Structural Analysis of Lift-Fan Rotor for Jet-VTOL Aircraft

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Introduction

The Japan Aerospace Exploration Agency (JAXA) has proposed new vertical take-off and landing (VTOL) aircraft known as the Jet-VTOL aircraft shown in Fig. 1 [1,2]. The Jet-VTOL aircraft is based on a canard wing configuration. The aircraft has the clustered lift-fans mounted near the center of gravity for vertical flight, and has the clustered fans mounted beside the vertical tail for cruise flight. Both fans are driven by the core engine mounted inside the aft end of fuselage. The propulsion system is innovative and attractive not to be seen even in the world.

In the present paper, the structural analysis of the lift-fan rotor was carried out. The structural strength of the lift-fan rotor under high centrifugal stress was evaluated based on the stress distribution and the deformation. On the basis of the analysis result, the configuration of lift-fan rotor was modified to improve the strength of structure.

Analysis model and procedure

The lift-fan rotor is shown in Fig. 2. This is an axial fan rotor with a tip-turbine. The rotor consists of 82 tip-turbine blades, the fan-blade shroud, 32 fan blades, the mid-span shroud, and 8 struts. The outer diameter of the rotor is 277 mm, and the tip clearance is 0.5 mm. The rotor is made of an aluminum alloy, A7075-T651. The Young's modulus of the material is 71 GPa, the poisson ratio is 0.33, and the density is 2769 kg/m^3. The weight of rotor is 419 g.

The analysis was carried out in the domain as shown in Fig. 2 in consideration of the geometrical symmetry of the present rotor. Two kinds of analysis models were tested. One was a simple model (model A) with flat plates instead of fan blades to make an analysis easy. Here, a cross-sectional area of flat plate was the same size as that of the fan blade. The other was a nearly original model (model B) to compare

Fig. 1 Jet-VTOL aircraft proposed by JAXA.

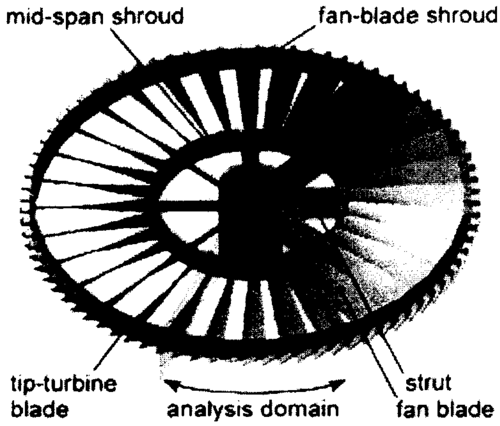
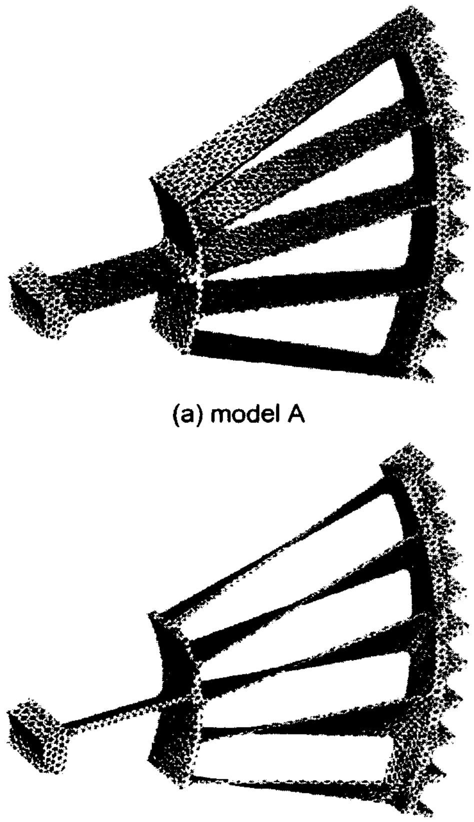


Fig. 2 Lift-fan rotor and analysis domain.



(a) model A

(b) model B

Fig. 3 Meshed model of lift-fan rotor.

