TRANSIENT ANALYSIS of NYLON 6/6 for a THIN SHELL STRUCTURE by FEM

H.R. Montazer Hojjat
Ruhr Universität Bochum, Bochum, Germany

http://www.imavs.org/

ABSTRACT

In the design of Micro Aerial Vehicles, decreasing the size is one of the most common challenging aims and to approach this aim, the weight of the whole aircraft shall decrease and structure is the second part which has the most weight [13].

In this paper, the use of a shell structure made from Nylon 6/6 is studied. Nylon was chosen because of its good mechanical properties and low mass density which is of great importance. Also due to the low aspect ratio, the shell structure is used without any kind of ribs or spars to let the user put the instruments easily inside the structure which facilitates assembly and maintenance.

Then the aerodynamic forces are calculated by CFD, Fluent, at Reynolds number 300000 at 5 AOA in a laminar flow. Afterwards the nodal results of Fluent after a nodal interpolation by MATLAB are imported in ANSYS for a full transient analysis. The model in ANSYS is a simple thin shell structure with low aspect ratio, AR=2, with 0.29 mm thickness and volume of 37.2 cubic centimeters, which is calculated in SOLIDWORKS.

Finally Nylon 6/6 is modeled as a nonlinear visco-elastic material and the model is assumed to have large deformations, and the constitutive model is based on the Prony series, which consists of 5 Maxwell elements parallel to a spring. The dynamic bulk and shear modulus are then defined in ANSYS.

Finally, the weight of structure is reduced to 42.40 grams, for the half of aircraft which is equal to about 16.74% of the whole aircraft's weight. Simulation results are presented to prove the efficiency of this material for this structure.

1 INTRODUCTION

Micro Air Vehicles (MAVs) are widely used in civilian and military fields for their light and agile characteristics [1]. Recently some researchers have focused on the development of MAVs and one of the biggest challenges is the reduction of size and weight of these aircrafts [8].
Some efforts have been done to decrease the weight and then the size, like using some light batteries or electrical engines; however, in this paper it is tried to decrease the weight by using Nylon 6/6, which is a light visco-elastic polymer and also has appropriate mechanical properties [2].

Also employing a thin shell structure is suggested. This structure is assumed to be like a sea shell and therefore user can easily open it, assembles the wing and its components which makes maintenance easy as well. Therefore, if one of the components like servos or engines does not work properly, there is no need to destroy the structure. So any change can happen in some seconds.

The procedure is done by the FEM software, ANSYS and Fluent, and the mesh generation of CFD part is done in Gambit and it is tried to have mapped meshing in all the procedure. So this paper analyzes the effects of aerodynamic forces on a simple shell structure wing as a Fluid Structure Interaction problem. Also Nylon 6/6 is modeled with Prony series, 5 Maxwell elements parallel to a spring, to consider the visco-elastic behavior of Nylon 6/6 in the analysis during the time [3].

The root of the model is 30 cm and the span is supposed to be 50 cm, "Figure 1."

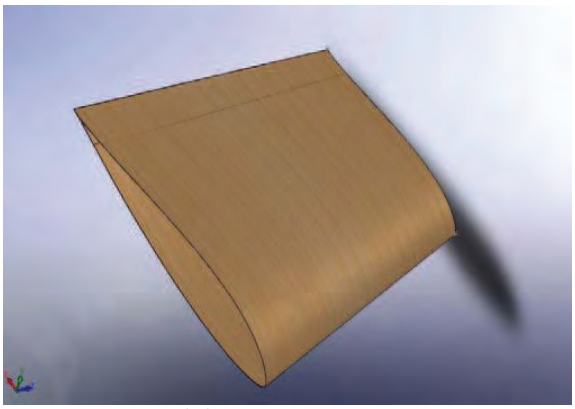

Figure 1: Half of the wing modeled in SOLIDWORKS

Also for calculating the aerodynamic forces the model is located in a laminar flow at 5 AOA with Rey=300000 [4].

