EXPERIMENTAL METHODS FOR UAV PERFORMANCE ASSESMENT

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This paper presents an experimental method for assessing the performances of a UAV based on telemetry data. Many flights, using the same UAV configuration, were performed before extracting flight data, in order to reduce the instrumental or statistic errors. Horizontal rectilinear uniform flight segments were chosen for statistical analysis. Starting from this data and using a theoretically thrust curve T(V) the airplane polar was determined and compared to the theoretical one. The aerodynamic efficiency is determined by selecting the areas in which the plane glides (throttle = 0), the speed is quasi-constant and the glide distances are long compared to the UAV dimensions.

Keywords: telemetry data, horizontal flight, gliding flight, plane parabolic polar, raw data processing

1. Introduction

As illustrated in the bibliography, fly tests are conducted in order to determine the actual characteristics of an airplane and to provide further research and development information. This paper is using the cruise performance test formulas from [1] but also develops a new test technique, which estimates the plane polar using gliding flight formulas from [5]. Having the lift and drag coefficients determined from gliding flight we can return to cruise flight and determine with more precision the thrust parameters. Raw data is selected from FFD 2013[3] international competition flight that took place in Istanbul, Turkey, between 10-12th of May 2013.

2. Factors to be considered in fly tests

Fly tests are one of the most challenging engineering problems. They are needed to determine the actual characteristics of the airplane and compared to computed or predicted characteristics, to provide further development information

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and to obtain research information. Because it needs to verify all of our theoretical and computed results, it's likely to be an integral part of development of most aerospace vehicles. Fly tests must be carefully planned in order to keep safety, cost and schedule considerations in balance.

The atmospheric conditions determine the performances and handling qualities of an aircraft and so they have a major impact over fly tests. Because two fly tests never produce the same result, the data must be carefully reduced to standard atmospheric conditions. The instruments that are affected by atmospheric conditions are the altimeter and the speed indicator (pitot).

Pitot measurements errors are:

- instrument error;
- pressure lag error;
- position error.

Instrumental error is simply the deviation of the instrument indications from a known differential pressure standard. It results from imperfections in the gauge itself and is typically measured in a calibration laboratory with the instrument disconnected from other parts of the pitot-static system. Several factors contribute to instrument error: scale error, manufacturing deviations, magnetic fields, temperature fluctuations, coulomb and viscous friction, and the inertia of moving parts.

Any pressure sensing system, like the conventional aircraft pitot-static system, is subject to errors due to time delaying transmitting the pressure from the point of measurement to the sensor. In an airplane, this error is typically only when rates of change of pressure are high. The lag error is proportional to the pressure drop through the system lines from the pressure orifice to the pressure indicator.

Position error calibration methods:

- Free stream static pressure methods in which pressure difference (ΔP) is obtained from measurement of static pressure and P_∞
- True airspeed methods in which ΔP is derived from values of V_∞ calculated from groundspeed measurements
- A temperature method in which ΔP is determined from measured temperature and a pressure-temperature survey
- Mach number methods, in which ΔP is obtained from Mach number.

Out of these four types of calibration methods the first two are the ones most often used. They are especially well-suited for low speed and low altitude, although the first category of methods includes several techniques useful at high altitudes and airspeeds.

3. Cruise performance tests for FFD 2013M1 plane

Using the logs from FFD2013 contest flights, several flight segments (Fig.1) were extracted according to the theory above. The key search of the flight segments (Fig. 1) were: constant altitude, throttle, airspeed, groundspeed and yaw, but also close to zero value for roll and pitch.

In order to use the speed-power test method described in [1] flight segments with different throttle values (or speed values) were needed. Flight segments were chosen from the competition days that took place in May 2013 [3].

