UAV[1] Airframe Development Using 3D Modeling Technology

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Abstract: 3D CAD modeling technology was used to development and building of a low range mini-aircraft, expected to make photo shots and video recording from the sky. The used software was: CadKey Workshop V21.5 and SolidWorks 2008 SP 2.1. Use of 3D CAD software is extremely useful when creating surfaces with double curvatures, which is a very usual case in airframe construction. The installation of electronic devices needs an appropriate modeling of the fuselage's interior also. If plastic-molded parts are incorporated in the airframe, the 3D geometry model may be exploited as basis of mould-tool as well. The main phases of developing process are as follows:

1. *Flight parameters identification.*
2. *Preliminary concept.*
3. *Creation of 3D shape model with respect payload and nature of on-board devices.*
4. *Fluid mechanics verification and modification of the shape if necessary.*
5. *Exploitation of the shape model for the construction.*

The 3D shape model may be exploited later according to requirements of various building technologies. Without sophisticated manufacturing hardware facilities, we used the traditional aircraft-modeling tools and technology. Consequently we prepared automatic manufacturing drawings for the construction of each part. Easy to use radio control and

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video technology was installed on-board. Standard input and output devices of the control system allow the further application of a GPS-controlled autopilot system. The authors give an overview of easy to use electronic systems for on-board applications.

Keywords: UAV, 3D modeling, aircraft building

1 3D Modeling in Mechanical Engineering

1.1 Common Features in 3D CAD Modeling

All CAD modeling software use similar proceedings to create model of solid bodies or surfaces. To create a volumic model of any technical object, there are two usual ways:

- combining elementary 3D objects then modifying them according to the required result
- using 2D entities, modeling the fabrication process itself in aiming to arrive to the required result

Surface generating tools are available in case of majority of 3D software, in aiming to simplify the creation of complex surfaces. Using elementary 3D objects is the fastest way of modeling, but generally simple shapes can be produced by means of it. More complex volumes and surfaces can be produced by using 2D entities as basis. Various splines may be as basis consequently the resulting surface may have a very complex shape with double curvatures.

The basic operations to create 3D objects are: extrude, revolve, swept, loft… These features with minor content modifications are available in all 3D CAD software. Sometimes the icons in toolbars are very similar.

1.2 Modeling and Manufacturing

Sometimes it is impossible to draw exactly in 2D surfaces of high complexity. Even in case when the 2D technical drawing is available, the proper interpretation of this drawing by the manufacturer is uncertain. However the exactitude of shape may have an important role in the efficient operation of the part, e.g. turbine blade. Using 3D modeling technology and transferring data from the model to a manufacturing software then to the CNC machine tool yields to a much better result [1]. This technology may be used even without any paper based documentation. Most modern ways of manufacturing of objects with high complexity of geometry are LOM (Laminated Object Manufacturing) and 3D printing.

2 Airframe Design Process

2.1 Flight Parameter Identification

When creating a new design, first the purpose of the UAV shall be identified exactly. Then a preliminary value of the following parameters shall be suggested:

- payload (kg)
- autonomy (h)
- action range (km)
- altitude (m)
- velocity range (m/s)

2.2 Preliminary Concept

Now you can make a first draft of the plane. Suggested a preliminary mass of the airframe plus the useful payload, taking into consideration a specific wing-charge (g/dm^2), one can choose a preliminary wingspan (m) from the diagram below [4]. For example with a specific charge of 50 g/dm^2, a wingspan of 1.5-3 meter is suggested. In spite of wide range of wingspan, one can choose a preliminary wingspan from it according to the purpose of the UAV. When the visibility is important (target drone) longer wingspan is suggested.

