CONCEPTAL DESIGN OF A ROADABLE AIRCRAFT

Masaharu Murai, Takatsugu Hayashi
Kanazawa Institute of Technology

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Abstract

As for a possible future vehicle, several types of roadable aircrafts have been studied recently. In this paper, a compact type roadable aircraft with a fixed ring wing and running stability are investigated.
When a roadable aircraft is driven on the road, its dimension has to be restricted by the Road Traffic Act, which indicates that the wing cannot be large. In flight, an enough wing size is needed to keep the weight and takeoff. One possible solution to solve this antinomy is an inflatable wing. In order to prove a possibility of use of an inflatable ring wing, the deformation of a ring wing The FEM simulations are using MARC.
In addition, for Roadable aircraft, a ground running is important. However, Gear of a plane is not most suitable for a run of a road. Therefore, a new landing gear is needed to run a carriageway to own the road surface which was desolate than an orchid way. We make a characteristic of a landing gear clear to solve a problem to do this antinomy.

1 Introduction

With the increase of travel speed and the expansion of the radius of action, demands for highly efficient and convenient transport have increased in recent years. It is certain that "flying" is the best way to save time in traveling, however, door to door travel by car would be much more convenient and glamorous. One possible solution to solve this antinomy would be a roadable aircraft. The overview and the basic design concept are proposed [1, 2, 3]. The present authors have been investigated a compact type roadable aircraft with a fixed ring wing. The design concept for the wing shape, the driven system, and aerodynamics characteristics was presented [4, 5].

In addition, roudable aircraft must run a road as a car. Therefore, wing structure is Inflatable ring wing. Figure 1 is sky figures of image of a roadable aircraft.

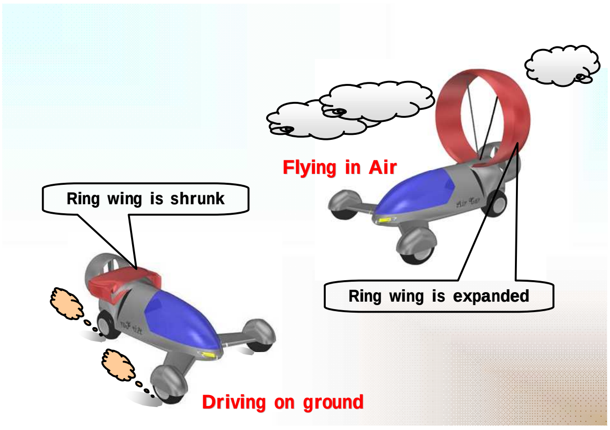

Figure 1 Image of a roadable aircraft

From the results of CFD simulations, it was clarified that a ring wing which diameter is 2.5m restricted by the road regulation cannot produce enough lift, and a ring wing which can be small on road and large in flight is needed for our roadable aircraft [4].

1.1 Study of Roadable Aircraft

There are two purposes of this study.

1. A compact type roadable aircraft with an inflatable ring wing is investigated.
2. Ground running stability is investigated.

Structure analyses were performed to predict the bending stress and the displacement of a ring wing, and the deformation of an airfoil by using commercial FEM code, MARC. Ground running stability is investigated by Excel.

2 A Compact Roadable Aircraft with An Inflatable Ring Wing

2.1 Concept of Inflatable Ring Wing

When a roadable aircraft is driven on the road, its dimension has to be restricted by the Road Traffic Act, which indicates that the wing cannot be large. In flight, an enough wing size is needed to keep the weight and takeoff. One possible solution to solve this antinomy is an inflatable wing. Figure 2 shows a concept of an inflatable ring wing. The ring wing can be shrunk on the road and expand in flight. Therefore, a dimension of a ring wing can be larger than the limit provided by the Road Traffic Act. If a ring wing consists of only a membrane, the airfoil cannot be kept its shape. In this research, space ribs were put inside a ring wing to keep the airfoil shape.

