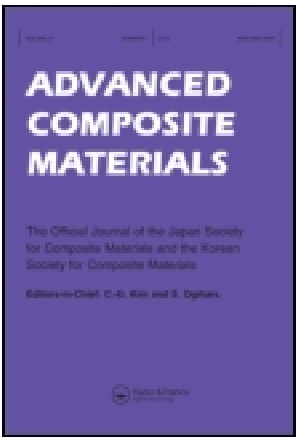

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Development of H-2A launch vehicle composite interstage structure

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Abstract—The Interstage structure of an H-2A launch vehicle was developed as CFRP and foam core sandwich structure by co-curing technique. In the design analysis, nonlinear buckling analysis for a sandwich panel cylinder was conducted considering the imperfection effect of the actual cylinder shape. The manufacturing process of the co-cured composite cylinder was established in various manufacturing tests. The Interstage structure was qualified by a full-scale strength test. The required cost and weight target was achieved.

Keywords: H-2A; launch vehicle; Interstage; composite; CFRP.

1. INTRODUCTION

The National Space Development Agency of Japan (NASDA) has been developing a new low-cost, high-performance launch vehicle named H-2A. The outline of H-2A is shown in Fig. 1. The Interstage is a structure that connects the first stage and the second stage of this vehicle. The Interstage of H-2A is a cylindrical structure, 7 m length and 4 m diameter. The Interstage of the former H-2 launch vehicle was an aluminum semi-monocoque structure. For H-2A we developed it as a CFRP and

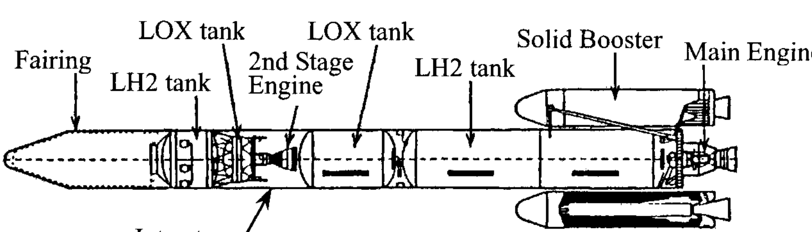

Figure 1. H-2A launch vehicle.

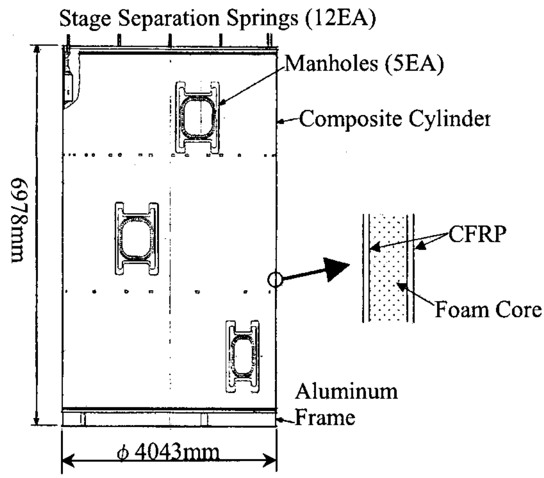

Figure 2. Interstage structure outline.

foam core co-cured sandwich structure to reduce cost and weight. Figure 2 shows the outline of H-2A Interstage. This report describes the Interstage development regarding designing, manufacturing and qualification testing.

2. DESIGN

The usual aluminum semi-monocoque structure consists of many parts, so much processing time and assembling time are required. The H-2A Interstage was designed as a monocoque cylinder made of CFRP and foam core sandwich in order to reduce the number of parts to one-tenth of those in H-2. The 4 m diameter, 7 m length composite cylinder has no partition, and is co-cured from CFRP and foam core. CFRP is 350F cure type inexpensive Gr/Ep fabric prepreg. The foam core is made of polymethacrylimide and each cell of the foam is independent, so this core does not explode under the high temperature and vacuum environment in flight condition, and this is the great advantage over the honeycomb core.