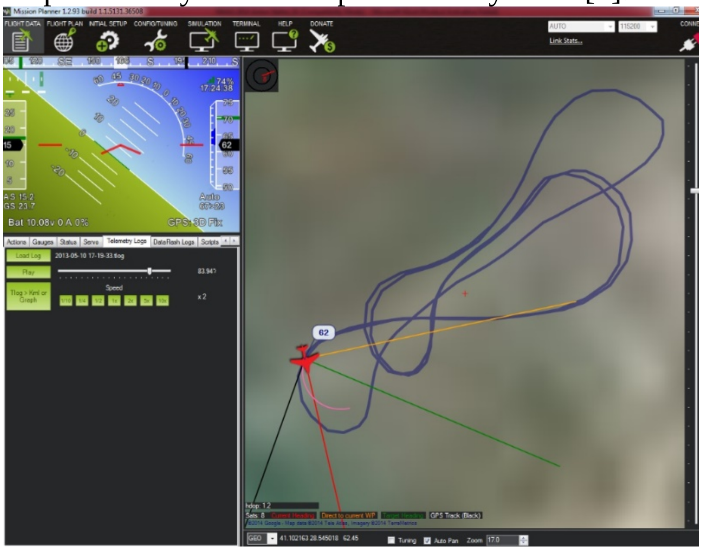

Fig. 1. “Mission Planner” course path

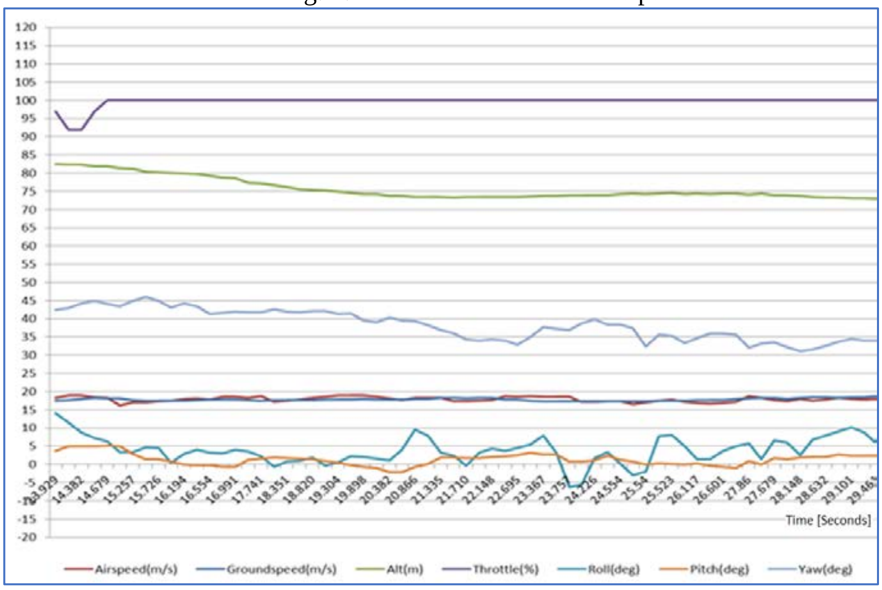

Fig. 2. Flight path I

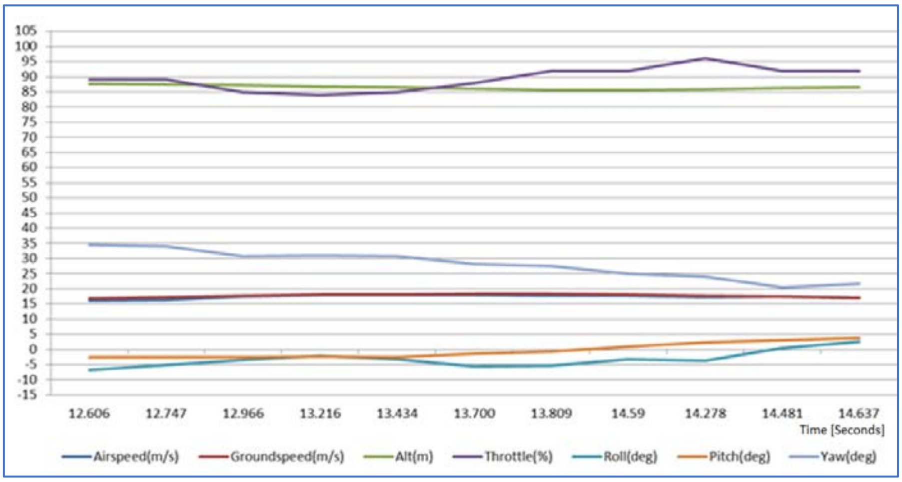

Fig. 3. Flight path II

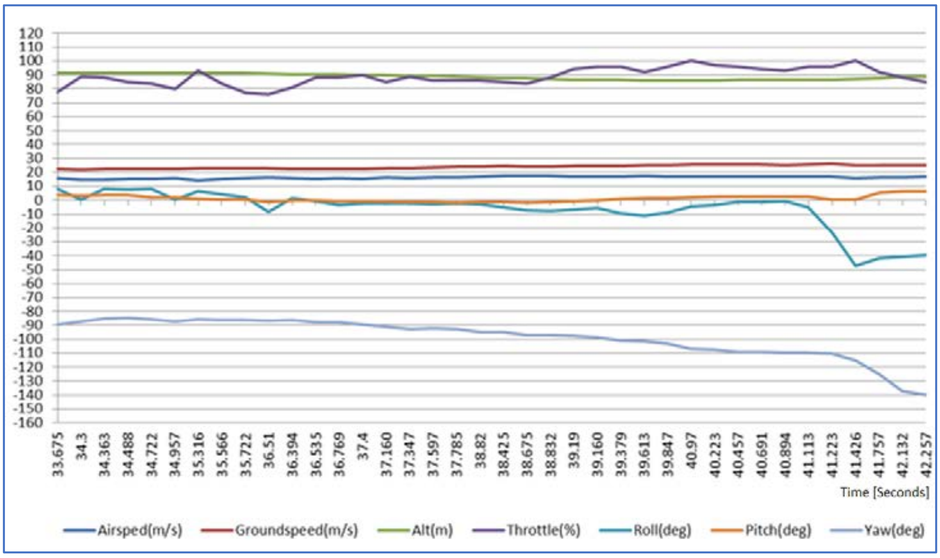

Fig. 4. Flight path III

From Fig. 2 – Fig. 4 we took the value of airspeed which varies slightly from groundspeed (measured by GPS), taking into consideration different values of throttle.

Considering the horizontal flight equation [5]:

$$W = L = \frac{\rho_0}{2} \cdot S \cdot V^2 \cdot C_L$$
$$T = D = \frac{\rho_0}{2} \cdot S \cdot V^2 \cdot C_D \qquad (1)$$

and with parabolic approximation of airplane polar $C_D = C_{D_0} + k \cdot C_L^2$ equation (1) becomes

$$T = \frac{\rho_0}{2} \cdot S \cdot V^2 \cdot C_{D_0} + \frac{\rho_0}{2} \cdot S \cdot V^2 \cdot k \frac{W^2}{\left(\frac{\rho_0}{2} \cdot S \cdot V^2\right)^2} \tag{2}$$

From the charts above, Fig. 2 – Fig. 4, the airspeed and throttle values are extracted for two airspeed values:

$$\begin{aligned} V_1 &= 18.5\ (Throttle \quad 100\%) \\ V_2 &= 15.5\ (Throttle \quad 80\%) \end{aligned} \tag{3}$$

Using the theoretical curve *T*(*V*) and with measured throttle and airspeed we can determine $T_D(V_1)$ and $T_D(V_2)$.

$$\begin{aligned} T_1 &= 0.8 T_D(V_1), \\ T_2 &= T_D(V_2) \end{aligned} \tag{4}$$

and:

$$\begin{aligned} y_1 &= \frac{2W^2}{\rho_0 \cdot S \cdot V_1^2}; \quad x_1 = \frac{\rho_0}{2} S \cdot V_1^2; \\ y_2 &= \frac{2W^2}{\rho_0 \cdot S \cdot V_2^2}; \quad x_2 = \frac{\rho_0}{2} S \cdot V_2^2; \end{aligned} \tag{5}$$

$$T_1 = x_1 \cdot C_{D_0} + k \cdot y_1; \quad T_2 = x_2 \cdot C_{D_0} + k \cdot y_2. \tag{6}$$

