VIRTUAL WIND-TUNNEL AND STRUCTURAL TESTING OF LIGHT AIRCRAFT MODELS

Géza Bognár; professor; Dennis Gabor College; bognar@gdf.hu

Zoltán Svébis; senior consultant; EuroSolid Ltd.; svebis.zoltan@eurosolid.hu

Keywords: 3D modelling, aeronautics, wind-tunnel, fluid mechanics, strength analysis

1. ABSTRACT

3D modeling technologies are more and more entering into the field of technical hobbies like aeromodelling. In respect of designing, 3D CAD software are widely used and in the production of complex shape parts 3D printing is more and more applied in the latest years. In this paper the authors present how a 3D modeling CAD software is used in aeromodelling, starting from the concept, up to the virtual flight and mechanical strength tests. The main conclusion of the authors is that the 3D modeling and simulation has evidence of use in case of industrial production of airplane models.

2. SCOPE

Goals: the authors purpose was to demonstrate the usefulness of SolidWorks as 3D modeling tool in the design and preliminary aerodynamic and structural testing of an airplane model. The historical background of Hungarian aeromodelling is presented also.

The theoretical basis of aeromodelling is approximately the same as that of the real flight, however the Reynolds number 50000÷100000 (or eventually lower) is considerably lower than that of in case of real airplanes $10^6 \div 100 * 10^6$ (or eventually higher) that's why some special rules are applicable in model designing. A very detailed theoretical basis and designer's guideline is given in Jászai [1]. Many of Hungarian modelers learnt the basics of aeromodelling from Hints [2], which book provided useful information on building and flying of model planes, but very few details on theoretical basis. A more theoretical approach of model flight is presented by Ramsac [6] who compares theoretical results with measured ones using photogrammetry technology.

History: Aeromodelling has been developed in parallel with the real airplanes in the XX$^{th.}$ century. Next to the pure interest of youngsters, governmental authorities understood early its importance in the technical and military educations of young generation. Before WW2 it was the case in Germany, USA, and USSR and many other countries. After WW2, during the cold war, the military and technical education became in the focus of all industrial countries, potential protagonists in an eventual war. It was the case in Hungary also, where aeromodelling activity was controlled and supervised by MHS (Hungarian Defense and Sport Association), later MHSz. The declared aim of MHS association was to provide technically qualified personnel for the army. The same role was played by DOSAF in the USSR. The AMA (American Model Association) providing the same function in the fifties, but in a little bit hidden way. In spite of this military aspect of aeromodelling the years 1950-1990 were the golden age. Dozens of model clubs were established and operated all over Hungary and a central supervising board as department of MHS controlled the work of them. Even a Central Model Research Institute (MOKI) was established and operated during these years [5]. Consequently the technical level of aeromodelling was very high that time, as well as its international reputation which later was manifested in the results of international competitions organized by FAI CIAM (Fédération Aeronautique Internationale, Section Modélisme) [8]. One of the outstanding Hungarian results of that time was the first place in the Aeromodel Word Championship 1958 (Cranfield, UK) by the famous modeler Ernő Frigyes in category F1C. A couple of years later Ernő Frigyes won the F1C Word Championship again (Wiener-Neustadt, 1963). In the sixties of the XXth century, and a decade later in Europe radio control devices became less and less expensive and accordingly more and more popular within the aeromodelling society [4]. Next to this phenomena, the self-built airplane models became more and more rare. Instead of them, modelers built their plane first from kits, than they used ARF (almost ready to fly) then RTF (ready to fly) technologies. In our days the ARF formula is the most popular one.