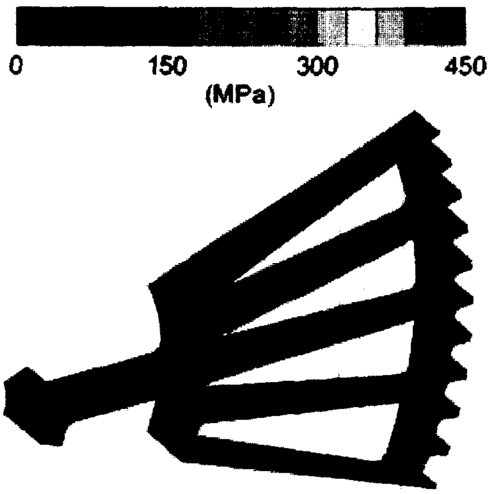
with model A. Figure 3 shows the meshed models of the lift-fan rotor. MSC.visualNastran for Windows was used for the present analyses. As a finite element, a tetra-solid element with 10 nodes was used. The numbers of node and element of model A, shown in Fig. 3a, were 35,481 and 16,912, respectively. Those of model B, shown in Fig. 3b, were 36,878 and 17,918. Since the analysis was carried out in the domain as shown in Fig. 2, boundary conditions were required in the cut planes. The symmetric conditions were given to the cut planes as boundary conditions. Here, there was a problem about an effect of a detorsion of fan blade in the analysis of model B. However, it was assumed that the effect was negligible for the present.

Results and discussions

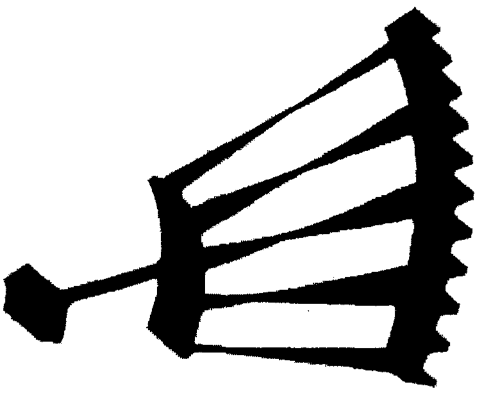
The analysis results of the lift-fan rotor rotating at 16,800 rpm are shown in Figs 4 and 5. Figure 4 shows the distributions of the von Mises stress. In the model A, shown in Fig. 4a, the stress concentration generates on the mid-span shroud of the root of strut. The maximum stress is 448 MPa. This is significantly close to the tensile strength of material, 455 MPa. Thus, the structural strength of mid-span shroud is weak for the present rotor. On the other hand, the stresses on the hub and the fan-blade shroud are relatively low. Therefore, the thickness of the hub and the fan-blade shroud can be made thin. The stress concentration also generates in the model B, shown in Fig. 4b. The stress distribution of model B resembled that of model A.

Figure 5 shows the deformation and the radial displacement. Color in the figure indicates the radial displacement. The maximum radial displacement of model A, shown in Fig. 5a, is 0.293 mm, and is below the tip clearance. The radial displacement of the rotor tip near the cut plane is large. On the other hand, that near the strut is small. Thus, the strut is important for reducing a deformation. Although the deformation of model B, shown in Fig. 5b, is complicated due to the twisted fan blade, the deformations of model A and B resembled each other well. The simplification of model, like model A, is therefore available for the structural analysis of the present rotor.

On the basis of the results, the structural analysis of a modified model (model C) was tried to improve