From (4), (5) and (6) we can determine C_{d0} and k

$$C_{D_0} = \frac{T_2 - T_1 \frac{y_2}{y_1}}{x_2 - x_1 \frac{y_2}{y_1}} = 0{,}016 \tag{7}$$

$$k = \frac{T_1 - x_1 \cdot C_{D_0}}{y_1} = 0{,}06 \tag{8}$$

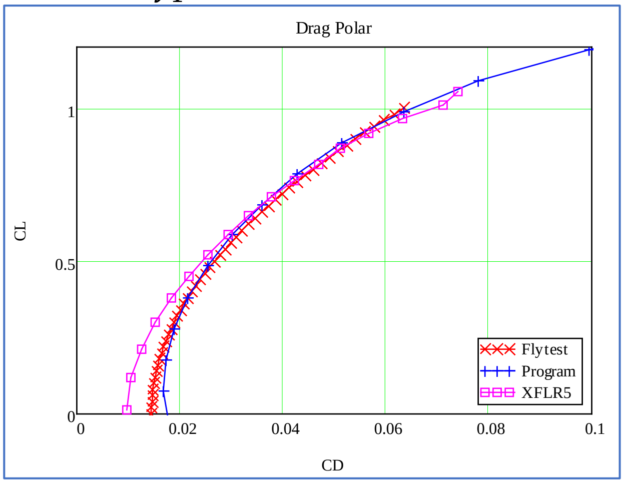

Fig. 5. Plane polar comparison

With C_{d0} and k obtained from gliding flight we can plot the experimental polar in order to be compared with the theoretical results (XFLR5 or Mathcad program). Against all measurements errors or theoretical approximations, we have obtained a very close result. To increase method precision, it is desirable that the two values $T_{1/2}$ to be as further apart as possible; angle of attack should be close to 0 for T_1 and close to critical angle of attack for T_2.

Function T(V) is theoretical; for better results it must be determined experimentally.

4. Descent performance tests for FFD 2011 plane

Every airplane on every flight takes off, climbs, turns, descends and lands. Thus, immediately after the pitot-static system is calibrated, the test team can begin collecting performance data for these phases of flight. The descent performance of a vehicle is of utmost importance to the operator and is directly related to lift and drag. Generally, measurements are made to determine either a speed or Mach number profile, minimum fuel to altitude or minimum time to a total energy level. The actual altitude and velocity measurements can be manipulated to describe the maneuver capability of the airplane or to evaluate the tactical capability of the vehicle relative to an adversary.

Gliding flight equation as described in [5]:

$$V^2 \cdot \left(C_{D0} + \frac{1}{\pi \cdot e \cdot AR} \cdot C_L^2\right) = \frac{2G \cdot \sin(\gamma)}{\rho \cdot S} \tag{9}$$

$$\frac{\rho}{2} \cdot S \cdot V^2 \cdot C_L = G \cdot \cos(\gamma) \tag{10}$$

From (9):

$$\frac{1}{\pi \cdot e \cdot AR} = \left(\frac{2G \cdot \sin(\gamma)}{\rho \cdot S \cdot V^2} - C_{D0}\right) \cdot \left[\frac{\rho \cdot S \cdot V^2}{2G \cdot \cos(\gamma)}\right]^2 \tag{11}$$

where the Oswald efficiency number is:

$$e = \frac{4G^2 \cdot \cos(\gamma)^2}{\pi \cdot AR \cdot \rho \cdot S \cdot V^2} \cdot \frac{1}{2G \cdot \sin(\gamma) - \rho \cdot S \cdot V^2 \cdot C_{D0}} \tag{12}$$

and zero lift drag coefficient is:

$$C_{D0} = \frac{2G \cdot \sin(\gamma)}{\rho \cdot S \cdot V^2} - \frac{4G^2 \cdot \cos(\gamma)^2}{\pi \cdot e \cdot AR \cdot \rho^2 \cdot S^2 \cdot V^4} \tag{13}$$

In order to determine $Cd0$ and e, we need at least two gliding segments with the following parameters measured: airspeed $V1$and $V2$, $\gamma1$ and $\gamma2$ determined from relation: $\gamma = arctan(altitude\ variation/flight\ segment\ distance)$.