The airfoil which is used for this wing is named MH-91 and is a thick proper airfoil with high thickness for use in MAVs [9].

2 Nylon 6/6

Nylon is the common name of linear polyamides which all have in common the carbonamide group –CO—NH-- recurring in a chain of methylene groups. In Nylon 6/6, --[HN—(CH2)6—NHCO—(CH2)4—CO]n--, the most common nylon, which is a polycondensation product of hexamethylenediamine H2N—(CH2)6—NH2 and adipic acid HOOC—(CH2)4 –COOH the first digit is derived from the number of carbon atoms in the diamine and the second digit from the number of carbon atoms in the dibasic acid [6].

For this analysis, the dynamic young modulus of Nylon 6/6 is obtained from literature [7] and then by using MATLAB, a curve is fitted on this diagram at T=25°C as shown below, "Figure 2", and then the exact data of E with respect to time are obtained for the final structural analysis.
Finally by assuming that the Poisson ratio is constant in this analysis, ν=0.4 [11], the shear and bulk modulus are obtained by the following equations with respect to time.

(1) $\mu=E/2(1+\nu)$
(2) $K=E/3(1-2\nu)$

Hamidreza.Montazerhojjat@RUB.de

http://www.imavs.org/

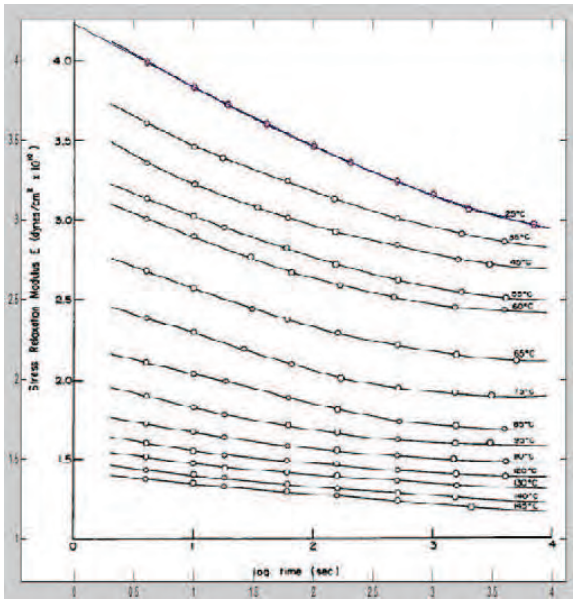

Figure 2: Dynamic young modulus with respect to time [7].

In the structure analysis by ANSYS, two curves are fitted on these data, "Figure 8".

3 CFD ANALYSIS

3.1 Modeling and Mesh Generation in Gambit

In this part, the wing is modeled in Gambit and then it is reduced from three other volumes, one half cylinder and two cubes. These volumes are presented as the flow of air around the wing. Also to have a mapped meshing and to prevent some elements with sharp edges, the last node of airfoil on the trailing edge is divided to two separated key points [5].

Also this wind tunnel is assumed to have 22.4c width and 9c height and the radius of half circle is 8c, where c is the chord of the root airfoil [5].

After defining successive ratio on the edges of geometry, the areas are meshed by Mapped Quad elements and afterwards the volumes are meshed by Mapped Hex elements, "Figures 3, 4".

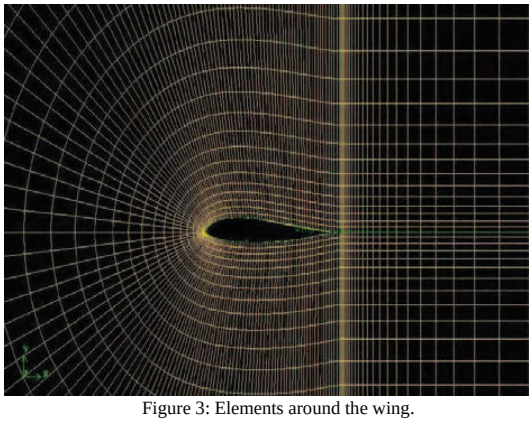
Figure 3: Elements around the wing.