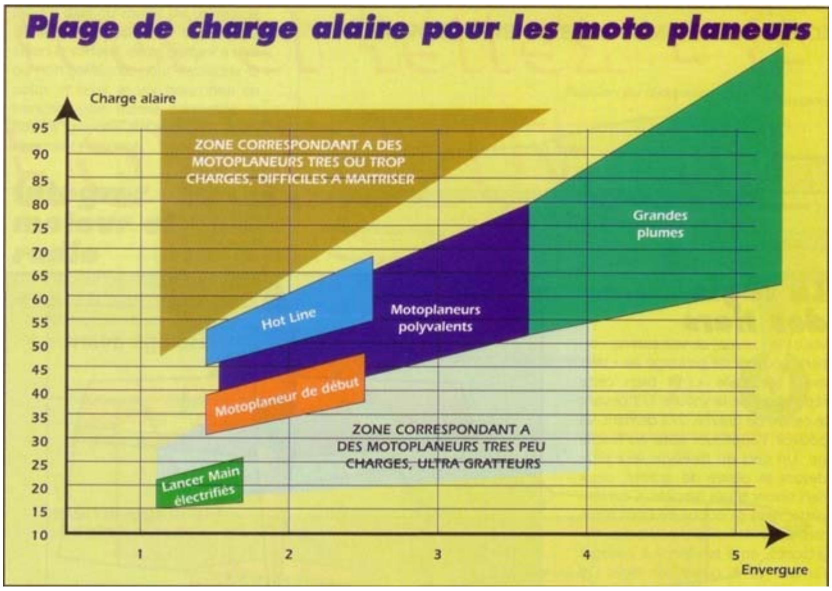

Figure 1

Specific wing-charge VS wingspan [4]

When the wingspan is defined, other dimensions of the airframe can be calculated using the usual dimension ratios related to wingspan. There are suggested ratios based on modeling practice in the international references [6] [7].

2.3 Airframe Shape Model with CadKey

Having the preliminary dimensions, one can create the 3D model of the airframe. The model shall meet the mechanical requirements as well as to house all electronic devices on board. We used CADKEY-98 modeling software for this purpose, however since that time we have more experiences with CADKEY Workshop V21.5 and Solid Works 2008 as well. See the 3D model of our plane below.

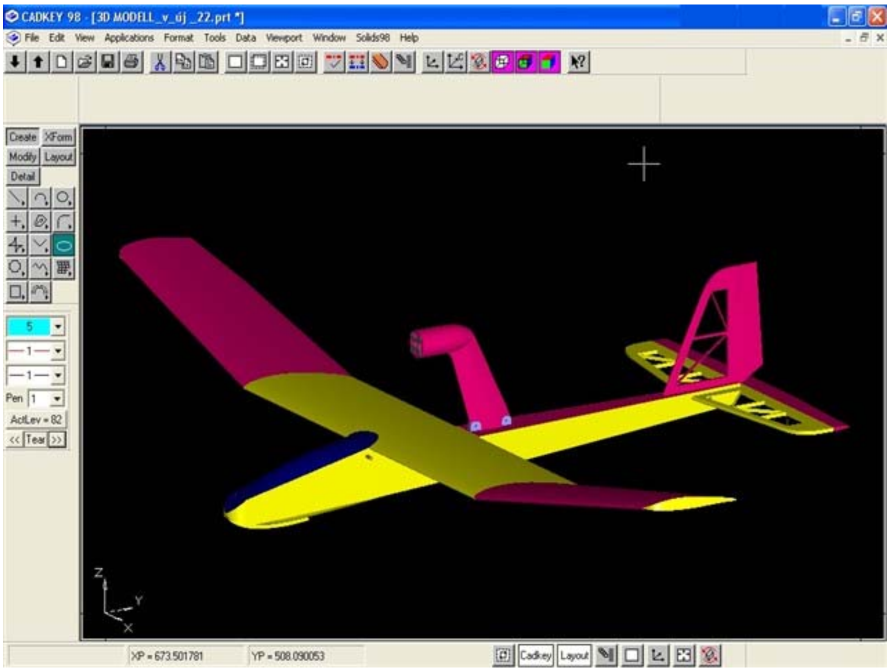

Figure 2
3D model of the plane [2]

A very meticulous work is required when modeling the inside part of the fuselage, in aiming to house the electronic devices properly. When all 3D parts are ready, one can verify the position of the center of gravity, which is suggested to be placed at the 33% of the wing airfoil's length. If it is not the case, supplementary masses should be applied for the proper balancing of the plane, which may result in reduction of useful payload, consequently all design process shall be repeated from the start. See the fuselage interior below.

