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Design and Computational Analysis of Da Vinci Parachute Design in Steady and Unsteady Flow with Varying Vent Hole Ratio

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***Abstract*: In this research a pyramid shaped parachute inspired by the design of Da Vinci is analyzed using computational fluid dynamics. The effects of Reynolds number on the pyramidal parachute is analyzed with and without vent holes. The Reynolds number is varied from 1×10^4 to 1.5×10^5, and the drag coefficient varies, beyond which the drag coefficient remains constant. Vent holes are provided at the apex of the canopy, the ratio of vent area to the base area is increased from 0% to 10%. moment coefficient values for canopy with varying vent ratio is obtained for different angle of attack to find the static stability of the parachute. It is seen that the canopy with vent ratio of 6% is more stable than the canopy without vent. The oscillation of the parachute is obtained by fluid structure interaction between the fluid and structural mesh. The oscillation of parachute with 0% vent hole ratio and 6% ratio is obtained.**

***Keywords*: fluid structure interaction, oscillation, parachute, stability, vent holes.**

1. Introduction

Parachute has long been used as one of the safety device during any fall. The canopy of parachute design has evolved a lot from time to time. There were various parachute designs in use which are flat circular ribbon parachutes, ribbon and ring parachutes. In this paper a parachute with pyramid shaped canopy is subjected to fluid flow of varying velocity. The design was inspired from the drawings of the LEONARDO DI SER PIERO DA VINCI which is preserved in the book called CODEX ATLANTICUS. Using his writings, the canopy dimensions are obtained which is 7.62m×7.62 m base with the apex height of 7.62m.To obtain the drag coefficient and stability of the parachute both in steady and unsteady conditions.

The parachute modal is developed in CATIA V5R20 and exported to the ANSYS academic version 2021 in IGES format. Fluid analysis is performed in ANSYS FLUENT. Structural analysis in ANSYS TRANSIENT STRUCTURAL. For the analysis shear stress transport modal is chosen to simulate the flow. Coupled algorithm is used for better prediction of velocity and pressure in a flow. The 1st order implicit formulation is used in fluent analysis. In 1 way fluid structure interaction method, the dynamic stability of the parachute model is obtained.

2. Governing Equations

The flow both considered steady and unsteady. The shear stress transport model is used in this paper. the equation is as follows,

$$\frac{\partial}{\partial t}(\rho\kappa)+\frac{\partial}{\partial x_i}(\rho\kappa u_i)=\frac{\partial}{\partial x_j}\left(\Gamma_k\frac{\partial k}{\partial x_j}\right)+G_k-Y_k+S_k$$

and

$$\frac{\partial}{\partial t}(\rho\omega)+\frac{\partial}{\partial x_i}(\rho\omega u_i)=\frac{\partial}{\partial x_j}\left(\Gamma_\omega\frac{\partial \omega}{\partial x_j}\right)+G_\omega-Y_\omega+D_\omega+S_\omega$$

Where,

G_k represents turbulence kinetic energy generation due to mean velocity gradients

G_ω represents specific rate of diffusivity generation

Γ_k and Γ_ω represents effective diffusion of k and ω

Y_k and Y_ω represents dissipation of k and ω

D_ω is the cross-diffusion term

S_k and S_ω are the source term.

1) Equations used

Any falling object exhibit an air resistance during fall which slows down the velocity at which the object reaches ground. The velocity at which the object reaches ground is the terminal velocity.

The terminal velocity is given by,

$$v=\sqrt{\frac{2w}{\rho s c_d}}$$

Where,

c_d is the drag coefficient of the object

W is weight of object in Newton

ρ is the density of air

S is the surface area of the object

To find the terminal velocity of the object the drag coefficient is necessary. The drag coefficient of the canopy is

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estimated by simulating flow over different Reynolds number. Stability of the parachute is obtained using the formula,

$$\frac{\partial c_m}{\partial \alpha} < 0$$

$$M(\alpha)=0$$

Where,
c_m is coefficient of moment
α is the angle of attack

3. Assumptions

- The flow is ideal with density of air, ρ=1.225 kg/m^3 and the air viscosity to be 1.7894× 10^{-5} kg/ms and the temperature of air is 288.16 K
- The flow is incompressible
- The parachute canopy is non-porous

4. Design

The parachute model is designed in cad software CATIA V5R20 using part design and the canopy vent ratio is increased gradually. Each design is saved and exported to ANSYS Academic version 2021 in IGES format.