Also as shown in "Figure 4", four boundary conditions, three types, are defined in this problem.

The outer surface of the half cylinder and the cubes, whose norms are parallel to the norm of wings' surface, are defined as far fields: 1(velocity inlet), 2 (velocity inlet) and 3(pressure outlet), respectively. Also all the side walls are defined as symmetry wall to prevent distortion along the edges [5].

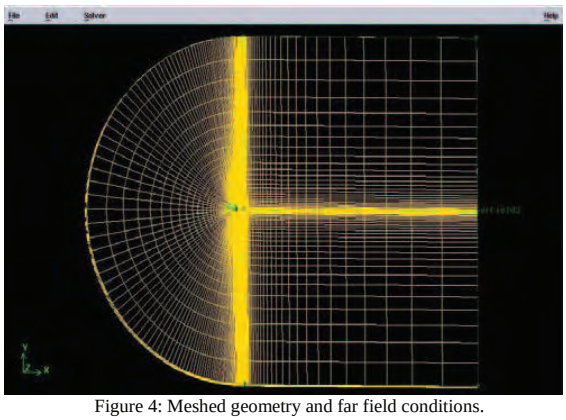
Figure 4: Meshed geometry and far field conditions.

3.2 Solution in Fluent

As already mentioned, the wing is located at 5 degree angle of attack in a laminar flow and the Reynolds number is assumed to be 300000 [4] and this value would lead us to calculate the V∞ by the following equation. Also the Mach number is then equal to *0.0319*.

$$(3) \quad V_\infty = Re.\mu/\rho c = 10.95 \ m/s$$

For the CFD solution in Fluent, due to the low Mach number, the energy equation is turned off and the model is solved in steady state with a pressure based and implicit solver.

The result is converged with lift coefficient of the wing equal to 0.54122. So the total lift produced by this wing at these conditions could be calculated as following.

$$(4) \quad L = 1/2 \rho V_\infty^2 S C_L = 4.9684 \ N$$

In "Figure 6" the static pressure around the wing, as the output of Fluent, is plotted and the maximum static pressure is about 69.8 Pascal.

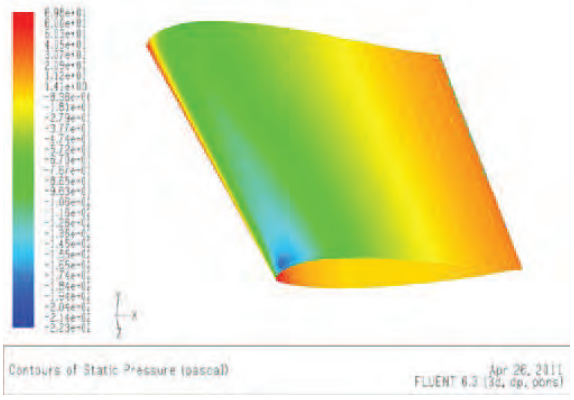

Figure 5: Contours of static pressure around the wing

http://www.imavs.org/

Finally the nodal forces and pressure are written on a file to use in other software.

4 INTERPOLATION OF NODAL RESULTS

After calculating nodal values in CFD, Fluent, it is desired to import these values on the nodes or elements in structural software but the problem which exists is that the nodes in CFD analysis are different in ANSYS.

The first way to solve this dissimilarity is a mesh refinement. Although, mesh refinement increases the accuracy and the procedure time there is another problem in this analysis which makes the interpolation necessary.

The element which is chosen to capture the nonlinear behavior of shell structure is a 8-node element with 4 mid nodes, "Figure 7", and ANSYS could not use this element, when the results are exported from Fluent to ANSYS.

