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Experimental and Numerical Investigation of Fabric Permeability on Drag of Conventional Parachute

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ABSTRACT: Maximum drag achievement is the main purpose in parachute design. Common assumptions in parachutes simulation are simplified inflated canopy geometry and impermeability of parachute canopy. In this research, these assumptions result in evaluation reduction of numerical simulation. By considering the permeability and its effects on flow domain, accuracy of numerical simulation increases. Coefficients of Darcy's modified equation were resulted from experiments applied for numerical simulation of some simplified canopies. Assuming permeability for the canopy, the drag coefficient showed a 24 percent decrease compared to the impermeable one. By experimental tests, drag of the permeable and impermeable canopy was measured in low speed wind tunnel test. Geometries of inflated canopies in wind tunnel were used in numerical simulation and then the numerical results were evaluated by the experimental ones. Comparison between solid canopy and permeable one, showed significant differences in the results, especially in streamlines, pressure distribution and drag coefficient. These differences highlight considering permeability assumption in numerical simulation of parachute canopies.

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1- Introduction

Drag is the main purpose in parachute design. In numerical simulations, canopy fabric is assumed as solid for simplicity. Wang [1] simulated permeability for fabric and calculated porosity coefficients with some theoretical equations for supersonic parachute. Yu [2] simulated opening phase of permeable fabric with FEM method and CFX software. Parachute drag can be examined in drop test, but it's high cost. Also, it can be tested in wind tunnel, that has some problems like blockage, scale effect, mounting parachute model and cost. Therefore, validation and developing computational simulations with low cost and high accuracy would be needed.

2- Methodology

2-1- Wind tunnel set up

A hemispherical permeable parachute model with 10 % vent is used in experiments. Solid blockage is an effective parameter making limitations on inflated diameter of parachute canopy. On the other hand, tested parachutes should be a minimum of 45 cm in diameter to obtain meaningful results [3] and normal fabric behavior.

Forces are measured with mini S-type load cell mount in drag direction and data logger with 200 Hz sample rate used to monitor the forces. Test set up is shown in Fig. 1.

2-2- Permeability

In terminal descent phase, air flow through fabric of canopy has low velocity and in the linear bound of the Ergun equation called Blake-Kozny equation. This equation states differential pressure trough permeable thin layer related to velocity and permeability coefficient.

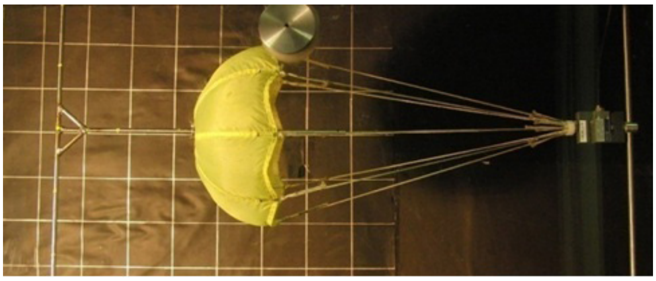

Figure 1. Test set up

Permeability is investigated on the MIL-C-7020 fabric with a common permeability meter that indicates pressure drop trough fabric and air velocity in it (permeable velocity).

Results of the permeability test are shown in Fig. 2. Permeability coefficient can be calculated from Blake-Kozny relation as given in Equation 1.

$$\frac{\Delta p}{\Delta x} = -\frac{\mu}{\alpha} U \tag{1}$$

3- Numerical simulation

3-1- Permeability modeling

Conventional form of momentum equations in FLUENT is given in Equation 2 [4].

$$\frac{\partial(\rho U_i)}{\partial t} + \frac{\partial(\rho U_j U_i)}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \frac{\partial \tau_{ji}}{\partial x_j} + S_i^M \tag{2}$$

The source term (S_i^M) can be written similar to Ergun equation as follows:

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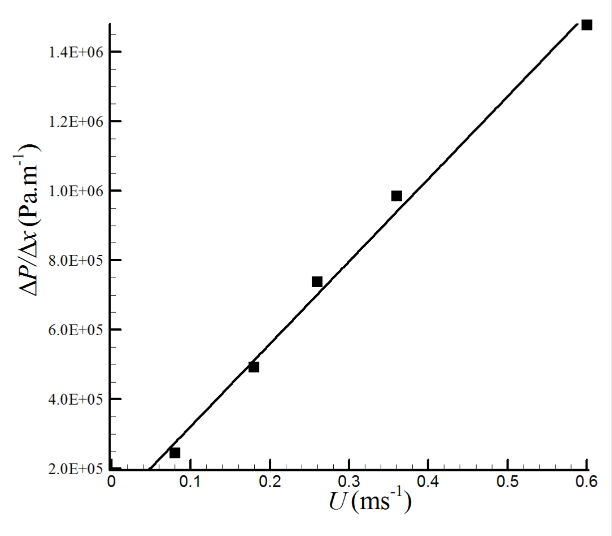


Figure 2. Results of the permeability test

$$S_i^M = -C^{R1}U_i - C^{R2}\left|U\right|U_i = -\left(\frac{\mu}{\alpha}U_i + \frac{1}{2}\rho C_2 U_i^2\right) \quad (3)$$

3-2- Parachute modeling

Both canopy geometries resulted from experimental test are simulated. When changes in CD are less than 0.001, simulations are converged. Flow separation occurs at the beginning of the parachute. Air flows through canopy; therefore, boundary layer would not develop [5].

