommended that a test programme be initiated to build and test three plastic doors.

The programme should include vibratory fatigue tests on a complete structure and on individual specimens representative of the joints and jointings used. Other structural tests should establish the resistance of the door to impact loading, and its behaviour under simulated aerodynamic loadings, especially in the hinge and attachment areas.

The replacement cabin door structure of an aluminium honeycomb core and lightweight skinning was proven unsatisfactory, mainly due to its poor impact resistance. If an expanded reinforcement core had been used, as permitted by the existing Contract, the weight limitations imposed by the build indicate that, although the initial failures would not be so severe, repeated impacts at floor level would reduce the material so much that little or no loads would be carried by the structure. It is recommended that the tests as detailed in the original programme be carried out on a door designed as a skin-stringer structure and suitably refaced in impact area.

Work done on the Contract to date indicates that pre-impregnated materials are too costly to process on items for helicopter airframe construction. This is principally due to the high tooling costs for short run production. It is considered, however, that the helicopter rotor blade could be manufactured from pre-impregnated materials at an economic price. The quantity required for a good production run aircraft, involving as it does at least four blades per new aircraft, plus numerous spares, would justify the expensive jigging required. Another factor is that the process lends itself to the requirements of the component. The blade must be produced to a constant envelope profile, aerodynamic shape, weight, and mass distribution. These requirements are readily achieved using a metal die, carefully selected pre-impregnated fibre reinforced materials, and an inflated bag technique to apply the moulding pressure.

Impending designs of new aircraft and improved designs of existing aircraft require the rotor blade to change from its accepted form of a constant flat profile to a highly tapered and twisted section. The metal blade would have to be produced from sheet or extruded shapes which subsequently would have to be reduced and twisted. This extensive processing and jigging would make it more costly than a reinforced plastic blade, which would be reduced and shaped in the initial build. Another advantage of the plastic blade, due to its method of construction, would be its relative freedom from residual stresses.

Lightweight filling of the blade would be effected by in-situ foaming with rigid polyurethane foams.

The working stresses in a rotor blade are comparatively low (in the order of 10000 psi) but as the vibrational frequency of the rotor system is high for reinforced plastic, a material evaluation programme in support of the production of a blade is required. The programme should evaluate the following properties: creep, tensile shear, inter-laminer shear, cross-breaking, compressive strength, tensile fatigue and bending fatigue. Testing should be carried out over a temperature range -40 to 90°C after extensive natural weathering and after ageing in various environments.

7.0. CONCLUSIONS

Variability in the low pressure polyester system vindicated the original choice of pre-impregnated fabric, the test specimens of which gave more consistent results. Results from the polyester system tests indicate that it is possible to build skin-stringer structures where the stress in the skinning is less than 30% of the UTS of the material. This will cater for variables occurring in the system and possible loss of properties due to the effect of various aircraft contaminants that may be present in the operational condition of the structure.

Lightweight honeycomb sandwich structures are sufficiently stiff to replace similar skin stringer magnesium structures. However, in reducing the skinning to a thickness suitable to achieve weight similarity, the structure is suspect to impact loading conditions. Because of this, further work is required to ascertain the suitability of such structures for helicopter components; it is considered that sandwich structures should be replaced by skin - stringer construction, provided that attention is given to redesign of the component concerned.