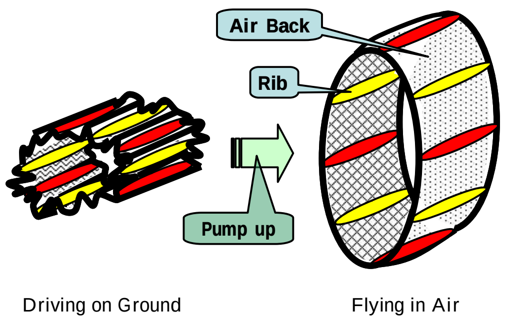

Figure 2 Concept of an inflatable ring wing

Table 1 characteristic of ring wing in this study

Diameter [m]	5
Cord length [m]	1.875
Thickness of wing [m]	0.222(t/c=12%)
Thickness of membrane [mm]	2
Wing section	NACA0012

Table 1 shows a characteristic of ring wing in this study. Composite material to use for Ring wing is aramid fiber (E=49[GPa]) and a carbon fiber (E=70[GPa]). As for the diameter of ring wing 5m and the cord length 1.875m are used in the following simulation. The wing section is NACA0012

2.2 Performance of Ring Wing

2.2.1 Airfoil of Internal Pressure Enough to Keep A Ring Wing

As a membrane is not stiffness, it cannot stand a compressive stress like a stiff wing. A membrane needs to be exerted internal pressure on a ring wing. Before proceeding to the simulation of a ring wing, structural analyses were performed to decide an internal pressure enough to stand a compressive stress. A commercial FEM code, MARC, was used to predict the deformations of an airfoil. The membrane thicknesses are 2mm. The rib space was 200mm. The inside of the airfoil was changed into four cases 1atm, 2atm, 4atm, and 8atm. Shell elements are used for the membrane, and beam elements are used for the ribs. The airfoil is completely restrained at the leading edge.

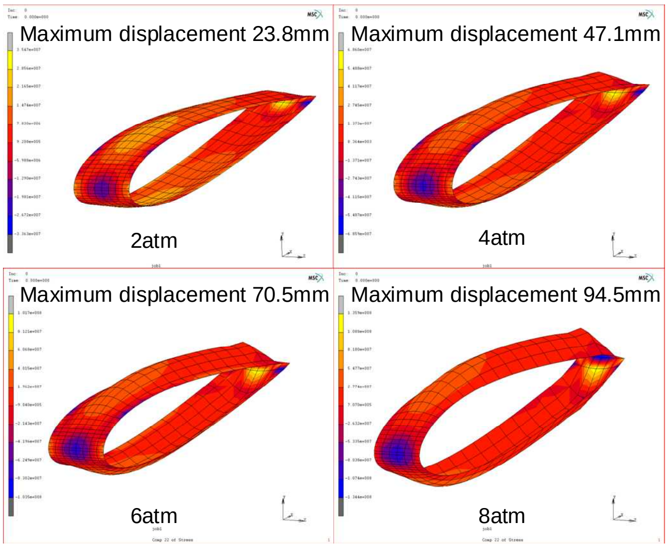

Figure 3 Deformation airfoil

Figure 3 shows the deformation airfoil made by aramid fiber and the normal stress distribution between the ribs with different distances.

Figure 4 and Figure 5 shows at the middle section of airfoil made by aramid fiber and carbon fiber at 2atm. Solid line shows an original shape NACA0012. The airfoil shape for the internal pressure at 1atm is almost the same as the original shape. The airfoil is deformed with the increase of the internal pressure at 2atm.

Airfoil made by a carbon fiber has a smaller quantity of greatest displacement than airfoil made by aramid fiber. As a reason, airfoil made by a carbon fiber has a smaller Young's modulus than airfoil made by aramid fiber.

From these results, we can suppress transformation of airfoil at the minimum by making internal pressure small. In addition,it was found that an ordinary airfoil shape can be kept when the internal pressure is less than 1atm.