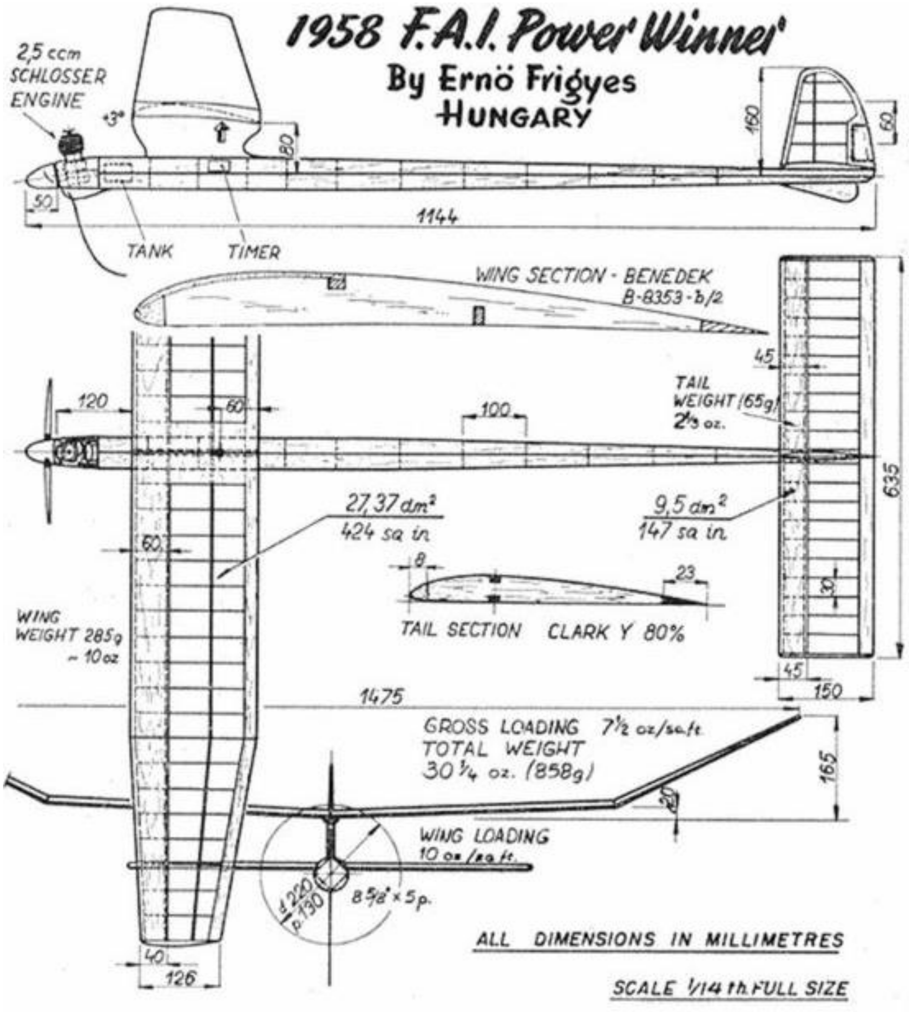

Figure 1.
F1C world champion model, 1958 Cranfield, UK (Frigyes Ernő: FM-58) [14]

The almost ready to fly means that the modeler should mount the prefabricated main parts of the plane and install the electronic devices. The application of ARF technology suggests some technical competences from the user, but far from the old style modelling namely the self-fabrication and installing of all the parts. Today there are only a few modelers who start with the design and built themselves their models. It is very difficult to estimate the number of “old style modelers”, but analyzing the data from the most popular Hungarian model forum [10], over 23000 total users, from 6000 active users (having more than 10 posts), there are about 100 who built themselves their models. All the others are dealing with ARF or RTF type models. Today a large number of ARF models are molded from ELAPOR (a very light, strength and shock resistant plastic), are subject to mass-production. When designing the airplane, the injection mold can be easily developed from the external geometry of the airplane’s 3D model. A famous German airplane model supplier using this technology is Multiplex Ltd. [12], the products of which are widely used all over the world and in Hungary also.

In the past decade the word-wide distribution of low price GPS systems yielded to a new field in modeling, the GPS controlled airplane models which may leave the range of ground based radio transmitters. By means of this system the model may leave the range of vision of the modeler and it may return to the starting point automatically. This feature induced a need for the legal regulation of aeromodelling, because the new potential hazards shall definitely controlled. According to FAI CIAM [8] suggestions all involved countries developed its own legal regulation, dealing with safety of aeromodelling. The current Hungarian legislation excludes the above type models from the airplane model category [13].

The general principle of the FAI-CIAM based regulation is to exclude GPS controlled aerial vehicles (UAV) and aerial systems (UAS) from the category of aeromodelling. UAVs and UASs are widely used in the military sector, but they have civil applications as well. The latest development in high-tech aeromodelling the so called FPV (first pilot view) flight, when the operator controls the airplane by visual information from an onboard camera. This way the operator senses the control of the model as that of a real airplane. As the distance of an FPV model from the operator may reach 80-100 km, this type of modelling yields to new safety and legal problems. It should be noted that the current Hungarian regulation [13] includes severe professional mistakes and it needs for urgent modification.