Flight loads on the Interstage are mainly axial compression and bending moment, so compressive stress that is generated by the axial compression and the compression side of the bending moment is critical. The limit load of equivalent axial compression at dynamic pressure maximum is 4.38 MN and the ultimate load is 1.25 times the limit load. The fracture modes of this structure include buckling of the cylinder, and wrinkling of the CFRP face with partial destruction of the manhole.

3. BUCKLING ANALYSIS

The buckling strength of the sandwich monocoque cylinder was evaluated by nonlinear FEM buckling analysis. The model elements of the CFRP face are shells and

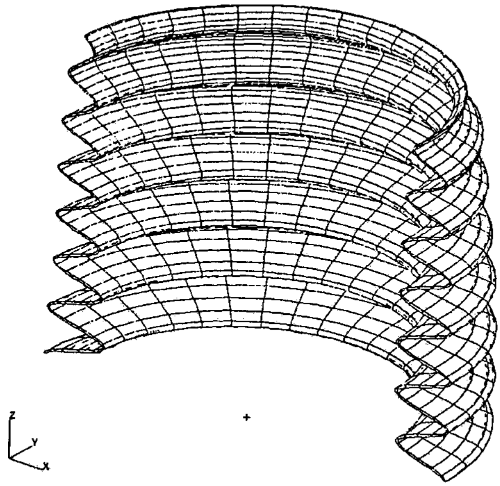

Figure 3. Modal shape of axial buckling.

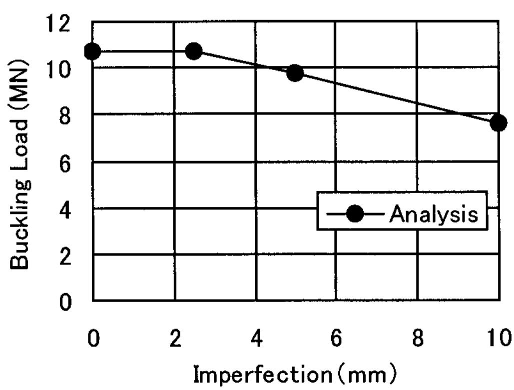

Figure 4. Imperfection influence on buckling strength.

those of the foam core are solid elements. Figure 3 shows the buckling modal shape of the first mode. The first modal shape has axial symmetry and the half wavelength of buckling is about 240 mm, in general. Actual structures are not a perfect cylinder and this initial imperfection greatly affects the buckling strength. We assumed that the imperfect shape is equal to the first modal shape shown (Fig. 3) and conducted the buckling analysis with various imperfection magnitudes. Figure 4 is the analysis result that shows the relation of buckling strength and imperfection. As the result of manufacturing tests, the actual imperfection value is under 8 mm. Consequently it is found that the Interstage structure has sufficient buckling strength.

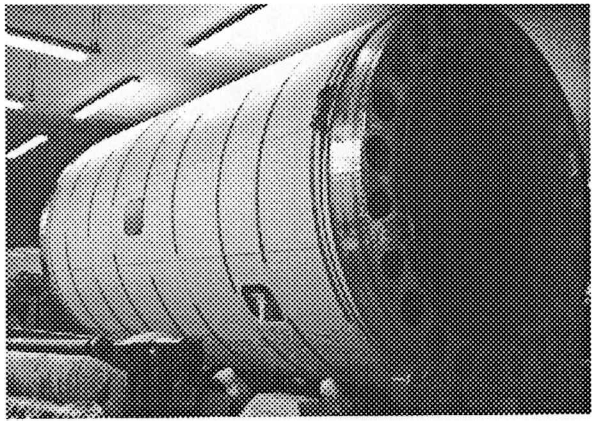

Figure 5. Cylindrical lay-up tool.