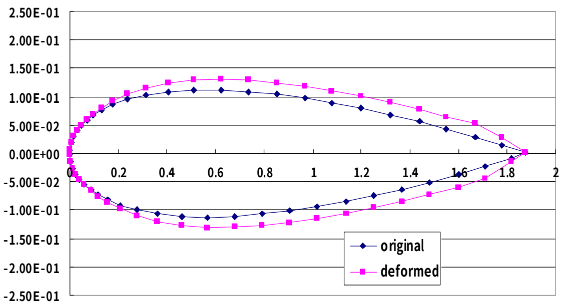

Figure 4 Airfoil made by aramid fiber

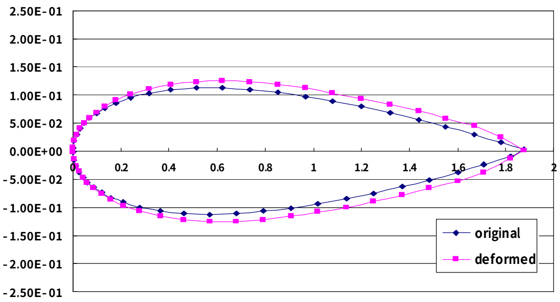

Figure 5 Airfoil made by carbon fiber

2.2.2 Deformation of A Ring Wing

We understood that airfoil made by a carbon fiber was suitable for ring wing, and even lower than internal pressure 2atm can hold transformation in check enough. Therefore we perform structure analysis of airfoil made by a carbon fiber which burdened internal pressure and flight load.

To investigate the influence of internal pressure and flight load upon a deformation, the three dimensional structural analyses was performed. A commercial FEM code, Marc was used to predict the deformations of a ring wing too. Cord length 1.875m calculates external pressure to influence ring wing. Flight load is 5.7G.

Figure 6 and Figure 7 shows stress when ring wing burdened different internal pressure and flight load 5.7G. Internal pressure at 1atm and 2atm. Table 2 shows the membrane maximum main stress, rib minimum main stress and maximum displacement in different internal pressure. Stress becomes maximum 898MPa at time of internal pressure 2atm and is lower than tensile stress of a carbon fiber. Therefore, a membrane sustain stress to occur in a range of internal pressure 1 - 2atm. Compression stress of maximum 765MPa occurs in rib, and it is necessary to make it materials resisting compression stress. A shape break of ring wing is displaced in the approximately 50mm upper part. When quantity of displacement compares it with a diameter of ring wing, there is extremely a little it. Displacement is the range that we can ignore.

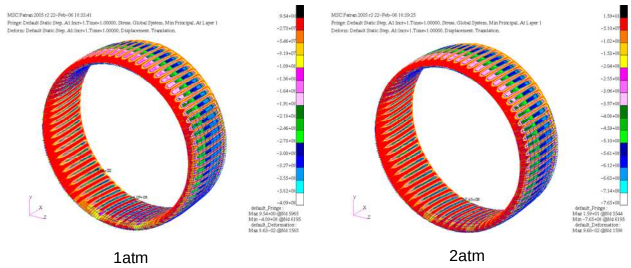

Figure 6 Maximum stress

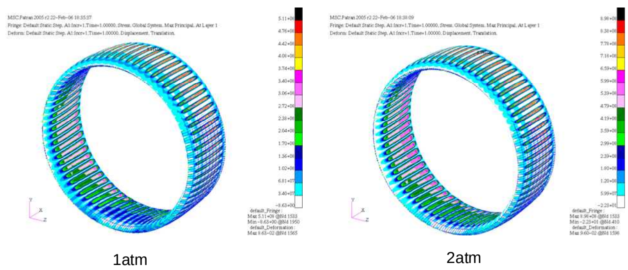

Figure 7 Minimum stress

Table 2 Membrane maximum main stress, rib minimum main stress and maximum displacement in different internal pressure

Internal pressure [atm]	Membrane maximum main stress [MPa]	rib minimum main stress [MPa]	Maximum displacement [mm]
1	511	-409	86.3
2	898	-765	96.0

3 Ground Running Stability

3.1 Concept of A Roadable Landing Gear

For Roadable aircraft, Road Traffic Act is important. However, Landing Gear is not most suitable for ground running. For example, we feel vibration when we are running runway in an aircraft. It seems to have though a puncture. However, there is little bump in runway. In other words a landing gear amplifies minute Road noise. Therefore, a new landing gear is needed to ground running to own the road surface which was desolate than a runway.

3.2 Performance of Landing Gear

We have to know a characteristic of a landing gear to clear this order. A landing gear of Aircraft is different from suspension of a car. Suspension performs the shrinkage of not only the absorption of a shock but also amplitude movement. However, a landing gear performs only absorption of a shock at the time of a landing. It is not thought that aircrafts performance ground running with a landing gear.