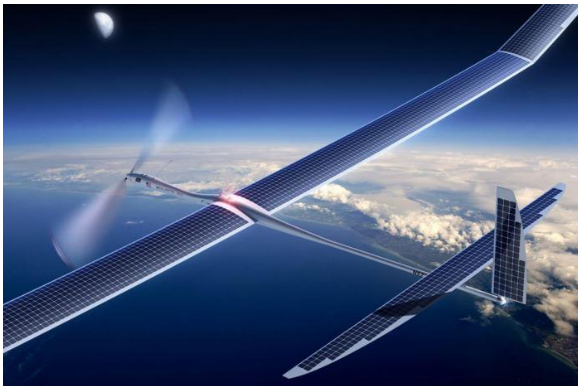

Figure 2.
Solara 50, 50 meter wingspan solar cell powered UAV [7]

3. CAD SOFTWARE IN AEROMODELLING

2D CAD software are rarely used by old-style modelers, 3D CAD software are even rarer in modelling. However when industrial production of model kits, ARF and RTF planes became more and more usual, the need for appropriate documentation and CAD applications has been increased also. First 2D technical drawings were produced with popular software, such as AutoCAD. When molded ELAPOR became one of the most popular basic material, especially when high number of serial production required, the proper design of injection mold needs absolutely a 3D CAD software. It should be noted that any other CNC based fabrication technology (CNC drilling, laser cutting, 3D printing) needs also CAD drafting and modelling for the design. There are plenty of such software on the market (ProEngineer, Catia, SolidEdge, SolidWorks, AutoCAD, CadKey, Kubotek 3D, DMT, …) providing standard export files, which may be the input of a manufacturing software necessary for the CNC production. In respect of quality/price relation we found that SolidWorks meets mostly our requirements. In our case we used SolidWorks 2014-15 Academic Version, supplied by its Hungarian distributor EuroSolid Ltd. [11]. Various 3D projects are uploaded from all over the world onto social web page GrabCAD [9], where all projects are well stocked with appropriate tagging. Using tags Aerospace, Aviation, Model airplane; plenty of projects may be studied or integrally downloaded. Even the developing software is subject to selection on this page.

4. TOP-DOWN MODELING WITH 3D CAD SOFTWARE

In the past century modelers rarely used CAD software for their projects, even detailed calculations were missing when the concept of a new model was elaborated. In spite of existing of good theoretical references [1, 2, 3, 4], new models were developed on the experiences with a previous one, without too much theoretical considerations. Even by this experimental way the characteristics of models more and more increased and some of them reached high ranking in international competitions. The first draft of a concept usually was based on a successful model. See the volumetric 3D model of airplane model SRG-12 below.

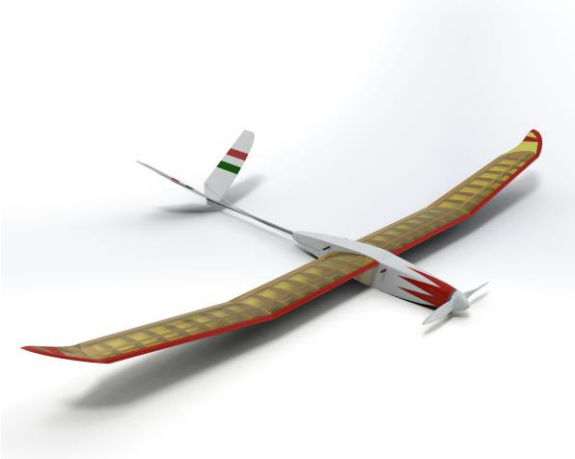

Figure 3.
Volumetric 3D model of a moto-glider,
1.20 meter wingspan (SRG-12)

Top down modeling means that starting from the external shape of the volumetric (or surficial) model the designer should determine the internal parts of the structure, the installation of which yields to the final shape. See the variable section of the airplane winglet in Figure 4. To build such a winglet on have to design ribs, the outer surface of which corresponds to the actual section of the geometry. First sectioning planes shall be placed along the winglet. The distance of planes each to other depends on the capacity of the covering film. When the length of the airfoil is 100-150 mm, the distance of ribs, and that of the sectioning planes, is usually 35-50 mm.

