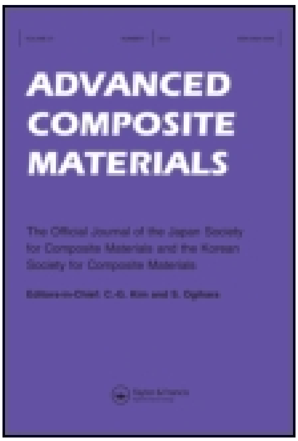


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# Low cost manufacturing approach for composite outer wing of SST

K. KOSUGI [1], S. MAEKAWA [1], Y. HIROSE [1], T. SANA [1], T. HATAKEYAMA [1] and H. TAMURA [2]

[1] *Aerospace Division, Kawasaki Heavy Industries, Ltd., 1, Kawasaki-Cho, Kakamigahara City, Gifu-Pref. 504-8710, Japan*

[2] *Japan Aircraft Development Corporation, Toranomon Daiichi Bldg., 2-3, Toranomon 1-Chome, Minato-Ku Tokyo, 105-0001, Japan*



**Abstract**—Studies on low cost manufacturing processes for composite outer wing of SST (Super Sonic Transport) have been undertaken since 1998. This paper presents the study plan and results of the first two years. An integral skin/stringer panel made of Gr/Bmi(Graphite/Bismaleimide) is set for structural concept. For automated fabrication of structural details, a FPM (Fiber-Placement Machine) is constructed and suitable lay-up conditions are established. To minimize distortions of a large sized composite panel, distortion sources are listed. Curing tests of simplified elements are conducted for evaluations of distortion sources. For the first step of assembly automation, an auto drilling device is constructed and evaluated.

*Keywords*: Fiber-placement; tooling; auto drilling/fastening.

## 1. INTRODUCTION

The key technology for the realization of SST is to design and manufacture a light weight structure with low cost. Materials to be used for SST should be heat resistant because the structures will be heated aerodynamically. Some heat resistant composites such as Gr/Bmi(Graphite/Bismaleimide) and Gr/Pi(Graphite/Polyimide) are the candidate materials for the SST structures. However, heat resistant composites are not easy material for manufacturing, so expensive tooling and skilled labor are required for current manufacturing technology.

A study to develop low cost manufacturing processes for the outer wing structure made of Gr/Bmi was started in 1998. The study is conducted by Kawasaki Heavy Industries Ltd. (KHI) with supervision of Japan Aircraft Development Corporation (JADC). This paper features current results on (1) composite lay-up automation, (2) low distortion fabrication of composite parts, and (3) drilling/assembly automation.

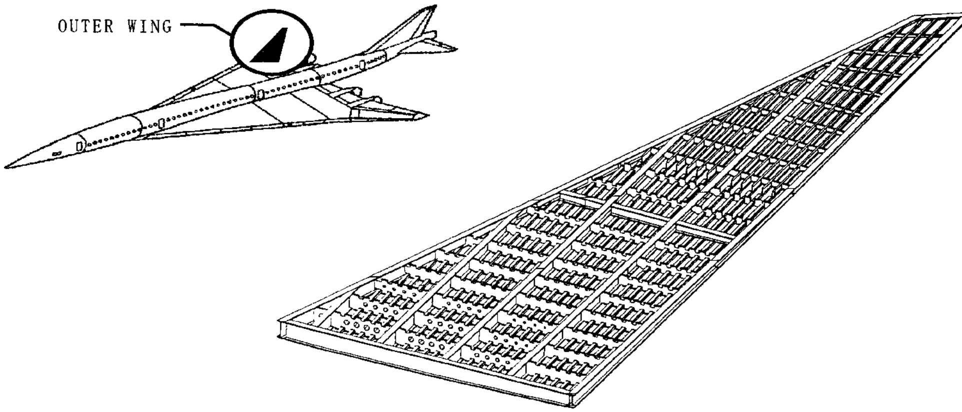



**Figure 1.** Structural concept of the outer wing.



## 2. STRUCTURAL CONCEPT OF THE OUTER WING

Figure 1 shows the structural concept of the outer wing. The structure consists of integrally stiffened panels, a front spar, a rear spar, 4 mid-spars and ribs. Ribs are located at every 600 mm pitch. The cruise speed of the SST is assumed to be Mach 2.2 and Gr/Bmi can be used for the structural component materials of the outer wing. The upper and lower panels consist of skins and I-section stringers made of Gr/Bmi.