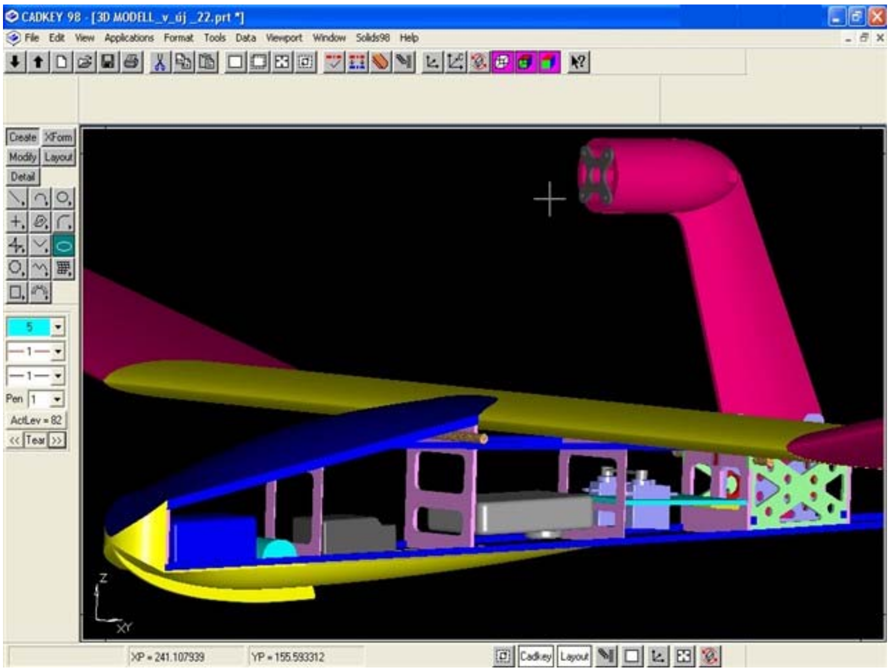

Figure 3
Housing the electronic devices in the fuselage [2]

2.4 Fluid Mechanic Verification

In case of horizontal flight with constant speed, the weight of the plane and the lift force F_y are in equilibrium. The aerodynamic forces are calculated as follows [3]. The lift force is:

$$F_y = \frac{\rho}{2} v^2 A \, c_y \tag{1}$$

Where the c_y lift coefficient is the function of the profile geometry, the incidence angle and the Reynolds number:

$$Re = \frac{vh}{\nu} \tag{2}$$

The drag force is in equilibrium with the traction force generated by the motor via the propeller:

$$F_x = \frac{\rho}{2} v^2 A \, c_x \tag{3}$$

For practical purposes the drag coefficient of the wing profile c_x shall be increased by 20-30% in aiming to take into consideration the drag of the fuselage too.

The useful mechanical power in flight is

$$P_U = F_x\, v \tag{4}$$

While the absorbed power by the motor is

$$P_A = \frac{P_U}{\eta} = \frac{F_x v}{\eta} \tag{5}$$

The overall efficiency of the driving system (propeller, gear, motor, and controller) for the first evaluation may be taken into consideration with a value around of 30%. It should be noted that in the reality the propeller efficiency itself is the function of many factors (geometry, pitch, speed of the airplane, rotation speed…). However for the first estimation the above value is quite correct.

All above equations governing the phenomena of horizontal flight are included and processed in Profili2.0 software [5] by means of which one can verify the preliminary data. If calculated data are corresponding to preliminary data within an acceptable range of tolerance, no need for modification. In other case one should repeat the design process beginning from the 2nd step.

2.5 Exploitation of the Shape Model for the Construction

On the basis of the 3D model a 2D drawing was generated automatically. Whoever made such an "automatic" drawing knows that it needs many-many working hours (text, labels, dimensioning, tolerances …) to create a drawing which can be used efficiently in the workshop. See our 2D drawing below:

