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Manufacturing Technology of Composite Torque Box of Vertical Fin

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ABSTRACT

This paper includes the problems we have met in research and fabrication of all carbon fiber composite torque boxes of vertical fin, such as selecting resin systems which act as basic matrix in composite, setting fabrication method and designing cure parameters,etc.. Technologies of fabricating full-scale composite parts(skin, hat-longerons, spars, ribs,etc.) and technologies for adhesivly bonding, mechanically fastening are discussed.

The full-scale composite torque box of vertical fin fixed on rear-fuselage has passed its static test. Based on that result, two composite torque boxes were installed on military aircrafts for preliminary flight tests, one of them has been served in flight for more than 100 hours.

INTRODUCTION

Being used on aircrafts, the advanced composite materials show excellent performance because of their inherent characteristics such as high strength and low weight, and this is a strong incentive for their increasing application. However,

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composite materials are quite different from traditional metal materials due to their anisotropic characteristic. In this case, experience of using them is very important.

During the past 17 years, Beijing Aeronautical Manufacturing Technology Research Institute conducted several development programs on carbon fiber composite structure elements. For instance, two kinds of secondary structures and a pair of outer lateral panel passed tests, including some flight tests before 1978.[1]

In order to pursue the development of advanced composite structure, all composite torque box of vertical fin was selected for our continuous evaluations of practical use of the material. This development program started in 1980, which includes the following investigating items:

1. evaluating resin system
2. preparing prepreg
3. element tests for obtaining basic data
4. fabricating method study
5. particular structrue(panel, imitate box,etc.)tests for static strength and stiffness
6. cutout reinforcing method
7. other studies--calculating analysis, mechanically fastening, NDT inspection,etc.
8. full-scale static test and flight test

Boxy thin-wall with twin spars structure was adopted for all composite torque box of vertical fin. Configuration of composite torque box consists of variant thickness skin, hat-stiffener with subside longeron, closed-angle channel spar, reinforcing cutout plate, access cover and ribs with various shapes(15 pieces of ribs),while the existing glass fiber leading edge and metal rudder were retained.

the dimension of skin:

spreadwise length	4230 mm
chordwise length	1135 mm
width at root	2940 mm
width at tip	862 mm

the dimension of spars:

front spar

corner angle	77^{o}
spreadwise length	3280 mm
flanger hight	40 mm

rear spar

corner angle	85^{o}
spreadwise length	2755 mm
flanger hight	35 mm

There are 6 big cutouts in left skin and 1 in right skin, for stiffening cutout edge, a carbon reinforcing plate were adhesively bonded to the area around each cutout.

MATERIAL SELECTION

The selected prepreg is 648/T300-6K made in our research institute. 648 resin system is a kind of novolak system. This resin system was chosen for its long shelf life of 3 months at ambient temperature and controllable high viscosity. The viscous characteristics are obtained through carefully formulating instead of advancing the chemical reaction by heating the prepregging opration.

specification of the prepreg

thickness	0.125±0.01 mm 0.110±0.01 mm
resin content	39%±3% (wt%)
fiber areal weight	$132\pm5 g/m^2$
gel time at 120^{o}c	> 10 min
volatiles content by weight	max 2%
flow content	10-25% after 150^{o}c $6 kg/cm^2$
tack of ambient temp	passed
gap	distance between adjacent tows less than 0.7 mm by 152 mm long

We have done some fundamental property investigations on typical unidirectional and multidirectional laminates, such as tension, compression, shear, flexure and joint pieces fatigue. We have also done some enviroment properties study, such as aging, moisture and temperature effected on composite performance,etc..

TECHNOLOGY OF FABRICATION

Three kinds of methods were used in fabricating advanced composite parts: bag molding, transfer molding and matched molding. most of composite parts are fabricated in an autoclave. During heating process, there is no significant reaction in 648/T300 system before the temperature goes up to 100^{o}c, and the reacting rate is still low enough to permit a dwell at 115-120^{o}c, if necessary, to ensure consolidation and to make resin flow out from the parts with thick section. Apart from this, 648 resin system can be cured in ideal "straight--up" simple cycle, practical cure cycle is illustrated in fig.1.

The thickness of skin is variant, varying from 36 plies at root to 18 plies at tip area. Prepreg tape was laid up in certain directions and sequences on a plain working table according to ply templates(as shown in fig.2), then plies was transported to a cast aluminum mould(see fig.3). After ply block sealed, the mould was pushed into an autoclave. Sealing materials used are:

vacuum bag film	Ipplon DP 1000
breather air weave	No 10
bleeder air weave	S
peel ply	release ply C
Dam material	Airpad
vacuum bag sealant type	GS-213

Spars were cured in transfer moulder. The femal of the mould is made of Airpad and the male is steel. Airpad is a kind of uncured non-silicone rubber, it can be used to intensify and transfer pressure that is necessary for curing composite components.