Preliminary sizing efforts for the integral skin-stringer panel were done using FEM based internal loads. The skin thickness and stringer shapes were determined to prevent the panel from buckling and keep the applied strain within allowable limits. The stringers are located about every 200 mm pitch and co-cured on the skins. Current analysis results indicate that the skin thickness will be 8 to 10 mm at the root of the outer wing.

## 3. COMPOSITE LAY-UP AUTOMATION — FIBER-PLACEMENT

As manual manufacturing processes, such as hand lay-up, result in a high cost, fabricating processes should be replaced by automation. Though ATL (Automated Tape-Laying) machines offer a lower cost of pre-preg lay-up, application of ATLs is limited to flat or gentle single-curvature parts with large area, such as simple skins. For cost reduction of complex parts fabrication, development of the fiber-placement technology may be the best solution.

Figure 2 shows the application area of the FPM (Fiber-Placement Machine) and ATL on the skin-stringer panel. To apply the FPM to local pad-up, such as circumference of access holes, reinforcement design methodology suitable for the machine are required; and, to apply the FPM to longitudinal parts like stringers, production methodology suitable for the machine is needed.

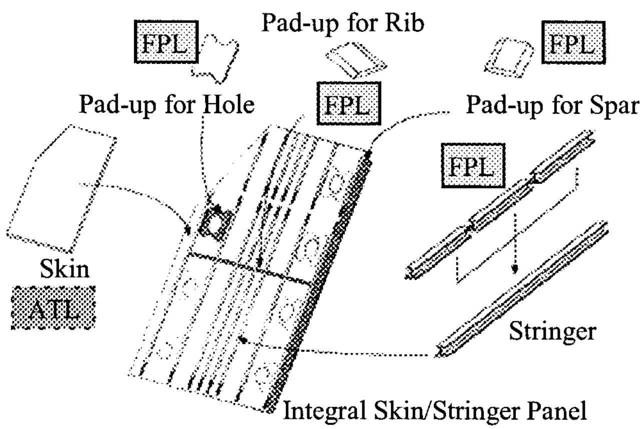



**Figure 2.** Application of FPM and ATL.

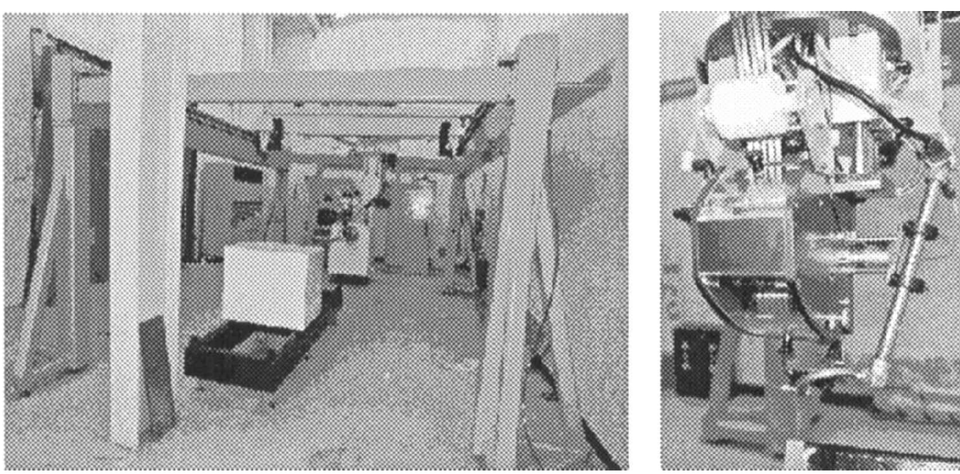


**Figure 3.** Constructed FPM.



A FPM, including the fiber-placement head and the moving platform, has been constructed (Fig. 3). The fiber-placement head put in five tapes of 5 mm width, and pressurized these tapes to complete the lay-up. To evaluate the FPM performances, conventional CFRP tapes were sliced to spools for the machine, and some trial parts including a flat panel with padded-up area and a triangular prism were fabricated. Spools of Gr/Bmi pre-preg for FPM were tried in manufacture and suitable lay-up conditions for the machine have been established. Next, a sub-sized skin/stringer panel will be fabricated for further technology development. Also, trade-off study of the fabrication cost, including material cost and tooling cost, will be performed.