4- Results

Surface streamlines and vectors around canopy are shown in Fig. 3. Flow around canopy can be divided into 3 zones: primary separation, flow through fabric and vent, and wake vortex above canopy. Zone 2 and 3 had close influence. In zone 2, more permeability or larger vent hole cause bigger and stronger zone and then zone 3 moves up. So, in non-permeable parachute, zone 2 becomes weak and wake vortex in zone 3 becomes bigger and drag will increase.

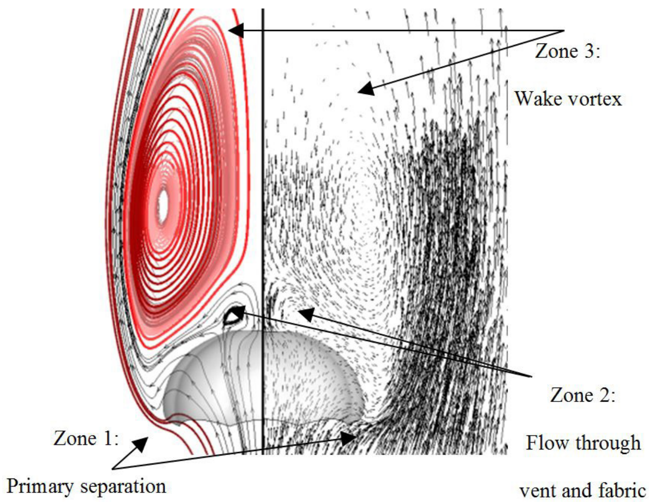


Figure 3. Surface streamlines and vectors around 3D parachute

In Fig. 4, experimental results are presented with an error bound.

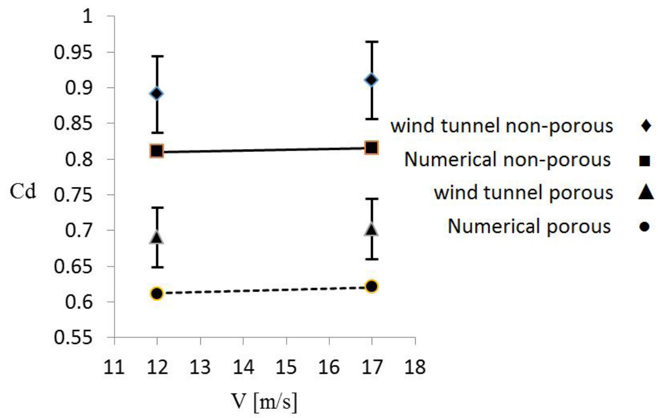
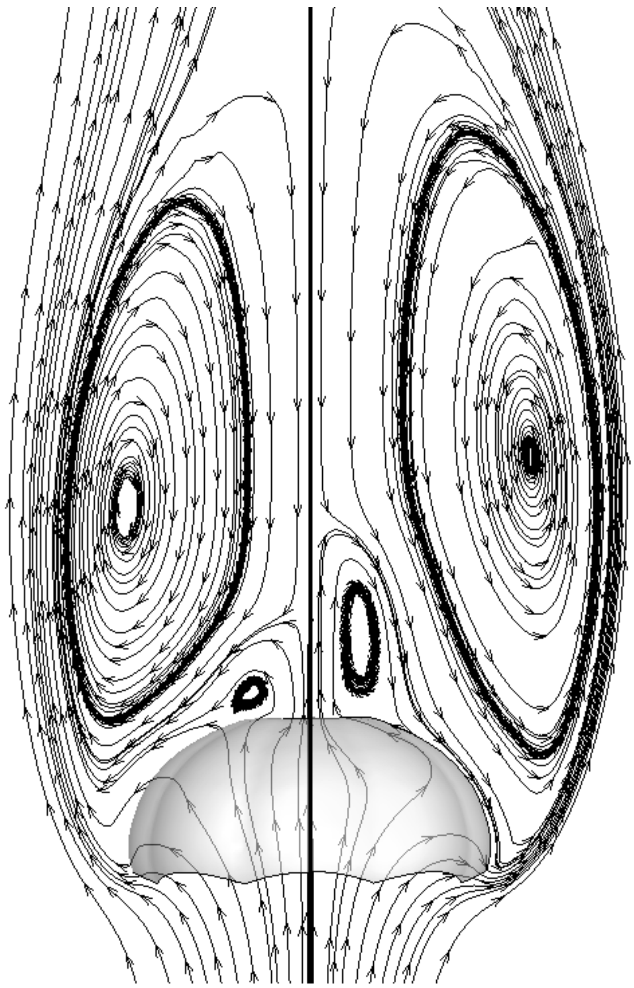


Figure 4. Drag coefficients

Permeable canopy has 11 % and non-permeable one has 16 % average errors. This difference results from assumptions, numerical errors and non-uniformity in the wind tunnel.
Drag reduction of permeable canopy is reported to be 21 and 24 % in experimental and numerical investigations, respectively. As mentioned, in non-permeable fabric, zones 2 and 3 become smaller decreasing differential pressure between sides of canopy, so the drag decreases. Streamlines of both canopies are shown in Fig. 5.



a- permeable canopy   b- non-permeable canopy

Figure 5. Comparison between canopies

5- Conclusion

Effect of canopy fabric permeability was investigated on hemispherical parachute with 10 percent vent. Experimental test on parachute was done in a wind tunnel. A test on permeable fabric was done to extract permeability characteristic, then these coefficients were used to simulate and validate permeability, numerically.

In order to validate the numerical simulation and compare the results with experimental data, canopy was simulated in test section with load cell and mounts. By comparing results, error was under 16%. Results show drag reduction in permeable canopy, so non-permeability of fabric is not an acceptable assumption.

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