Hat-longerons were cured in a steel matched mould. At first we tried to use expanasion rubber as mandrel for cocuring skin and hat stiffeners, but soon we found it was too difficult to pull the mandrel from a very small and long cave space enclosed by the hat-section stiffeners and the skin surface.

So finally we decided to produce hat stiffener seperately, then to join hat stiffeners and skin together by adhesivly bonding(see fig.4). For enhancing the peel strength of bonding area, titanium rivet was added in regular distance. fig.5 and fig.6 show the left and right bonded skin cover

After curing , edge trimming can be done by using water jet cutting or a special milling cutter.

Numerous analytic techniques have been exploited for process quality control:

1. differential scanning calorimetry
2. liquid chromatography
3. infrared spectroscopy
4. dynamic dielectric analysis
5. DMA modulus and Damping

The main means for inspection of composite parts are ultrosonic and X-ray radiography. If composite parts which we produced satisfied following criteria, we would consider them as qualified products:

1. no edge delamination
2. voids less than 2% (volume)
3. delaminations reference DPS 4.738-1[2]
4. dimension tolerance ±8% in autoclave
   (thickness tolerance) ±4% in match mould

IMITATIVE BOX TEST

Apart from axial compression and diagoual shear of composite panel, for continuously certifing design, stress analysis and calculation program of the composite structure as well as the quality of the parts produced, we made a imitative box in size of 1065x400x104mm(see fig.7)to imitate the root section structure of composite torque box. This box consists of a top panel and a bottom panel, each panel was bonded with two pieces of hat stiffeners, riveted with two pieces of channel spars located in longitudinal direction at the right and left sides and riveted with three pieces of ribs in transversal direction in regular span. One end of the box was fixed on a forced wall by test jig, the other end was loaded, including pure bending, torsion and combination bending with torsion.

The result showed that predicted values of displacement, strain and stress from computers agree quite with which experiment determined and the difference between the two groups of values is less than 8% only. Table 1 showed the displacement at several measure points.

Table 1 Comparision between Calculated Value and Actual Value of Displacement at Several Points

	point number			
	1	2	3	4
actual(mm)	23.4	23.4	23.2	23.5
calculated (mm)	23.7	24.1	24.1	23.7
error(%)	2.6	3.0	3.9	0.9

ASSEMBLY OF FULL-SCALE BOX AND STATIC TEST

Assembly sequence for all composite torque box is as follows, first, spars and ribs are assembled to an integral bone frame (shown in fig.8), next, put the skin covers over the bone frame one by one to combine the torque box. Vertical fin assembly is completed by adding a glass fiber leading edge and an aluminum rudder, finally, vertical fin is installed, by fittings, to the rear fuselage of a military aircraft(see fig.9). During assembling, mechanical fasteners, hi-lok and titanium rivets, etc. are used.

Before static test, we placed the vertical fin into a room in $-55^{\circ}c$ to observe the rudder active movement condition.

The MTS loading and measuring system was used during the static test.

According to the feature of weak interlaminate shear strength of fiber composite material made by laying up prepreg tape, we substitute the foam rubber cushion for the adhesive tape partially. The foam rubber cushion can easily transfer stress uniformly and prevent peeling between plies.

There are two kinds of test conditions: forth pressure-heart and behind pressure-heart.

After finishing up 100% forth pressure of design load(no abrupt noise recorded on acoustic emission signal paper, no knee point appearing on stress-strain curves), we started behind pressure test, loading didn't stop until torque box had broken down. The breake took place in the area around the mid-connect point with rudder. This is because the rigging pin was taken off and so delamination failure was caused locally. The breake load is 126.7% of design load. The max strain measured is 2250 $\mu\varepsilon$.

FLIGHT TEST

Primary flight tests containing 14 items were completed in August 1985, then, the plane switched to ordinary flight(see fig.10).

BENEFIT

Advantages of using new material and constructure are:

1. simplifying structure and **saving** weight

   Composite material design for the torque box requires only 134 parts and 4479 fasteners, in contrast,an equivalent alumium design requires 190 parts and 8151 fasteners.

   This composite torque box assembly contains 80.6% carbon/epoxy composites by weight, and is totally 32.44% lighter than those of correspondent alternated alumium parts.

2. improving performance

   Using composite material on the torque box results in significant improvement of the structure performance, for example, torsional stiffness and flexural stiffness rise of 15.9% and 4.46% separately. Obviously, the efficiency can be advantages to improve airplane stability.