## 4. LOW DISTORTION FABRICATION OF COMPOSITE PARTS

Lay-up mold tools for composite parts tend to be designed without consideration of parts distortion. But large parts of composites may be distorted after curing. If distortion of stiff parts cannot be corrected by finger-push at assembly, the mold tool should be re-worked to cancel the distortion. This is time consuming and expensive to remedy the deficiency through trial and error. The aims of the study are to enable distortion estimation and correcting mold surfaces, to reduce trial fabrications. This development has been undertaken using two approaches.

### *4.1. Evaluation of distortion mechanism*

The distortion mechanism should be researched to estimate distortion value. The thermal variation in the tool, difference of the CTE (Coefficients of Thermal Expansion) between the tool and the laminate, friction between the tool and the laminate can all cause distortions. Shrinkage of resin during cure can be another cause of distortions, for instance, at the enclosed angle of channel or angle components are ‘sprung-in’.

Temperature variation in tool between the windward and the leeward point in the autoclave brings prepreg curing time lag. Temperature distribution of a large (8 m length) tool at curing was measured. Maximum temperature gap was 40°C. The influence of this temperature variation was investigated by curing tests of simple specimens with simulated temperature distribution. The distortion after curing was measured and compared to that of a specimen without temperature variation. The result was that temperature variation did not have much influence on distortion.

Distortions caused by CTE difference between the molding tool and the laminate were investigated. Figure 4 shows an example of the test results. Long, simple specimens of various lay-ups were cured with 3 types of base-plate materials,

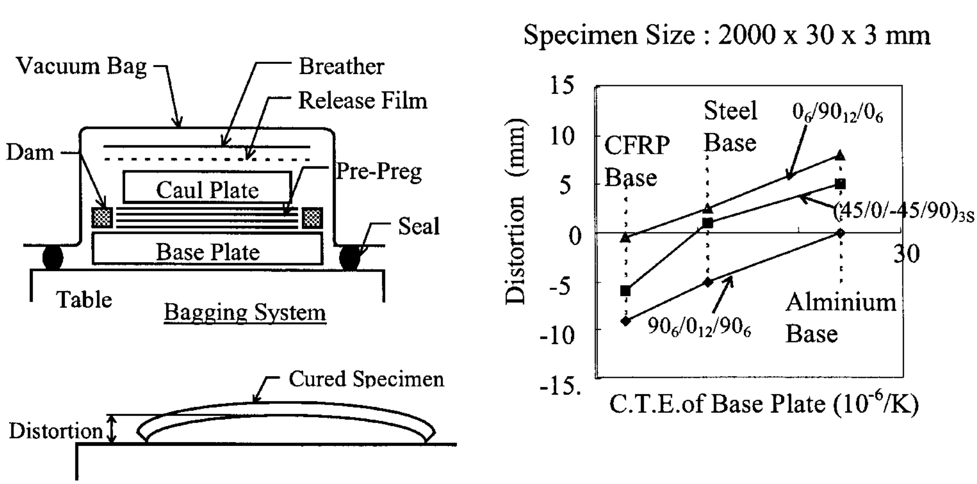
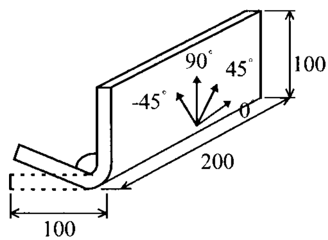