On the other hand, each node on the trailing edge is divided to two separated nodes, to have a better mesh generation in CFD, but in structural analysis there is no tendency to increase the thickness of trailing edge. Hence to use this powerful element, it is decided to do a simple linear interpolation on the nodal results of CFD to find the nodal forces which should be imported on structural nodes. To do the interpolation, a code is written in MATLAB and then the ASCII code is read and the interpolation results are exported as the ANSYS format.

5 STRUCTURAL ANALYSIS

5.1 Element and Mesh Generation

In this part, the wing is modeled in ANSYS and the first step is choosing an appropriate element to capture the nonlinear behavior of thin shell structure and the chosen element should support visco-elastic material behavior and large deformations as well. For this purpose the 8-node shell element, SHELL 281, is selected.

To have more accuracy it is suggested not to use triangular shapes [10]; therefore, in this paper, meshing is done by mapped quadrilateral elements, "Figure 6".

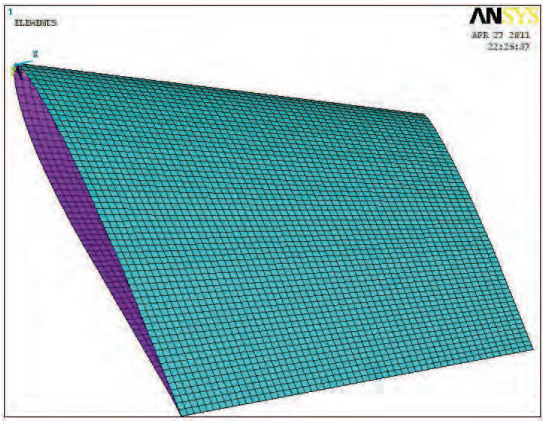

Figure 6: Modeled wing in ANSYS with quadrilateral elements

SHELL 281, "Figure 7", is suitable for analyzing thin to moderately-thick shell structures. It is an 8-node element with six degrees of freedom at each node: translations in the x, y, and z axes, and rotations about the x, y, and z-axes. (When using the membrane option, the element has translational degrees of freedom only.) SHELL 281 is well-suited for linear, large rotation, and/or large strain nonlinear applications. Change in shell thickness is accounted for in nonlinear analyses [10].

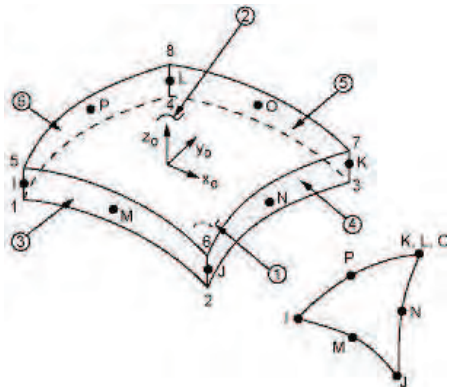

Figure 7: mid nodes in shell 281 [10]

5.2 Material Modeling in ANSYS

For the constitutive model of Nylon 6/6, due to its visco-elastic properties, Prony series is used. Here five Maxwell elements parallel to a spring are modeled by curve fitting in ANSYS. For this approach the Bulk modulus and shear modulus with respect to time are imported in ANSYS and two 5th order curves are fitted on these data, "Figure 8".

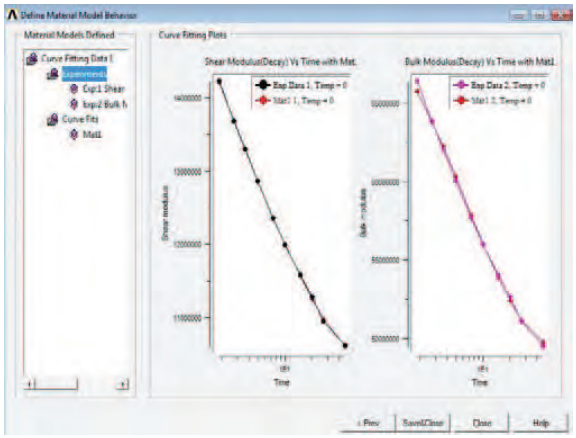

Figure 8: Bulk and Shear modulus with respect to time

In the last part, the solution is started with the "full dynamic" solution in 2 steps. It is assumed that at *t=0* the forces are zero and they increase linearly until they reach nodal results, which are interpolated by MATLAB, and at time *t=4* sec, the forces reach their maximum value and afterwards remain constant.