CONCLUSION

This program aimed at obtaining useful experiences in applying composite to primary structure.

In the past five years, many technology developing and demonstration programs were conducted to gain the expertise and confidence for applying advanced composite materials to primary structure.

Successful flight evaluation of all composite torque box shows that advanced composite has good prospects in future aircraft structure.

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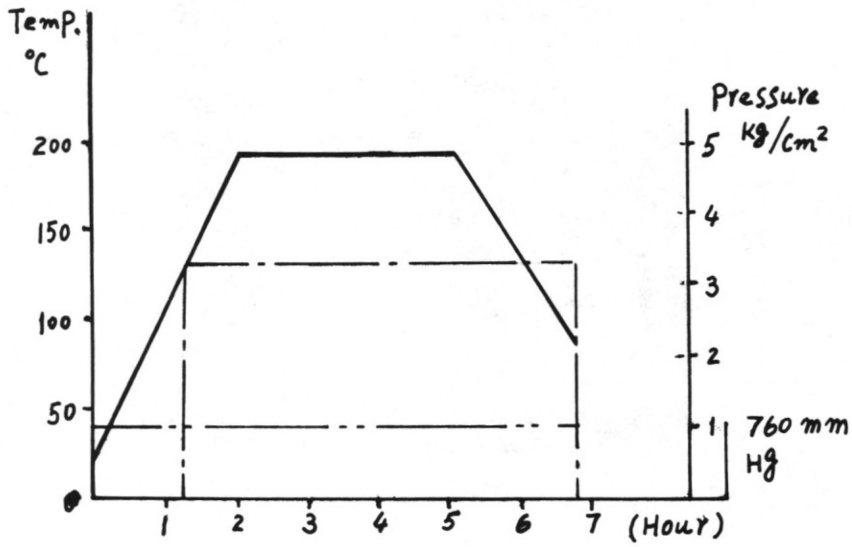

Fig. 1 Temperature and Pressure in the Curing Cycle of 648/T300 System

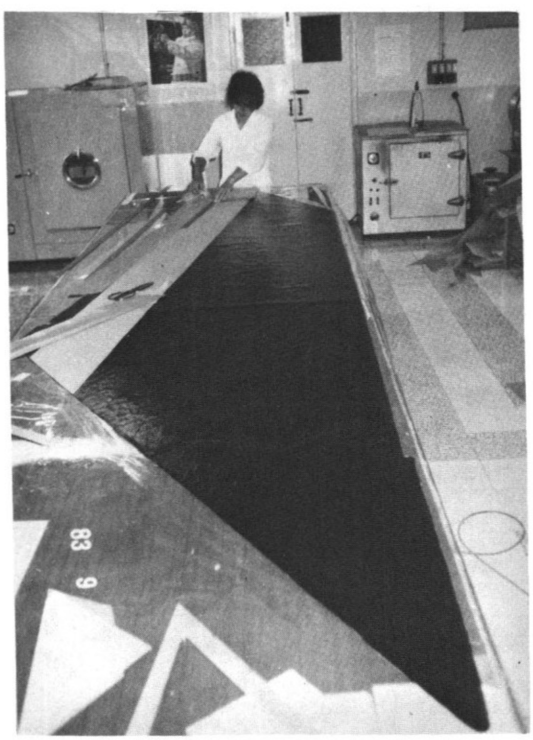

Fig.2 laying up prepreg tapes

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Fig.3 Preparation Work before Curing

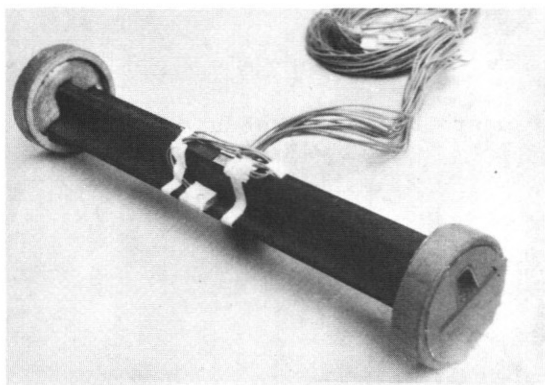

Fig. 4 Adhesively Bonded Hat Stiffener
(single element)