Table 1
Dimensions of parachute

Components	Dimensions
Canopy area	129m^2
Canopy thickness	1mm
Suspension line length	14.03 m
Suspension line diameter	10mm

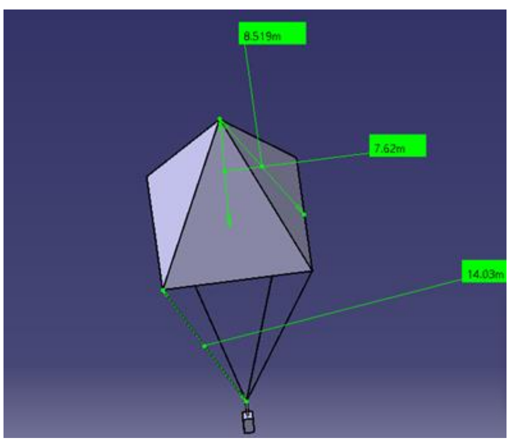

Fig. 1. 3D Model of Parachute Design

5. Numerical Setup

The parachute canopy with varying vent hole ratio is subjected to flow with Reynolds number varying from 1×10^4 to 1.5×10^5, the drag coefficient obtained for Reynold number is given below.

Using the drag coefficient obtained the terminal velocity of the object is found using the formula mentioned above. The calculated terminal velocity is 9m/s.

1) Meshing and solution setup (fluent)

In this mesh sizing is done in various parts of the model. The mesh size kept at 500mm at canopy surface. The mesh size is kept 40mm in suspension lines. The payload mesh size is 70mm. the mesh size in fluid domain is 1250mm. Initially the mesh failed due to very small thickness.to overcome this problem virtual topology is used in affected parts. The tetrahedral elements are used to mesh. For the solution, quadratic element order is used. The total mesh elements are 194706 and the no of nodes is 43819.

The flow domain chosen is box domain. Which is 10×10×10 m. The inlet boundary condition is velocity inlet, outlet is set to pressure outlet and the far field is set to wall boundary condition without slip. Flow velocity is set equal to the terminal velocity. SST k-ω model is used to simulate the flow. Coupled algorithm is used. To obtain different angle of attack, the velocity components are changed accordingly. For the steady state flow, the moment coefficient for different angle of attack is obtained. For the transient flow analysis, dynamic mesh zones are created. In which the inner, outer and tip of the canopy are set to deforming along with the suspension lines and payload. While the inlet, outlet and the far field are kept stationary.

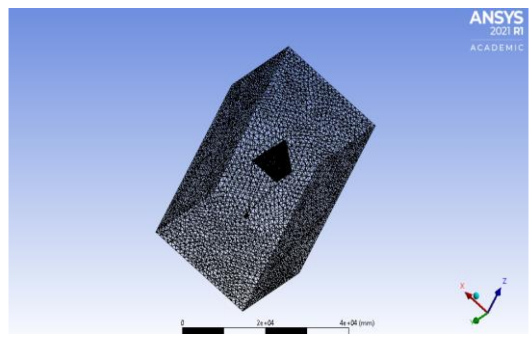

Fig. 2. Mesh of model in fluid domain

2) Meshing and solution setup (structural)

Table 2
Material properties

Components	Material	Young's Modulus
Canopy	linen	11Gpa
Suspension line	nylon	2.7Gpa

In this mesh sizing is done in various parts of the model. The mesh size kept at 300mm at canopy surface. The mesh size is kept 40mm in suspension lines. The payload mesh size is 70mm. Quadratic element order is used. The no of elements is 39163 the no of nodes is 90318.

Since the parachute model used for analysis is in the fully inflated shape to restrict any movement the edges of the canopy are fixed. Standard earth gravity is applied. A payload of 1100 kg is attached to the suspension lines end.

3) Fluid structure interaction

To obtain the oscillation of the parachute during descent the fluent mesh and structural mesh are coupled. The oscillation is measured along the pitch angle. The solution from the fluent analyses is imported to the structure as pressure load. By this 1-way fluid structure interaction is established for the parachute with vent hole ratio of 0% and 6%.