6 RESULTS

Finally solution is done and the desired results are plotted. As shown in "Figure 9", the stress is reduced with respect to time during the second step of loading. Also in this analysis all the values are converted to cm and therefore the final results shown in figures are in cm.

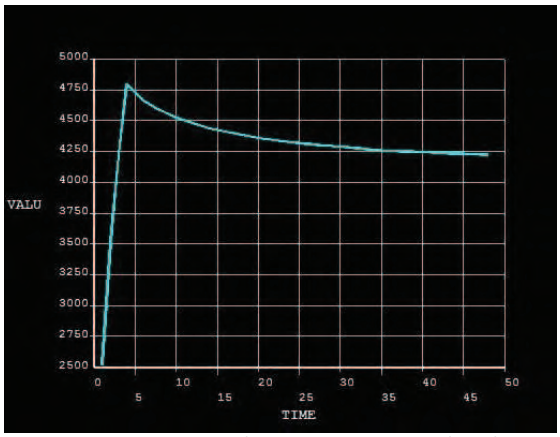

Figure 9: Stress relaxation for a point on the upper surface of wing

At time *t=48* sec, the maximum value of von misses stress is 1.5266 MPa, and the maximum displacement in Y direction at this time is 0.1412, "Figure 10".

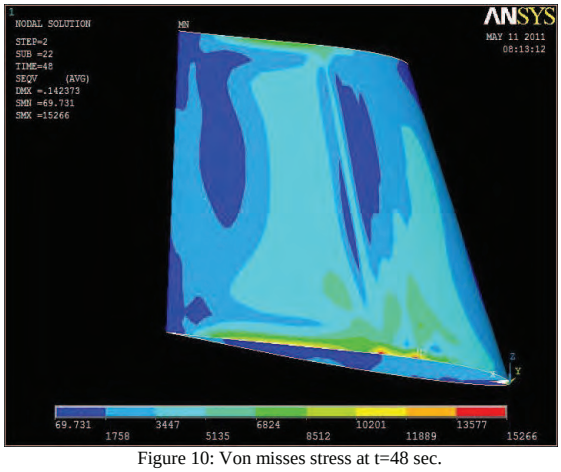

Figure 10: Von misses stress at t=48 sec.

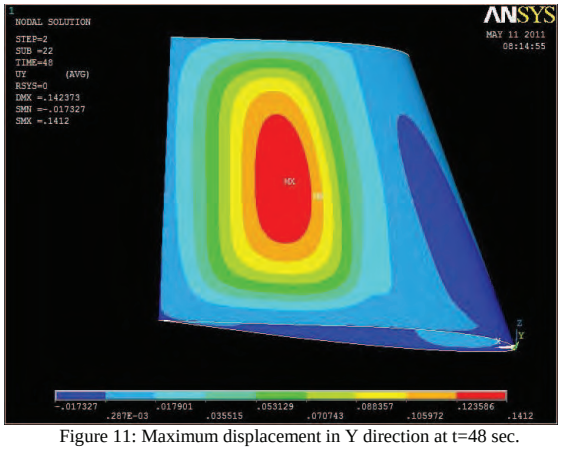

Figure 11: Maximum displacement in Y direction at t=48 sec.