AR, G, S and ρ are constants in this case.

The flight parameters used are described in the pictures Fig. 6 and Fig. 7.

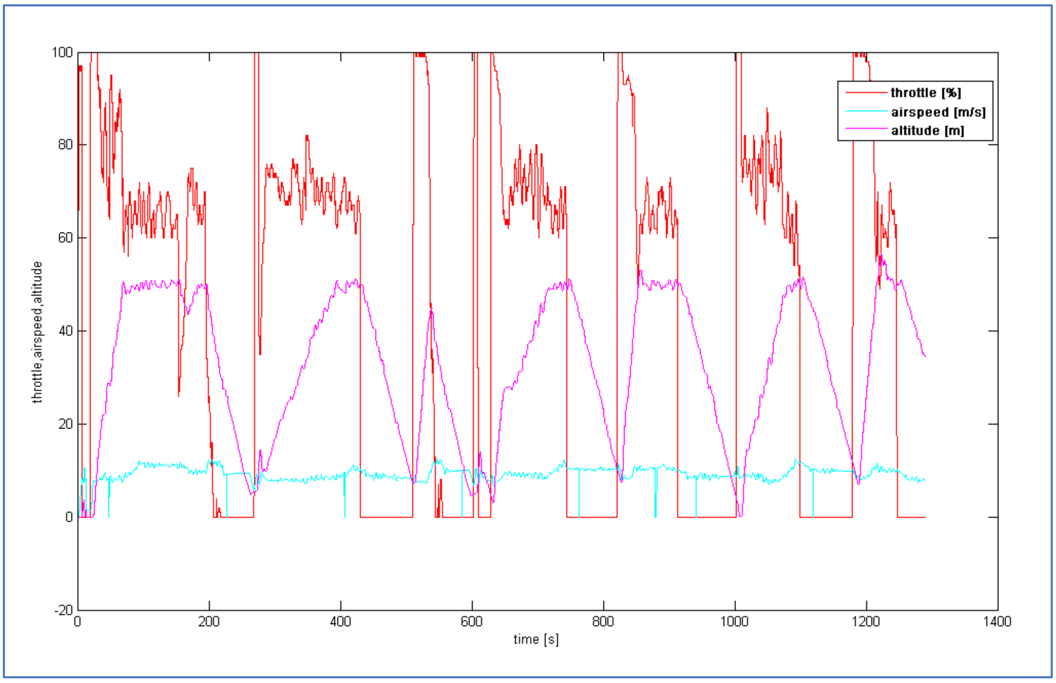

Fig. 6. Plane flight parameters – full flight

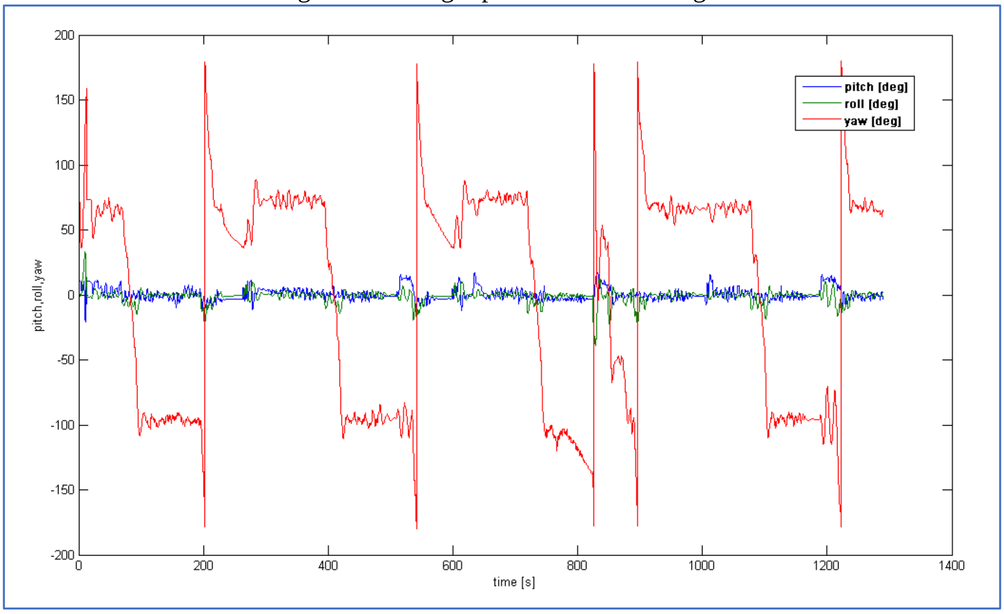

Fig. 7. Plane flight parameters – full flight

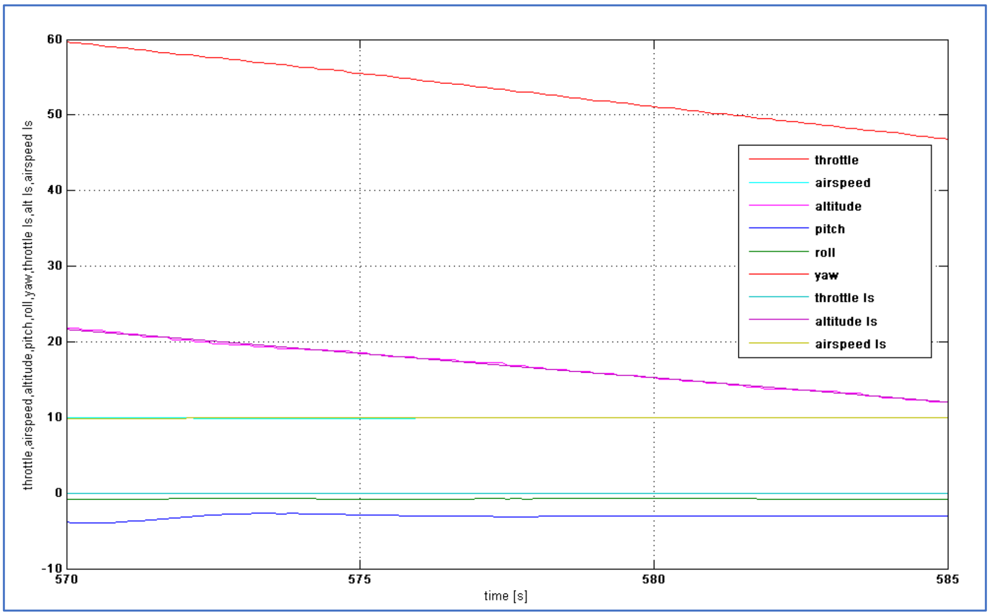

Fig. 8. Gliding flight segment 1

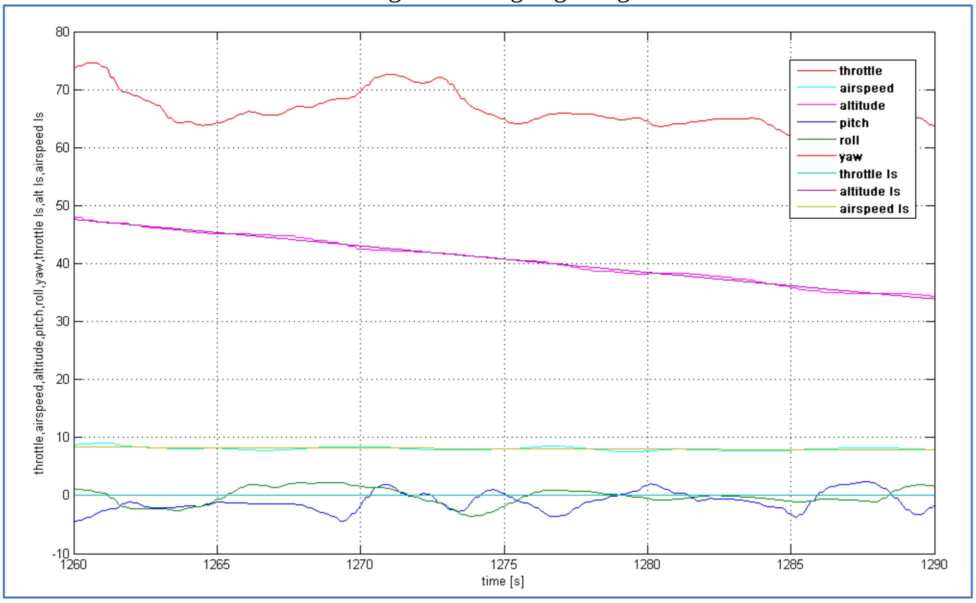

Fig. 9. Gliding flight segment 2

$$V_1 = 9{,}9322;\ V_2 = 7{,}9516;$$
$$dist_1 = 110{,}6;\ dist_2 = 226{,}28;$$
$$\Delta alt_1 = 9{,}64;\ \Delta alt_2 = 18{,}3823$$
$$\gamma_1 = atan\left(\frac{\Delta alt_1}{dist_1}\right);\ \gamma_2 = atan\left(\frac{\Delta alt_2}{dist_2}\right)$$
$$A_2 = \frac{4G^2 \cdot \cos{(\gamma_2)^2}}{\pi \cdot AR \cdot \rho^2 \cdot S^2};\ A_1 = \frac{4G^2 \cdot \cos{(\gamma_1)^2}}{\pi \cdot AR \cdot \rho^2 \cdot S^2}$$

$$B_1 = \frac{2G \cdot \sin(\gamma_1)}{\rho \cdot S};\ B_2 = \frac{2G \cdot \sin(\gamma_2)}{\rho \cdot S}$$

$$\begin{bmatrix} C_{D0} \\ e \end{bmatrix} = \begin{bmatrix} V_1^2 & \frac{A_1}{V_1^2} \\ V_2^2 & \frac{A_2}{V_2^2} \end{bmatrix}^{-1} \cdot \begin{bmatrix} B_1 \\ B_2 \end{bmatrix} \quad (14)$$