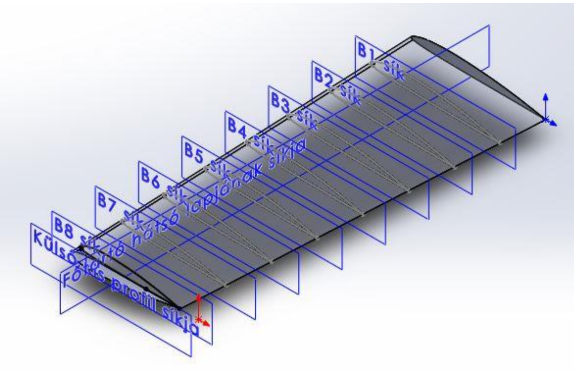

Figure 4-A.
Sectioning of the variable geometry winglet (SRG-12)

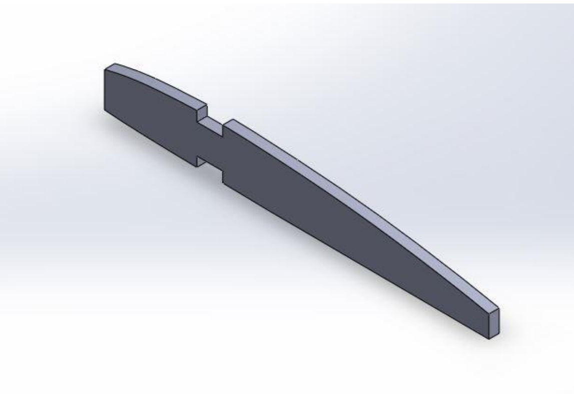

Figure 4-B.
Rib developed on the basis of winglet section (SRG-12)

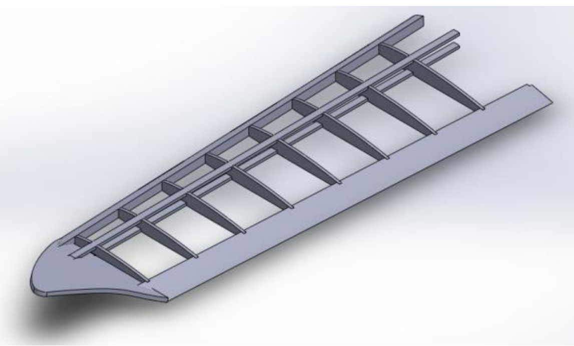

Figure 4-C.
Winglet structure with variable geometry ribs (SRG-12)

When the profile section is obtained in a given section, the shape of the rib shall be determined with respect to the geometry of leading and trialing edges as well as mainspars. The rib at the position of B4 plane (Figure 4-A) is given on Figure 4-B.

When the 3D model of parts: rib, leading edge, trialing edge, mainspar is ready, one can develop an assembly structure of the winglet. In aiming to determine the position of parts relative to each other, one have to join them by the meat function.

5. STRUCTURAL MODELING AND DRAFTING

With the newly appeared industrial production of models or eventual UAVs both for civil and military use, the manual drafting is no more applicable. Due to the high economy risks of serial production detailed preliminary studies are required to carry out such a project. Next to the advantage of 3D modeling in injection mold fabrication, preliminary aerodynamical and strength simulation may be effectuated with 3D models. Any way the proper paper-support documentation is necessary to build up accurately a model. One of the SolidWorks features is the automatic drawing on the basis of 3D model. The disadvantage of this method of drafting is that the 3D model must be imperatively fully correct. While in case of traditional manual drafting some minor inaccuracies or missing data are tolerated the 3D based drafting does not accept these imprecisions, as usually the drawing function does not work while there are mistakes in the 3D model. When the parts of the structure are ready, first we create subassemblies eg. the wing is built up from two winglets and a central part.