4. MANUFACTURE

Figure 5 shows the cylindrical lay-up tool for CFRP prepreg and foam core. This tool has rotation equipment on both ends of the cylinder and operators can lay-up prepreg and core on all of the surface of the tool by rotating it.

The composite cylinder is co-cured under heat and pressure in the autoclave. Under the normal cure pressure condition for this CFRP, we found thickness of the foam core decreases. So we carried out some tests and obtained the pressure condition under which the foam core thickness does not change and CFRP properties do not deteriorate.

For non-destructive inspection of the sandwich panel cylinder, ultrasonic inspection is applied. A probe, which is like a rubber tire, inputs ultrasound from the outside surface of the Interstage and another probe senses it at the inside surface. We conducted compressive strength tests with sandwich articles with an artificial defect and obtained the defect size that would critically influence a decrease in strength and decided on the allowable defect size. Figure 6 shows sandwich panel compressive strength change with size of square delamination as an example of tests results. We confirmed that the ultrasonic inspection equipment could indeed sense the minimum allowable defect.

In order to evaluate the manufacturing process, tests were carried out using a short (2.1 m) cylinder and a full size (7 m) article; then finally the whole cylinder co-cure process was established.

Figure 7 shows the completed Interstage assembly.

5. TESTS

In the development of the Interstage, many tests were conducted as material data tests for design, partial structure strength tests, manufacturing tests, allowable defect tests, acoustic test, static strength tests (qualification tests) and repair test.

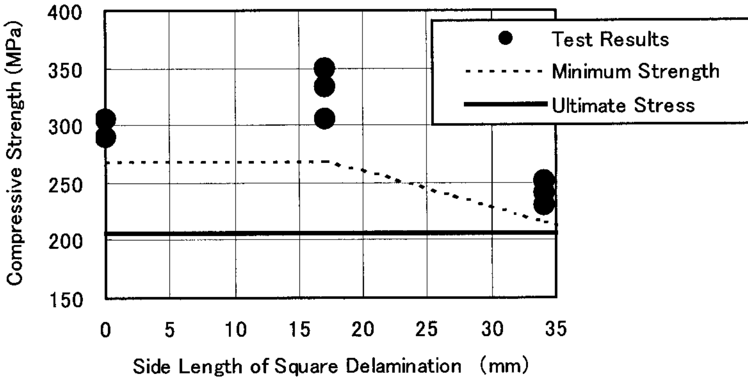

Figure 6. Compressive strength of sandwich panel with a delamination.

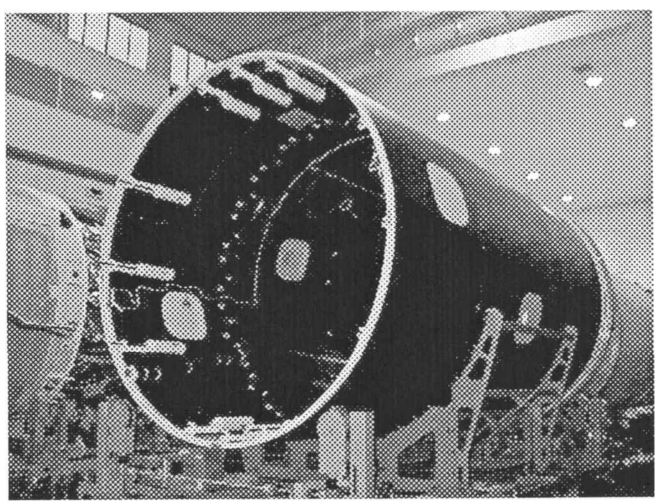

Figure 7. Completed interstage.

In the static strength tests, flight loads were loaded on a full size test article. In total, 7 tests (3 Limit, 3 Ultimate and 1 Overload) were performed, and the test article bore all loads. The maximum load of equivalent axial compression was 6.72 MN.