Also the maximum value of the von misses total mechanical strain is 0.00057. This value is very small in comparison with yield strain of the material (5% at dry conditions) [11]. On the other hand, the maximum von misses stress is much smaller than yield/break stress of PA 66 (Nylon 6/6), $\sigma_y > 54MPa$ in dry/humid conditions [11].

7 Weight

After calculating forces and stresses, for this thin shell structure with 0.29mm thickness, the weight is calculated with the density of Nylon 6/6 ($\rho=1.14\ gr/cm^3$). The volume is calculated with SOLIDWORKS, V=37.2 cubic centimeters and then it is clear that the weight of structure would be 42.4 grams for half of the wing.

If the total weight of aircraft is considered equal to the lift, then the weight of structure divided by the total weight would be 16.74%.

This value is estimated in other MAVs about 17% [12],[13]. Thus by this shell structure the weight of aircraft is decreased.

8 CONCLUSION

In this paper we tried to show the high mechanical properties of Nylon 6/6 on a simple thin shell structure for MAVs. Also this structure omits some difficulties during the assembly, maintenance and after crashes.

Finally, the weight of the aircraft is reduced to 42.4 grams. Considering that one wing accounts for about 16% of the whole aircraft's weight, this means a significant reduction in weight however, the wing has still very good strength and reliability for Micro Aerial Vehicles.

ACKNOWLEDGEMENT

I am heartily thankful to Prof. Dr. Ing. Holger Steeb, chair of Continuum Mechanics (Ruhr University Bochum), for his kind helps throughout this research and I would also like to thank Dr. Fritz Menzer for his help with the curve-fitting.

REFERENCES

[1] J. Luo, Z. Jiang, W.M. Cheng, Z.B. Gong, Y.Z. Deng and Q.C. Liang: *Journal of Shanghai University (Natural Science)*, Vol.7-4 (2001), pp.293-296.

[2] Takayuki Murayama. John H. Dumbleton. Malcolm L. Williams. The viscoelastic properties of oriented nylon 66 fibers. Part III: Stress relaxation and dynamic mechanical properties. *Chemstrand Research Center, Inc., Durham, North Carolina, Journal of Macromolecular Science*, Part B

[3] Tzikang Chen, Determining a Prony Series for a Viscoelastic Material From time Varying Strain Data. *NASA*/TM-2000-210123 ARL-TR-2206

[4] X.Q. Zhang, L. Tian. Three-dimensional Simulation of Micro Air Vehicles with Low-Aspect-Ratio Wings. *Key Engineering Materials* Vol. 339 (2007) pp 377-381Trans Tech Publications, Switzerland

[5] Nathan Logsdon, A procedure for numerically analyzing airfoils and wing sections. *University of Missouri*, Columbia.

[6] Gerhard Hopf, Nylon 12-Huels in comparison to other nylons, Technical representative of chemische werke *HUELS AG* West-Germany.

[7] Takayuki Murayama, John H. Dumbleton, and Malcolm L. Williams, The Viscoelastic Properties of Oriented Nylon 66 Fibers. Part 111: Stress Relaxation and Dynamic Mechanical Properties. *Chemstrand Research Center, Znc. Durham, North Carolina*

[8] http://www.compositesworld.com/articles/composites-enable-micro-air-vehicle (May 01, 2011)

[9] http://mh-aerotools.de/ (May 01, 2011)

[10] Release 11.0 documentation for ANSYS, Element libraray, shell 281. ANSYS help

[11] BASF Campus Data bank: http://campusi.plasticsportal.net/matdb/matdb.php (May 01, 2011)

[12] Francis Barnhart, Michael Cuipa, Daniel Stefanik, Zachary Swick. Micro-Aerial Vehicle Design with Low Reynolds Number Airfoils. 7th March 2004.

[13] Joel M. Grasmeyer and Matthew T. Keennon. Development of the Black Widow Micro Air Vehicle. *AeroVironment, Inc.* AIAA-2001-0127

http://www.imavs.org/