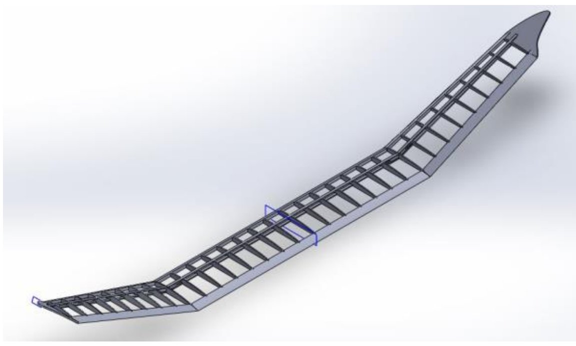

Figure 5.
Wing structure assembly (SRG-12)

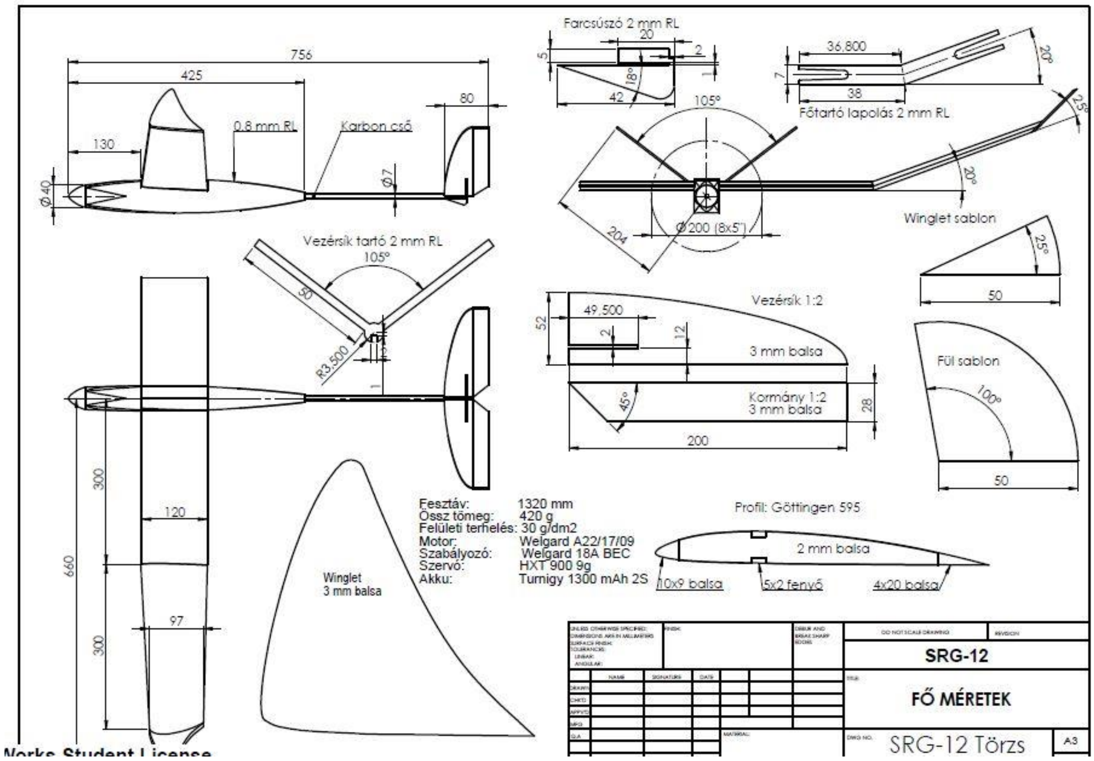

Figure 6.
Main assembly drawing developed from the 3D model (SRG-12)

Figure 7.
The real model glider, built on the basis of 3D model (SRG-12)