**Figure 4.** Distortion tests — mold material and lay-up.

**Table 1.**
Spring-in test results

| Lay-up | Thickness | Tool angle | Spring-in |
|---|---|---|---|
| $(0)_{16}$ | 2 mm | 90 deg | −1 deg 19′ |
| $(0/90)_{4S}$ | 2 mm | 90 deg | 1 deg 05′ |
| $(45/0/-45/90)_{2S}$ | 2 mm | 90 deg | 1 deg 09′ |
| $(45/0/-45/90)_{4S}$ | 4 mm | 90 deg | 1 deg 04′ |
| $(45/0/-45/90)_{2S}$ | 2 mm | 91 deg | 1 deg 08′ |




without caul plates. It is indicated that distortions are correlative with the CTE difference between near the tool surface of the stacked pre-preg and the tool.

Another set of tests with caul plates indicate that the CTE difference between the base plate and the caul plate results in larger distortion. So, it is hoped to be able to use the same material for the caul plate and the molding tool.

Spring-in angles of various lay-ups are shown in Table 1. Except the all 0 degree lay-up, spring-in angles were about 1 degree for this Gr/Bmi material system.

### *4.2. Low deflection tool design*

The molding tool itself deflects by thermal expansion and its own weight. Analysis of deflection and development of the design for the high stiffness/low heat capacity tool are underway. With regard to the ease and cost of tool fabrication, the most suitable material for a large sized tool bed may be aluminum alloy. On the other side, caul plates may be made of CFRP for ease of tool fabrication and bagging operations. As indicated in the test results on distortions caused by CTE difference, it is hoped to be able to use the same material for the caul plate and molding tool. So, one answer is that 'slip plates' made of CFRP may be inserted between aluminum tool bed and pre-pregs. These tooling concepts will be verified by analysis and tests in the next step of the study.

## 5. AUTO DRILLING/FASTENING

The conventional fastening process of a thick composite part with a metal part is complicated because they are drilled separately and reamed together. Also, a conventional fastening machine is too large; limited structural shapes can be fastened because it restricts access for fastening. For assembly automation, a