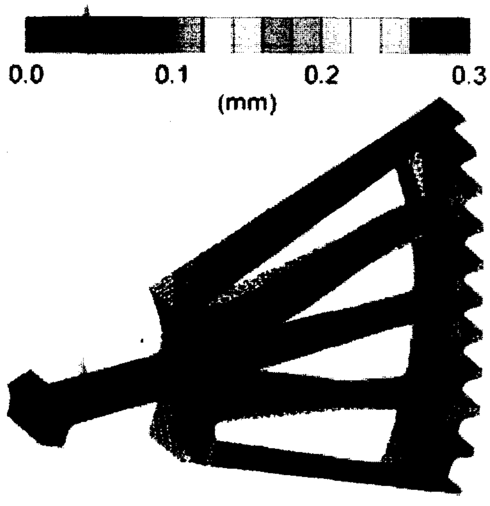


(a) model A

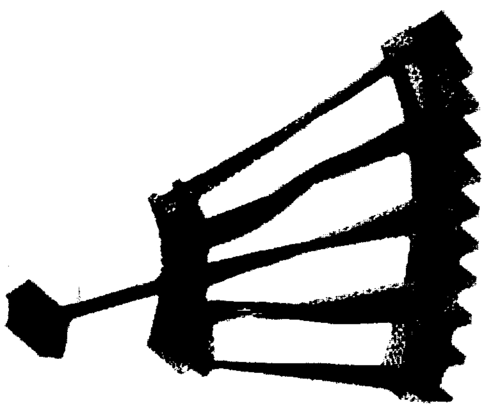


(b) model B

Fig. 4 Distribution of von Mises stress.



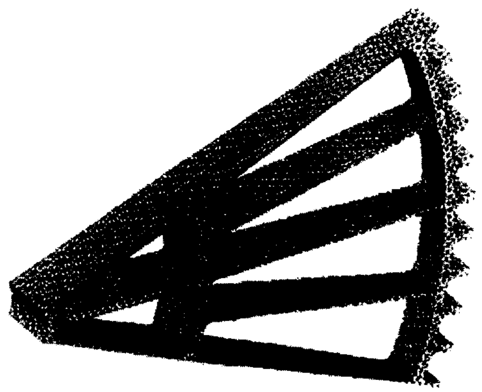
(a) model A



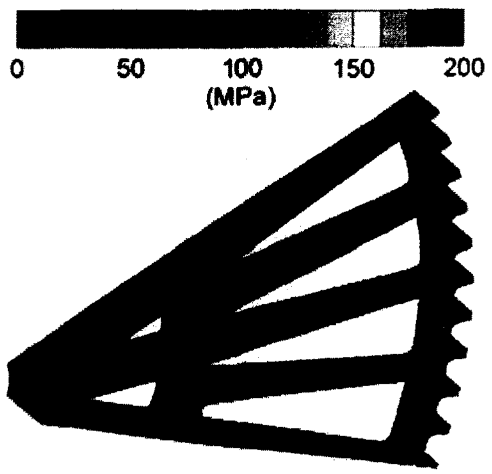
(b) model B

Fig. 5 Deformation and radial displacement.

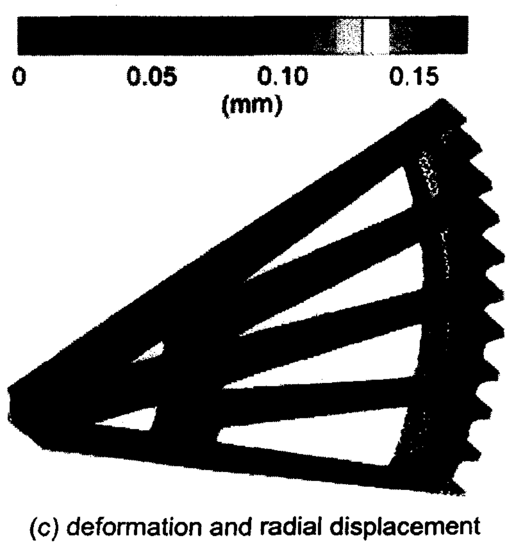
the strength of structure. The analysis result of model C is shown in Fig. 6. Figure 6a shows the meshed model. The number of strut was doubled, and the thickness of mid-span shroud was made thicker compared with that of model A. In addition, the thicknesses of hub and fan-blade shroud were made thinner than those of model A to keep the model weight. The large stress concentration is not recognized anywhere in the stress distribution shown in Fig. 6b. The maximum stress is 174 MPa, and is significantly reduced compared with that of model A. The deformation, shown in Fig. 6c, is also reduced. The structural integrity is improved by increasing the number of strut and the thickness of mid-span shroud.



(a) meshed model



(b) distribution of von Mises stress



(c) deformation and radial displacement

Fig. 6 Structural analysis of alternative model.

Conclusion

The structural analysis of the lift-fan rotor specially designed for the Jet-VTOL aircraft proposed by JAXA was carried out using MSC.visualNastran. The structural integrity of the lift-fan rotor under high centrifugal stress was evaluated based on the stress distribution and the deformation. On the basis of the analysis result, the structural strength of lift-fan rotor could be improved.

References

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