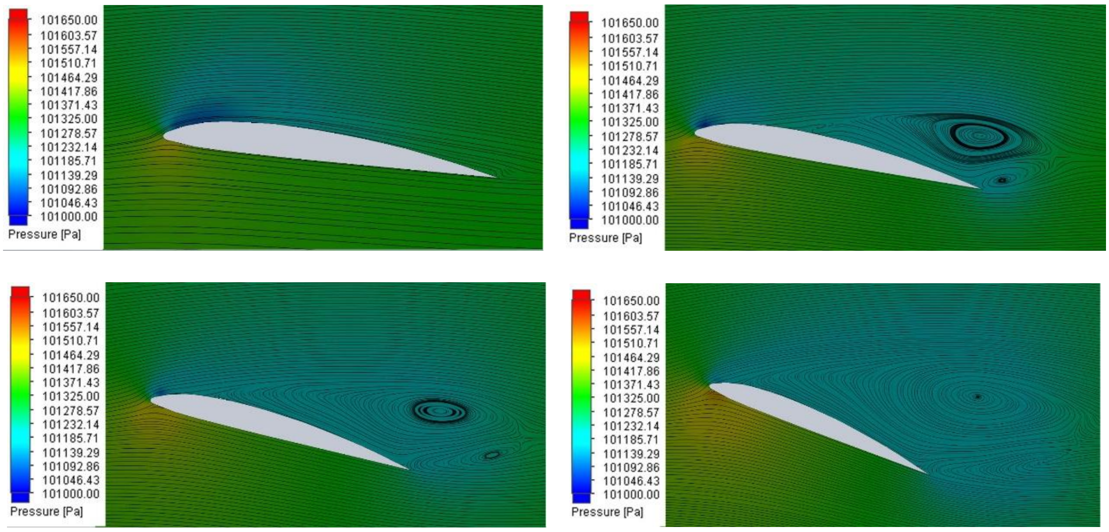

Figure 8.
Streamlines and pressure distribution around the airfoil Göttingen 595 installed in our moto-glider SRG-12
(Reynolds number: 80000; incidence: 3, 15, 20, 40 degree)

When all the subassemblies are ready one can attack the assembly of the complete airplane. Paper documentation for self-builder modelers are targeted, are quite different than that of intended to be used in industrial production. As modelers are often using 1:1 scaled plans as paper template for the parts, the wing and the stab shall have enough place on the paper to show them in all of their integrity. That’s why the positioning of parts on the sheet sometimes does not meet the strict rules of traditional machine drawing. See the technical drawing of our moto-glider above.

6. VIRTUAL WIND-TUNNEL TESTING

The principle of wind tunnel testing is to study the behavior of an airplane with various flight conditions, such as velocity, and relative position of the airplane. In the great majority of cases a downscaled model is used for the test as there are no available wind tunnel to test a real airplane. Usually the flow visualization is made by means of a steam-generator, and the streamlines are recorded by video technics. Even if the downscale factor is important, in case of real airplanes there is a need for very big installations the permanent and operational costs of which are very high. The SolidWorks Flow Simulation module allows the majority of flight test virtually. The concept is to create one integrated solid body from the assembly, and consider it as a rigid solid. Then this solid body is placed into the flow in various positions. One can change the velocity (Reynolds number) of the flow. See the streamlines around the wing on Figure 9.

With the above test the whole airplane is placed in the wind tunnel, however Figure 8 shows the streamlines in the section parallel to the fuselage axis. It is well demonstrated by this test, that with 8^{o} of angle of attack a vortex development occurs behind the airfoil, which increases the drag forces and decreases the efficiency of the wing.

The lift force and the drag force on an endless wing (no induced drag) with perfect flow conditions are calculated as follows:

Lift force (perpendicular to the streamlines in infinite distance):

$$Fy = \frac{\rho}{2} v^2 A c_y (\alpha, Re)$$

Drag force (parallel to the streamlines in infinite distance):

$$Fx = \frac{\rho}{2} v^2 A c_x (\alpha, Re)$$

Where Fy lift force; ρ density of air; v velocity; A surface area of wing; c_y lift coefficient; c_x drag coefficient (both of these two coefficients are the function of the angle of attack and the Reynolds number).

The results coming from the above two equations, are too much theoretic, with no considerations of the other parts of the airplane. In aiming to improve them various experimental coefficients and diagrams are suggested to be applied [1]. In the reality the wing is newer endless nor the flow is perfect. When a real airplane is put into the flow, a considerable induced drag force will be generated due to the vortex at the wing-tip.

Not only the primary drag forces, but drag forces from the effect of fuselage and stabilizator will act on the airplane, which can be modelized and visualized by the SolidWorks Flow Simulation module. Instead of using various “improving” co-efficients in case of virtual wind-tunnel testing we put the whole airplane into the flow. This way one can calculate all eventual forces: the real lift and drag forces. The ratio of the above forces give the efficiency of the model. Our flight test results are given on Figure 10.

It is seen from the diagram, that the maximum efficiency is about 12, found at approximately 4° of incidence. With such a low Reynolds number it is an excellent result for a glider model.