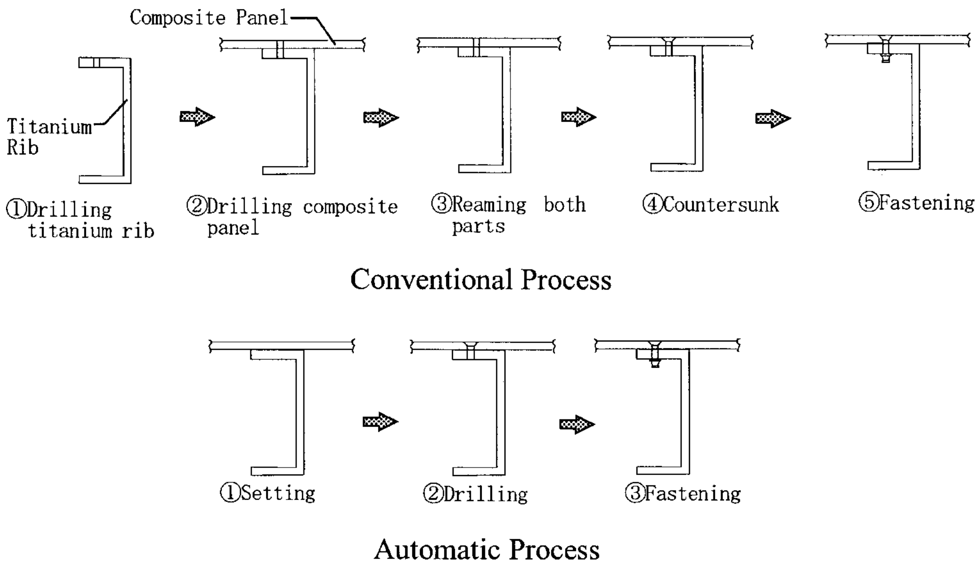



**Figure 5.** Auto drilling/fastening concept.

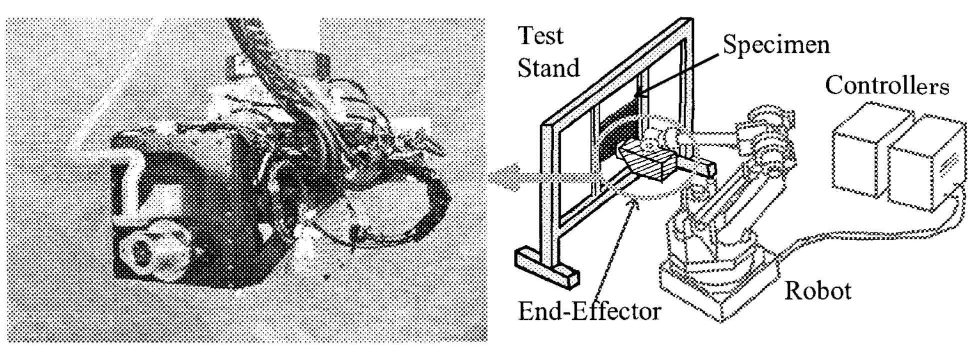



**Figure 6.** Auto driling end-effector on the robot arm.



machine to automate drilling thick composite and metal parts at the same time using the one drill, and a small fastening machine to improve accessibility are needed. Furthermore these drilling and fastening processes will be integrated to establish systematic assembly (Fig. 5).

As the first step for developing the auto drilling/fastening system, a prototype drilling end-effector has been developed (Fig. 6). This end-effector is set on an industrial robot arm, and this can drill through holes for composite and metal joints. Drilling tests for both Gr/Bmi laminates and titanium alloy material have been conducted, and automatic through drilling conditions are established. It is confirmed that automatic drilling technology is effective for thick and hard-to-cut materials.

## 6. DEMONSTRATION AND EVALUATION PLAN

The development of automated manufacturing processes and tooling concept for minimum distortion are to be demonstrated using a large (8 m length) article. This article is a part of the upper skin/stringer panel for the outer wing. The tooling concept for minimum distortion and automated manufacturing machine are evaluated from this integral skin-stringer panel article.

The process components are:

- Checking local and general distortion.
- NDI and destructive inspections at typical structural details.
- Strength test of small panel cut from integral panel.
- Quality evaluation of structure assembled by auto drilling/fastening machine.

## 7. CONCLUSIONS

This project started in 1998 and will solve several technical issues on the way. The achievements of the first two years (designated ‘Done’), and plans for next step of the research program (designated ‘Next’) are summarized below. To reduce the expensive labor cost, fiber placement and the auto drilling/fastening technology will be established. To improve geometric qualities of composite parts, and to reduce the trial-and-error manner of composite tooling/fabrication, low distortion fabrication technology will be required. These manufacturing technologies will be evaluated through the application to trial manufacturing and testing of the large sized panel for the outer wing of a SST.

- Fiber-Placement

  Done A FPM (Fiber-Placement Machine) has been constructed. Suitable lay-up conditions for Gr/Bmi pre-preg are established.

  Next Trial fabrication tests of structural details will be conducted.

- Low Distortion Fabrication

  Done Distortion sources have been listed and evaluated by curing tests of simplified elements.

  Next An analytical method will be developed and evaluated by trial fabrication tests.

- Auto Drilling /Fastening

  Done An auto drilling device has been constructed and evaluated.

  Next An auto fastening device will be constructed and evaluated. Then the system will be evaluated through trial assembly tests.

- Structural Article Fabrication and Evaluation

Done Preliminary design of the large sized panel has been achieved. An evaluation test concept is developed.

Next The large sized panel will be fabricated for trial. Details taken from the panel will be evaluated by structural tests.

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