$$C_D(C_L) = C_{D0} + \frac{1}{\pi \cdot e \cdot AR} \cdot C_L^2 \quad (15)$$

Table 1

Numerical results, gliding flight

Aerodynamic parameter	Value
Parasite drag, C_{D0}	0,0471
Oswald coefficient, e	0,7226

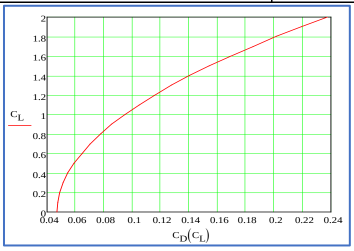

Fig. 10. Plane polar - gliding flight

5. Conclusions

Cruise performance tests are described in [1] and this paper only highlights the numerical results on FFD plane with the particularity of using the theoretical T(V). Because of the uncertainty introduced by the T(V) function, this paper is suggesting a new simple method by performing gliding flight test. This new method does not involve T(V), the propulsion system is not used (throttle = 0) and the folded propeller is not influencing the plane polar. When cruise tests are performed, it is assumed that the propulsion system is already measured in the lab thus resulting T(V) graph but any measurement involves errors and a high cost (time, manpower and equipment). This can be avoided by performing gliding flight tests. The method can be applied for any plane configuration (conventional, canard, flying wing) and it shows less errors for larger planes which have greater inertia moments. These are less influenced by wind speed during tests and allow for more accurate result for:

1. pitch, roll, yaw
2. distance flown between initial and final time
3. difference in altitude, minimizing barometric sensor error

The method has the advantage that supplies very quick results that can be used in preliminary design for the full-scale plane. This result is very useful because the theoretical results can be compared with the experimental results, which allows for design adjustments if needed. In both situations we have errors in calculations or measurements. For the experimental results we have a higher degree of uncertainty because certain steps of instruments calibration could not be checked and the flight segment is represented by just one flight and not an average of several flights that would have been performed under different weather conditions.

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