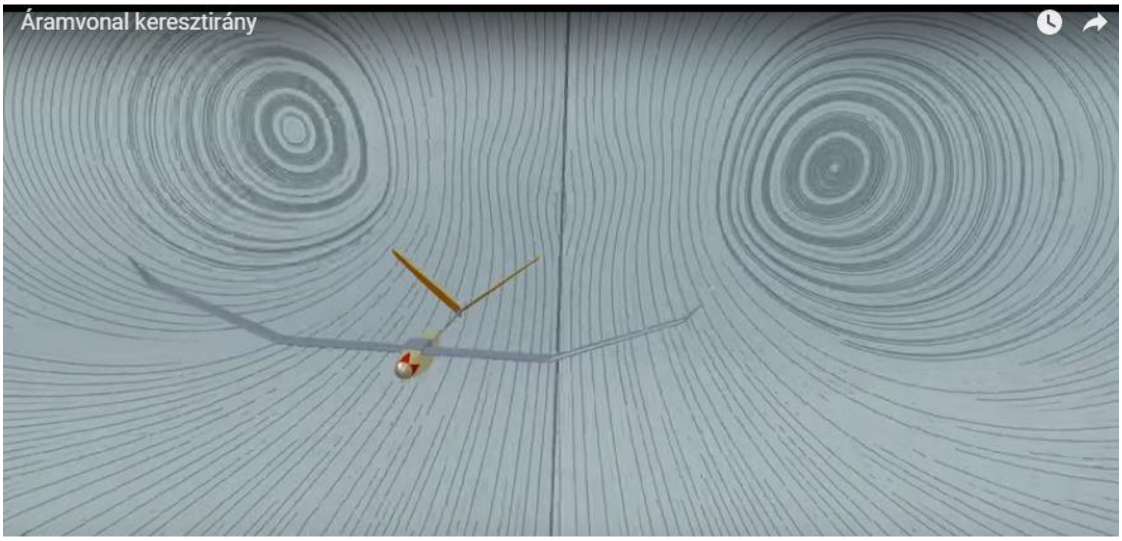

Figure 9.
Vortex at the wing-tip of our moto-glider SRG-12 (Reynolds number: 80000)

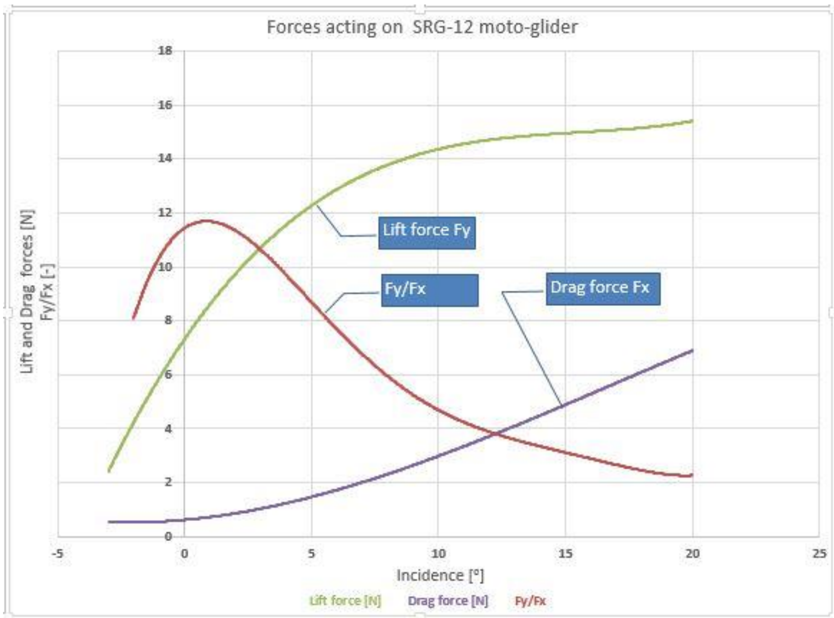

Figure 10.
Forces acting on our moto-glider SRG-12 (Reynolds number: 80000)