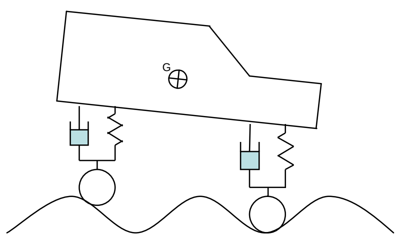

Figure 8 Summary of a simulation model

Therefore a landing gear inspects ground running stability when I run before designing Roadable Landing Gear. Excel was used to predict a landing gear and substitution of vibration of two degree of freedom. Figure 8 is summary of a simulation model.

We understand a landing gear from a spring constant and a damping coefficient.

Table 3 Spec of Oleo Pneumatic Shock Strut and a value of shock absorber of a car

	Oleo Pneumatic Shock Strut	Shock absorber
spring constant [N/m]	9206	510 (Front)
		459 (Rear)
damping coefficient [N･s/m]	179	962 (Front)
		288 (Rear)

As for Table 3, body weight shows a value of theoretical Oleo Pneumatic Shock Strut in case of 751.6kg and a value of shock absorber of a car. These get together at the time of 1G. Table shows that Oleo Pneumatic Shock Strut compares with shock absorber of a car and has high spring constant and low damping.

Figure 9 and Figure 10 is a result of theoretical Oleo Pneumatic Shock Strut and shock absorber. On a road, bumpy of 20 ㎜ thinks it to be a period of 10m. An aircraft and a car speed is 50km/h. As for shock absorber of a car, displacement damps smaller than bumpy. However, as for Oleo Pneumatic Shock Strut, displacement is bigger than bumpy. In other words it does not damp. Because a spring constant of a aircraft is much bigger in comparison with a spring constant of a car. In addition damping coefficient of an aircraft is smaller.

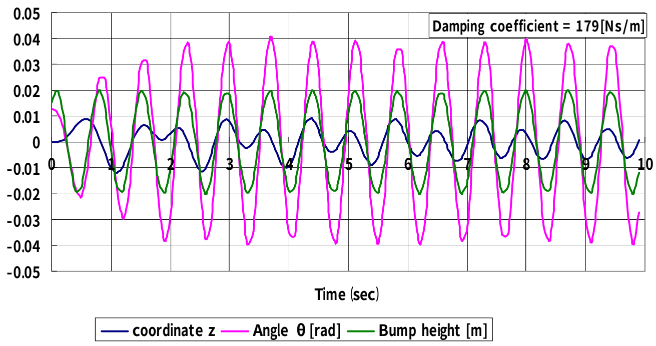

Figure 9 Result of Oleo Pneumatic Shock Strut

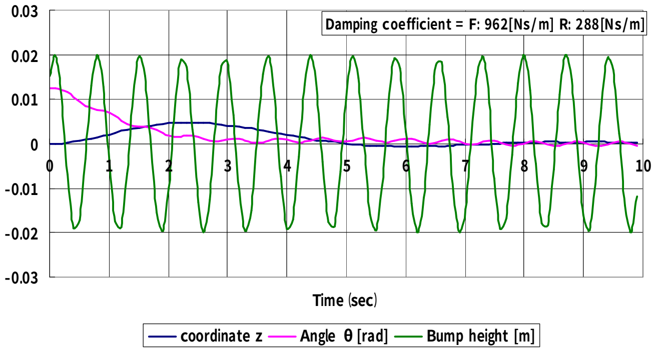

Figure 10 Result of shock absorber

In addition, a tire is different from a car by aircrafts, too. Table is a tire of an aircraft and relations of tire internal pressure of a car.

Figure 11 is a vibration wave pattern when we used a damping coefficient of Oleo Pneumatic Shock Strut and spring constant of a tire. Spring constant of tire is 294N/m. In other words an aircrafts tire performs a role same as shock absorber of a car. However, a spring constant of tire becomes smaller than a car. This cannot be worthy of cornering force.

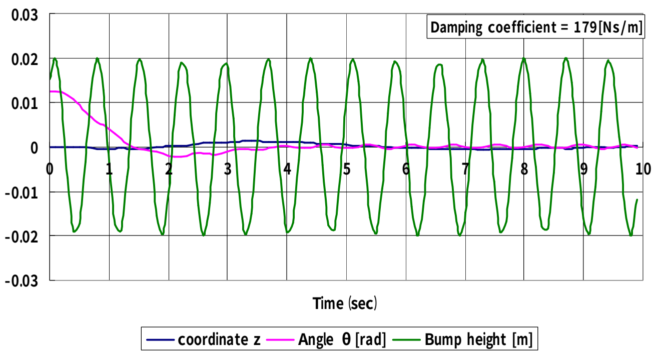

Figure 11 Result of a damping of Oleo Pneumatic Shock Strut and spring of a tire

4 Discussion

4.1 A Compact Type Roadable Aircraft with An Inflatable Wing

Referring to the FEM simulation results shown in the previous section, Materials of ring wing is estimated. From the FEM simulation results,

Quantity of displacement at rib-rib and stress to occur become small so that internal pressure to burden in Ring wing is small. In addition, tensile stress and compression stress to act on airfoil change internal pressure, but an outbreak point does not change.