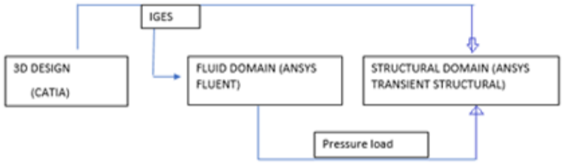

Fig. 3. Block diagram

6. Result and Discussion

As the parachute canopy is subjected to increasing Reynolds number the drag coefficient stabilizes at 1.5×10^5 beyond which the drag coefficient remains constant. The drag coefficient of pyramid shaped canopy is found to be 0.73 at 0% vent hole ratio. From the fig. 5, It is seen for the parachute without vent hole the static stability is about $\pm$ 4 deg of the angle of attack. results after the fluid structure interaction indicates the parachute oscillates between 6deg during descent.

The vent hole is increased to 4% here the drag coefficient obtained is 0.71 but the static stability of parachute is poor compared to the parachute without vent hole

The vent hole is further increased to 6% here the drag coefficient obtained is 0. 7. From the graph (2), It is seen for the parachute without vent hole the static stability is about $\pm$ 2 deg of the angle of attack. Results after the fluid structure interaction indicates the parachute oscillates between 3deg during descent.

The vent hole ratio is further increased to 8% the drag coefficient obtained is 0.69 but the static stability of parachute is poor compared to the parachute without vent hole.

The vent hole is further increased to 10% the drag coefficient is further low which is 0.31. hence any further increase in vent hole ratio is avoided.