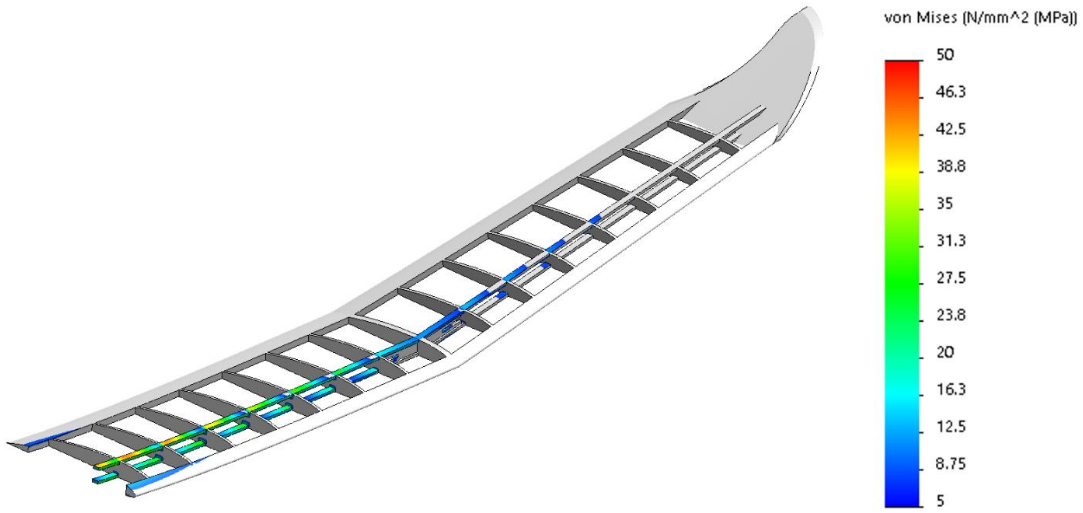

Figure 11.
Deformation of the wing as result of distributed force acting from the top direction

7. VIRTUAL MECHANICAL TESTING

In aiming to carry out strength test we used the structural model of the wing. When a distributed force is acting on the wing from the top direction, the deformation of the wing is like on Figure 11. The stress distribution on the parts are demonstrated by various colors. Usually the mainspars are subject to maximum strength effect, and consequently the first parts to broken will be the mainspars. In our case the total lift force was applied alongside the wind structure as homogenously distributed force. When the relative airspeed increases the lift force is increasing as the quadrate of the velocity. In case of exceeding a critical value of velocity the mainspars will be broken.

However it should be noted that it is very rare when a wing is broken due to a distributed force from the lift force even it is much higher than the operational force during normal flight. The usual case of braking is the crash when the wing touches the ground or any other object. In this case the leading edge will be broken first.

8. CONCLUSIONS

(A) Use of high-tech control systems and ARF, RTF type airplane models has basically transformed aeromodelling in the past decade, which yielded to industrial production of the above models.
(B) CNC technology based industrial production of airplane models requires use of 3D modeling CAD software in the designing procedure.
(C) Use of 3D volumetric or surficial CAD models allows the preliminary virtual aerodynamic and strength analysis of models.

9. REFERENCES

[1] Jászai Sándor: *Repülőmodellek tervezése*, Magánkiadás, Budapest, 1953
[2] Hints Ottó: *Repülőmodellezés.* Ifjúsági Könyvkiadó, Bukarest, 1955
[3] R. H. Warring: *Basic Aeromodelling*, Argus Books Limited, Wartford, 1976
[4] Maurice et Michel Mouton: *Aéromodélisme et radiocommende*, Atlas, 1978
[5] Pinkert György: *100 éves Magyarországon a repülőmodellezés*, Mayer Nyomda és Kiadó, Budapest, 2009
[6] M. Ramsac: *Radio Controlled Sailplane Flight: Experimental and Numerical Analysis,* Journal of Mechanical Engineering, 58(2012)3, 147-155, http://sl.sv-jme.eu/data/upload/2012/03/01_2009_153_Ramsak_04.pdf

Internet references (last download: 15. 04. 2016):

[7] Caroline Rees: Insight; US Airborne Base Stations, Unmanned Systems Technology, http://www.unmannedsystemstechnology.com/technical-article/insight-uavs-as-airborne-base-stations/, 2015
[8] Fédération Aéronautique Internationale: www.fai.org
[9] GRABCAD community: www.grabcad.com
[10] RCmodell Fórum: www.rcmodell.hu
[11] EuroSolid Ltd: www.eurosolid.hu
[12] Multiplex Modelsport Ltd.: http://www.multiplex-rc.de/en/home.html
[13] Hungarian Legislation: 2015. évi CLXX. Törvény, Modification of 1995, XCVII Law on the Air Traffic
[14] Volar Libremente: http://aeromodelismovolarlibremente.blogspot.hu/2010/04/fai-power-de-erno-frigyes-campeon.html