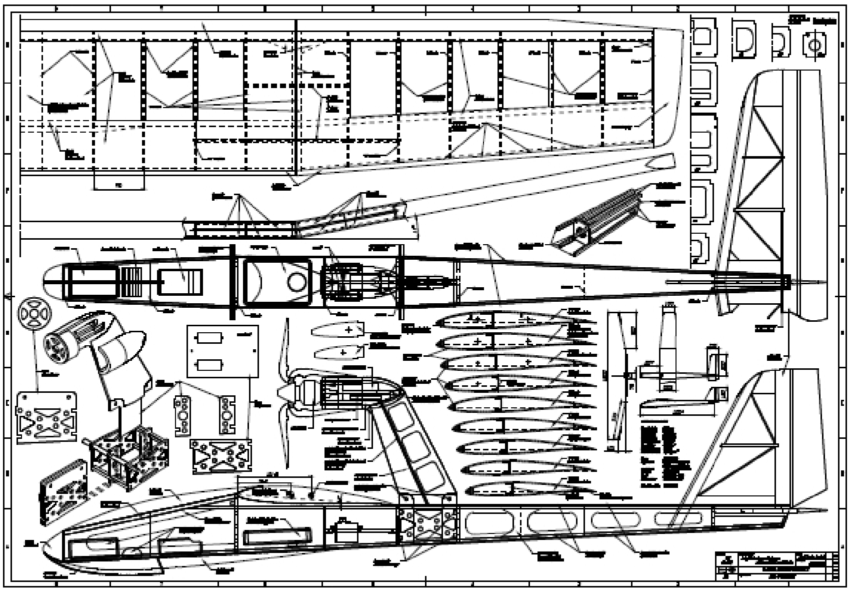

Figure 4
2D drawing of the plane [2]

3 Building Process

The building technology depends mainly on the production series-number. If relatively important number of airplanes is required (target drones), it is suggested to evaluate the application of CNC manufacturing. In extremely high number of airframe production (Multiplex EPP models) the tool design is exclusively made by means of 3D modeling. In case of low series-number, manual wood and plastic technology is used.

3.1 Airframe Building

As our plane was made as a single prototype, we used the traditional model building technology. From the 2D workshop drawing we copied the shape of parts on laminated wood, then we cut the draft shape of the part and the final precision was made manually by means of rasp. When all the parts are cut, the assembly is carried out following the assembly drawing. A thermo-rectable plastic cover (Oracover) is applied to the outer surfaces of the airframe, while the inner surfaces are varnished. When all electronic devices are mounted, the placement of the center of gravity shall be rectified by adding supplementary lead bullets. The correct movement of governs is subject of detailed checking.

3.2 Onboard Control Devices

Our plane was made for direct radio control from the ground, consequently we used ordinary model control system consisting of FM transmitter and receiver (35 MHz), equipped with two servos (elevon and rudder). Standard outputs of the receiver allow the connection of any standardized programmable flight control system. A special output interface was developed by us in aiming to control the camera operation from the ground. Unfortunately our limited financial resources allowed us only a low quality camera (3 Mpx), which is expected to be changed by a real ortho camera (maximum weight 1 kg).

4 Programmable Flight Control Devices

The airplane may fly under a usual Radio Control (RC) equipments (by operator's hand) or automatically, by a robot pilot. RC airplane models are usually controlled by a radio control system. This consists of a transmitter, receiver and servos. The transmitter is the device that we hold in our hands to control the speed and steering of the RC airplane, the receiver is a small device mounted inside the motion directions of the airplane. The receiver receives electromagnetic radio signals from the transmitter and sends the electrical signal to the servos. Servos control the power of engine, the ailerons, elevon and rudder. In case of RC controlled flights the visibility of the airplane is required on all length of its trajectory.

If we want to carry out a flight mission "beyond a hill" we need an automatic flight control device, or robot pilot. The "robot pilot" or "auto pilot" or "programmable flight control device" is a navigation mechanism which maintains automatically a preset course or full preprogrammed mission. The modern robot pilot device shall include:

- GPS waypoint navigation with constant altitude and airspeed.
- Completely independent operation including autonomous takeoff, bungee launch, hand launch and landing.
- Fully integrated gyros and accelerometers, GPS module, pressure altimeter, pressure airspeed sensors.
- Onboard data logging.
- Ground control software.