Fig. 5 The left Bonded Skin Cover

Fig 6 The Right Bonded Skin Cover

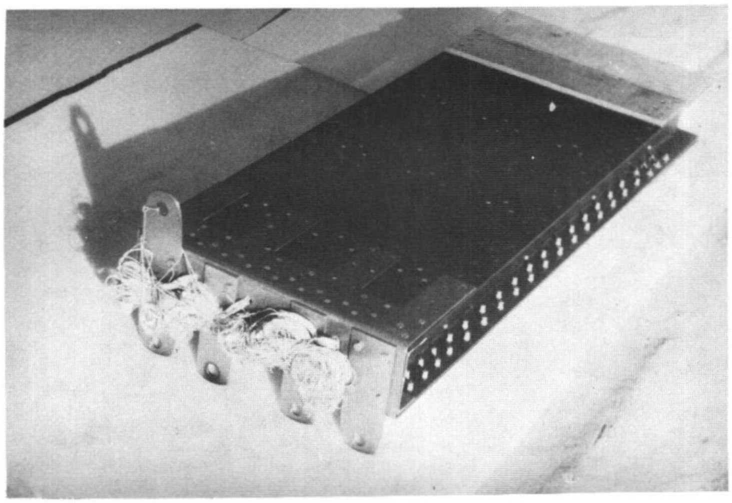

Fig.7 Imitative Box to Be Tested

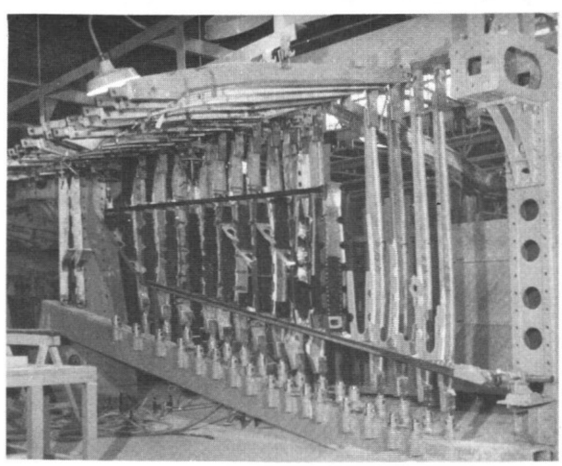

Fig.8 Assembly of Torque Box Bone Frame

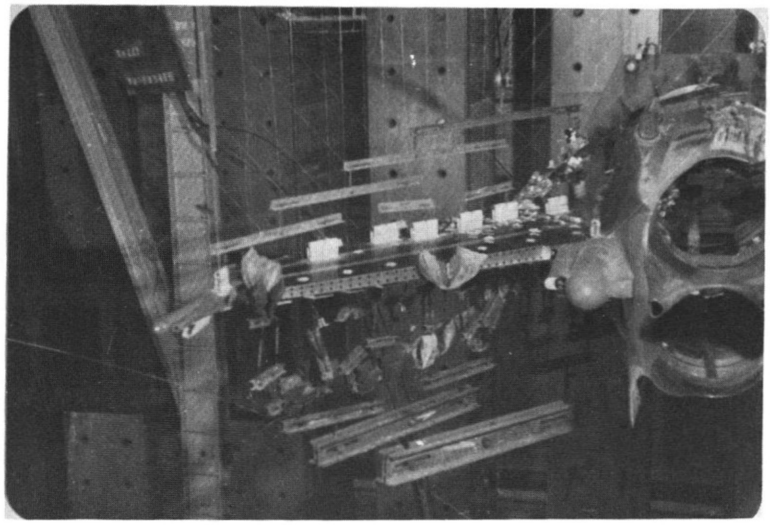

Fig. 9 Composite Torque Box Fixed on Rear Fuselage in Static Testing

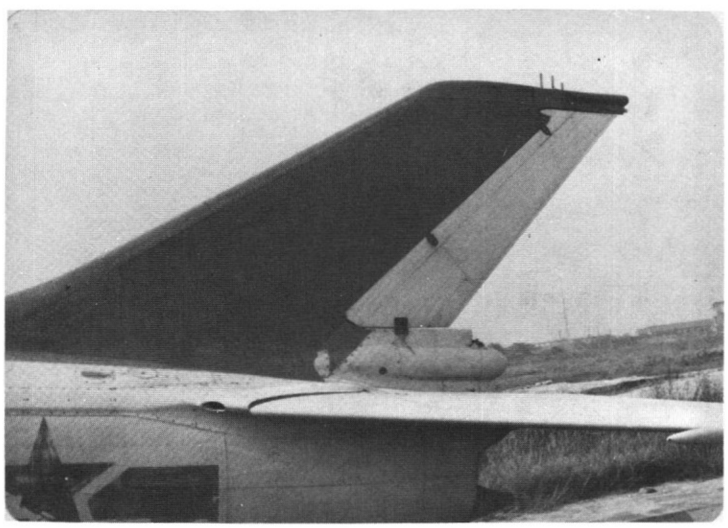

Fig.10 All-Composite Torque Box Installed in a Military Plane