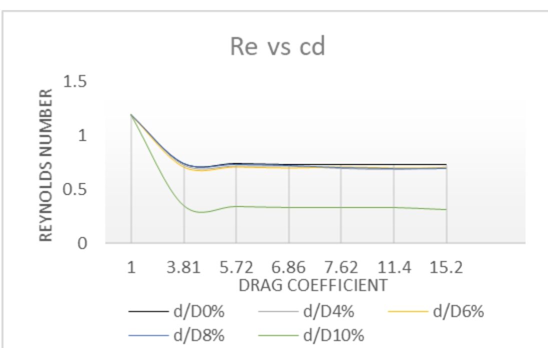

Fig. 4. Reynolds number vs. Drag coefficient

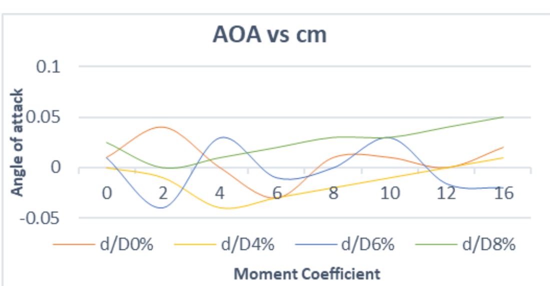

Fig. 5. Angle of Attack vs. moment coefficient

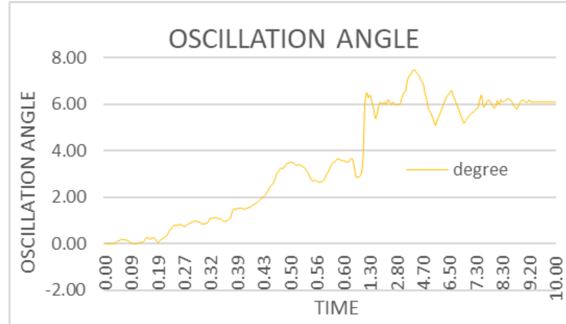

Fig. 6. Oscillation angle for 0% vent hole ratio

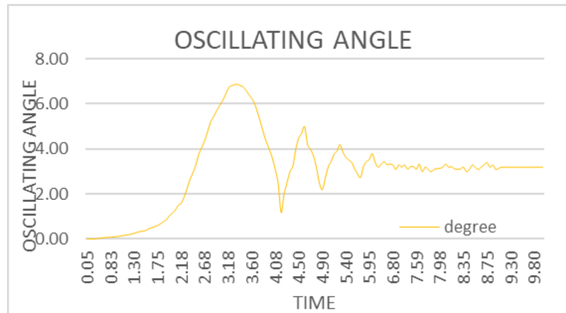

Fig. 7. Oscillation angle at 6% vent hole ratio

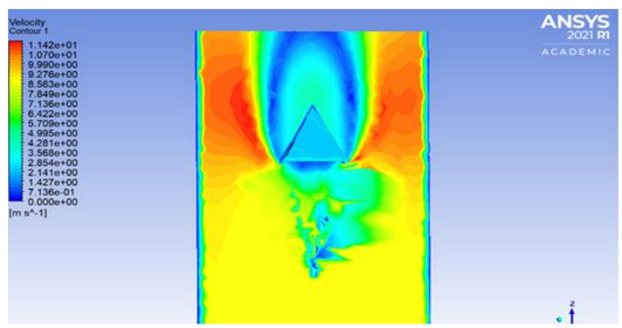

Fig. 8. Flow separation 0% vent hole ratio

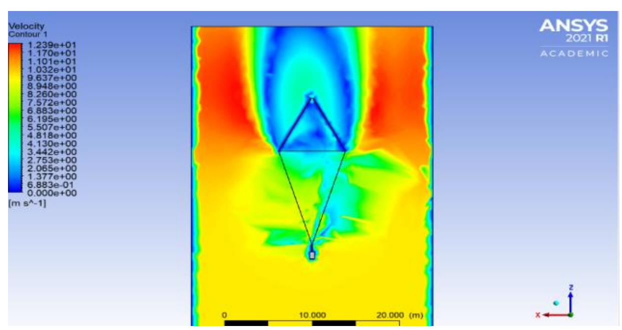

Fig. 9. Flow separation 4% vent hole ratio

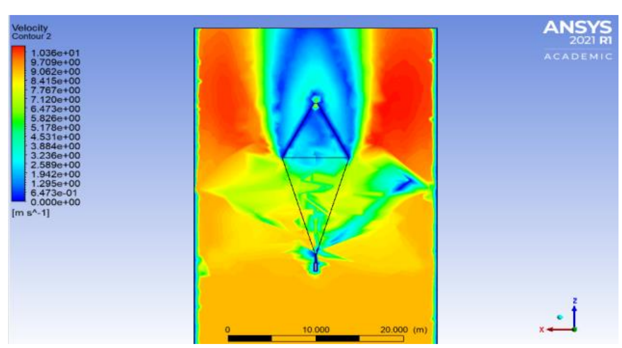

Fig. 10. Flow separation 6% vent hole ratio

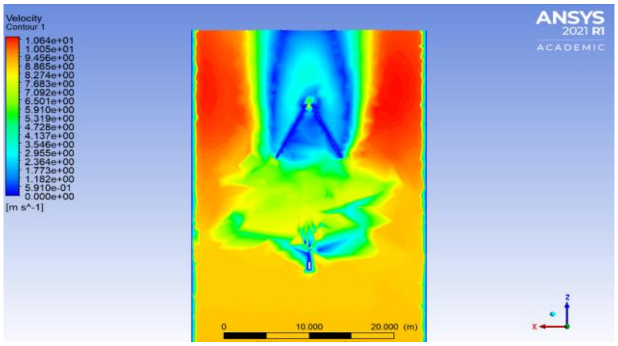

Fig. 11. Flow separation 8% vent hole ratio

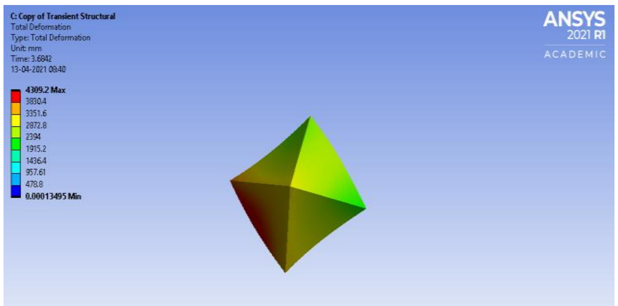

Fig. 12. Deformation at 0% vent hole ratio

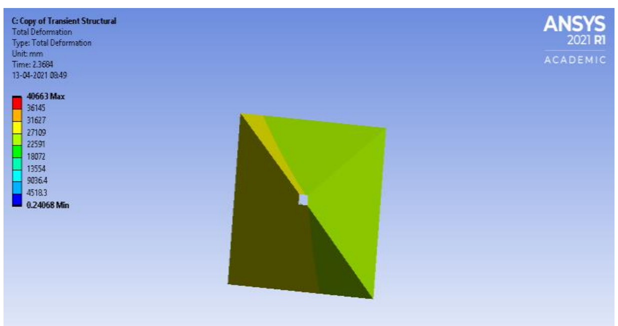

Fig. 13. Deformation at 6% vent hole ratio

7. Conclusion

From the paper the aerodynamic efficiency, static and dynamic stability of the da Vinci parachute design with and without vent hole is analysed.it is seen the drag coefficient with 6% vent hole ratio is as stable compared with the cruciform parachute, with slower descent. however, the inflation phase is not analyzed in this paper it will be carried out for future research works.

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