4.1 Overview of the International Market

The Canadian company MicroPilot is the world's leading manufacturer of small autopilots for unmanned aerial vehicles (UAV) and micro aerial vehicles (MAV). The leading product is MicroPilot MP2028 series. [8]

Weighing in at only 28 grams, MicroPilot's MP2028g has raised the bar all around the world for functionality and value in small UAV autopilots. Paired with this powerful technology, the HORIZONmp ground control software provides a user friend point-and-click interface for mission planning, parameter adjustment, flight monitoring and mission simulation.

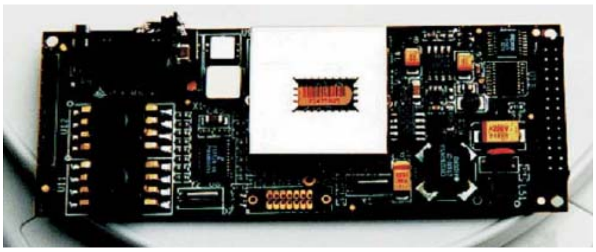

Figure 5
The MicroPilot 2028g UAV autopilot, 28 grams, 4 cm by 10 cm [8]

4.2 Developments in Hungary

The developments of UAVs have started about 15 years ago, from model airplanes to target drones such as METEOR series. Ten years ago a scientific research group has been created, at Zrínyi Miklós NDU [9], in aiming to coordinate the UAV related researches. The successful PhD dissertations dealt with new topics such as computer-aided analysis and synthesis of controllers, safety technology of MAV, onboard flight control systems, application of Digital Terrain Model in application of UAVs.

4.2.1 Flight Control Devices

- Three following PhD dissertations dealt with problems of development of automated flight control system:
- András MOLNÁR: The new methods and technical features in development of civilian and military robot vehicles [10]
- Antal TURÓCZI: Onboard flight control system of an unmanned quad-rotor helicopter [11]
- Miklós Tamás KONCZ: Application and electronic systems of the Meteor-3R target drone [12]

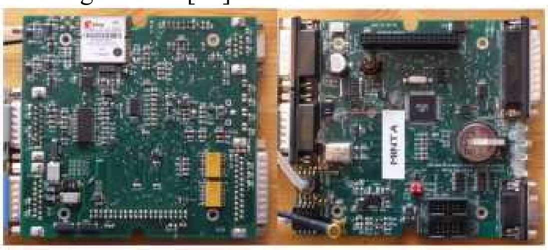

Figure 6

MAYFLAY-TWO onboard control system [12, p.74.]

4.2.2 Digital Map Integration in Flight Control Process

One PhD research theme dealt with problems of use of digital map, Digital Terrain Model in flight control process. Zoltán HORVÁTH in his PhD dissertation thesis pamphlet had written: “In the second chapter I pointed out the dangers when modifying the flight trajectories. I demonstrated that the data processes which need to have a safe route plan are not simple when determining the minimum height of safe flight and when considering the technical possibilities of the UAV.

I worked out algorithms for setting flight routes by the application of DTM so that a route can be flown safely with the consideration of the abilities of UAV and the effects of the terrain. Therefore this mode of flight is able to follow the terrain.” [13] So theoretically the use of digital map in the mission planning process is worked out. Now we have to found a usable onboard flight control system, where this process can work in practice.

Conclusions

1 An easy design process is proposed by the authors in aiming to build a simple airframe for low payload.

2 Using 3D CAD modeling technology may facilitate considerably the airframe design process.

3 Easy to use fluid mechanics verification software is available on the market which can be involved efficiently in the design process.

4 An important development was carried out at Zrínyi Miklós NDU in respect of programmed flight control devices in the past decade.

5 By means of a low-cost, easily accessible technology a dangerous arm became available even for terrorist purposes, which phenomenon needs urgent counter steps.

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Nomenclature:

F_y	(N)	Lift force
F_x	(N)	Drag force
ρ	(kg/m^3)	Density of air
v	(m/s)	Velocity
A	(m^2)	Area
c_y	(-)	Lift coefficient
c_x	(-)	Drag coefficient
Re	(-)	Reynolds number
h	(m)	Length of airfoil
ν	(m^2/s)	Cinematic viscosity
P_u	(W)	Useful power
P_A	(W)	Absorbed power
η	(-)	Overall efficiency

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