Aramid fiber and carbon fiber cannot keep airfoil when internal pressure rises. Therefore ring wing of aramid fiber has to set internal pressure in 1 - 3atm. In addition, ring wing of a carbon fiber has to set internal pressure in 1 - 2atm. However, airfoil keeps form in 1atm enough.

As for ring wing made by aramid fiber, transformation grows big than ring wing made by a carbon fiber.

Therefore, in this study, we make internal pressure to burden in ring wing 1atm, and a carbon fiber is most suitable for materials of ring wing.

We must lower internal pressure to reduce uneven of a wing. Ring wing which fell down of internal pressure must investigate shape stability by agitation at the same time.

Compression stress occurs in Rib. Therefore rib cannot use materials same as airfoil. Because rib becomes not worthy of compression stress. We must make rib and airfoil with different materials.

4.2 Ground Running Stability

Referring to the Excel simulation results shown in the previous section, ground running of a landing gear is estimated. From the Excel simulation results, Oleo Pneumatic Shock Strut is not most suitable for ground running.

However, we can make roadable landing gear by putting the spring constant that is most suitable for a dumping coefficient of Oleo Pneumatic Shock Strut together.

This study used an approximation line of a target point to think Oleo Pneumatic Shock Strut to be linear. As a reason, Excel simulator cannot use a non-linear spring constant. Therefore, the experiment was not able to lead an ideal calculation result.

It is necessary for us to use a non-linear spring constant to succeed by this experiment. In addition, roadable aircraft catches big cornering forces to turn at high speed like a car. Therefore we must design suspension with a few changes of alignment. Structure unlike a landing gear is necessary. Furthermore, we find weight than a design of suspension, and the calculation that considered spring bottom weight will be necessary. And a lightweight landing gear must be investigated in the future.

5 Conclusion

The possibility of use of inflatable ring wing was investigated and A Roadable Landing Gear was investigated by FEM and Excel simulations in this paper. Obtained conclusions are the follows:

1. It becomes clear that airfoil made by a carbon fiber is suitable for ring wing. In the case of internal pressure less than 2atm, an airfoil shape can be kept an ordinary shape NACA0012.
2. Displacement of ring wing when internal pressure 2atm compares it with a diameter of ring wing, there is extremely a little it. Displacement is the range that we can ignore.
3. A membrane sustained stress to occur in a range of internal pressure 1 - 2atm. But it is necessary to make rib material resisting compression stress.
4. Oleo Pneumatic Shock Strut can make roadable landing gear by putting the spring constant that is most suitable for own dumping coefficient together.
5. We have to simulate it with a non-linear spring to simulate the oleo pneumatic gear characteristic.

References

[1] M.D.Moore, *Personal Air Vehicle Exploration(PAVE)*, Revolutionary Aerospace Systems Concepts (RASC), NASA Langley Research Center, (2002), http://rasc.larc.nasa.gov/rasc_new/rasc_fy01_top/

[2] R.N.McGrath, *Economic Viability of NASA's Next-Generation Aviation Paradigm*, A Summary of Research Findings, SAE paper 2002-01-2924, (2002).

[3] B.Sarh, *Advanced Flying Automobile*, http://www.afaco.com/index.html

[4] M. Nakajima, T. Fukasawa, H. Kikukawa, A. Yanagisawa, *Design of a roadable aircraft of fixed wing and the investigation of the aerodynamics characteristics*, SAE technical paper 2004-01-3124.

[5] M. Nakajima, H. Kikukawa, T. Fukasawa, A. Yanagisawa, *Investigations on Inflatable Ring Wing of a Compact Type Roadable Aircraft*, WAC 2005 technical paper 05WAC-43