The lower end of the Interstage connects directly with an aluminum alloy liquid oxygen tank, and the tank radius shrinks by about 9 mm as a result of the cryogenic temperature and tank pressure effect, and so the lower end of the Interstage deforms. In the static strength tests, we simulated this situation by using liquid nitrogen and a tank simulator and we confirmed the effect of the cryogenic deformation on the composite structure. Figure 8 shows the test setup.

Figure 9 shows the axial strain data of inner and outer CFRP sandwich faces at the critical load phase as a typical test result. Test results show a good matching with predicted design analysis and adequacy of the analysis is confirmed.

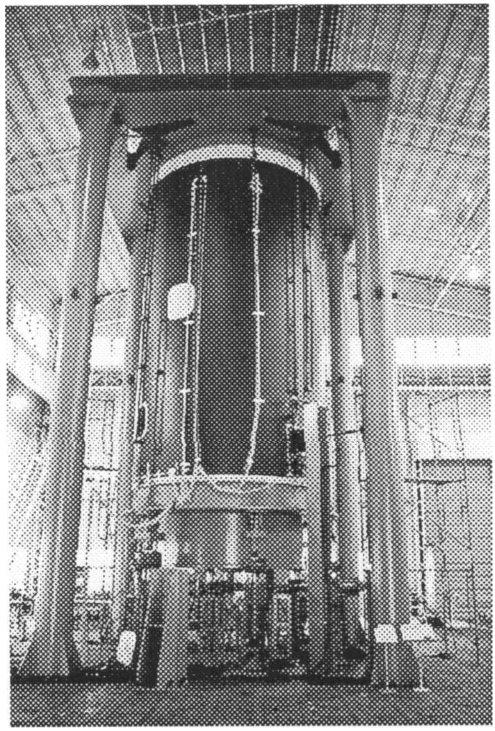

Figure 8. Static strength tests setup.

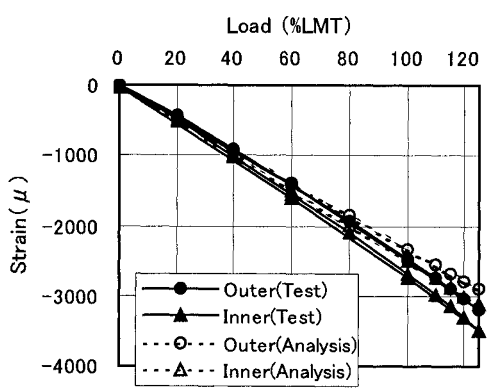

Figure 9. Axial strain of CFRP cylinder lower end.

6. CONCLUSION

In the development of the Interstage, we succeeded in establishing the manufacturing process for a large composite cylinder by co-curing in a short period. Figure 10 shows the comparison of the cost item value between this composite Interstage and an aluminum structure. About 30% cost reduction is achieved. The weight of the Interstage is 820 kg, except for stage separation spring actuators. This is 20% less

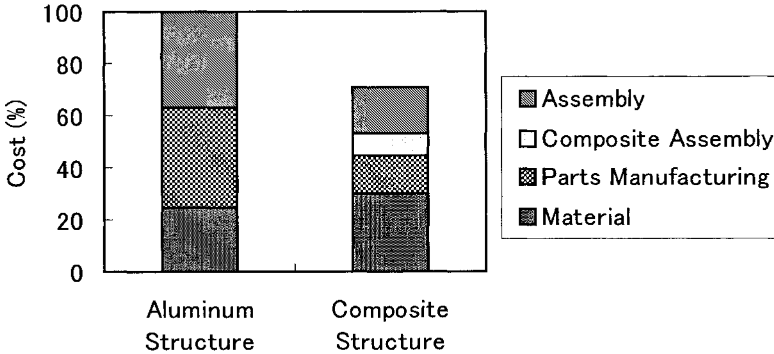

Figure 10. Cost comparison of interstage structure.

than an aluminum structure. Also various useful technical data about the sandwich structure of a CFRP face and foam core have been obtained.