The Physics of the Aircraft Pilotage

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Abstract

In this paper we adopt a modelling approach in order to study the dynamics of longitudinal aircraft flight. The implementation of a "flight simulator" based on this model is used in order to analyze the dynamic effects of the main aircraft controls and explain how and when those controls are employed by pilots during all the phases of a flight.

Introduction

Many research studies [1,2] have pointed out that modelling-based didactical approaches, dealing with real-world systems and everyday problem solutions, can contribute to avoid disaffection in physics subjects, making them more attractive to pupils.

Physics of flight is usually considered one of the most fascinating real-world topics belonging to the everyone's common experience. Despite this, it is very often neglected in all the school curricula and, for this reason, bad known by pupils. In most cases, textbooks reduce the treatment to rough discussions about flight causes [3,4] that, sometimes, develop inaccurate models as well as approaches unable to describe phases of flight different from the horizontal one.

1 A model for flight

An aircraft is an essentially stable system. Its equilibrium configurations depend on the values of the relevant physical parameters associated to the fundamental forces regulating motion. These are: weight, lift, drag and thrust. Experiments in the wind tunnel show that lift and drag may be, within a good precision, considered proportional to the squared air-speed v of the aircraft:

$$L = k_L v^2$$

$$D = k_D v^2$$

where k_L (lift coefficient) and k_D (drag coefficient) depend on the aircraft geometry (shape, wings surface etc.), on the angle of attack and on the air density. The lift to drag ratio $L/D = k_L/k_D$ is usually called aerodynamic efficiency. Among these four forces, only the weight has a fixed direction because thrust and drag must be considered parallel to the instantaneous aircraft velocity, whilst lift is at right angle with this direction (Fig. 1).

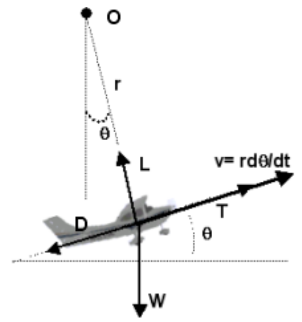

Figure 1. Free-body diagram

By assuming that the aircraft velocity is always parallel to its longitudinal axis and introducing the pitch θ, given by the angle between the longitudinal axis and the horizontal, it can be shown that the motion equation may be written in terms of tangential and radial contributions as

$$T - k_D v^2 - W \sin\theta = m\frac{dv}{dt}$$

$$k_L v - \frac{W\cos\theta}{v} = m\frac{d\theta}{dt}$$

2 The flight simulator

The motion equations are a non-linear system of two first-order differential equations. This system can not be solved exactly. However, as we are interested in steady-state configurations, these may be calculated exactly by setting to zero the second members of both equations. We find that the steady-states of the aircraft are represented by a given value of speed v and pitch θ depending on the particular choice of the four parameters: lift and drag coefficients, thrust and aircraft mass. On the other hand, as these parameters, except the mass, may be regulated acting on the aircraft controls, this means that pilots, acting on the controls, essentially modify a steady-state of the aircraft. In particular, the longitudinal flight is affected by the action of three main controls: throttle, flaps and elevators. Action on throttle and flaps changes the thrust value and the lift and drag coefficients respectively. The elevators, placed on the horizontal tail of the plane, allows to lower or to lift up the aircraft tail inducing variations of the angle of attack and then of the lift coefficient.

By using the Interactive Physics simulation environment [5], that is suitable for visualising the time dependence of dynamic variables and for changing the parameters of the model during simulation, we have analysed the behaviour of a light commercial one-propeller aircraft (mass = 1300 Kg, T_{max}=2.5 kN, k_D = 1 Kg/m and k_L = 9 Kg/m) during a complete flight from take-off to landing.

A screen-shot of this simulator is reported in Fig. 2. We can observe a frame just after the take-off. We have implemented also two panel instruments: the anemometer measuring the speed and the variometer measuring vertical speed.

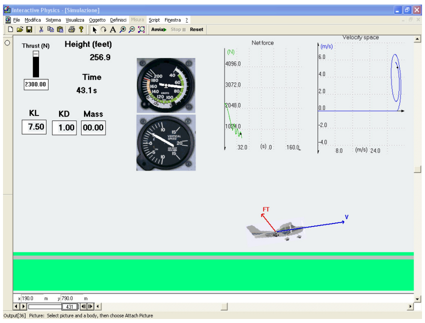

Figure 2. A screenshot of the flight simulation showing a frame just after the take-off.

3.1 The results of simulation

The flight has been divided into five different phases:

a) *Take off* - Plane initially at rest on the runway with throttle set to the maximum value of 2.500 kN.

b) *Climb* - Throttle maintained to its maximum value during all the climb until the flight level of 1,000 ft is reached.

c) *Cruise* – At height of 1,000 feet, thrust is reduced to 1.416 kN (thrust for horizontal flight given by W/E).

d) *Descent* - Throttle is reduced to 0.700 kN.

e) *Landing* – Flaps are extended and thrust is left unchanged.

The complete flight path is shown in Fig. 3.

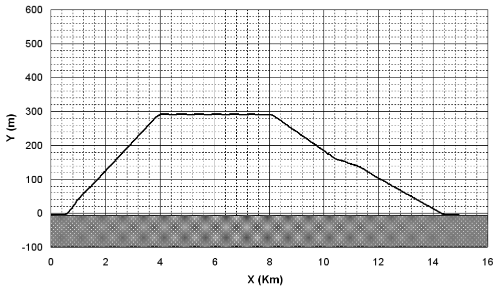

Figure 3. True trajectory drawn by the plane.

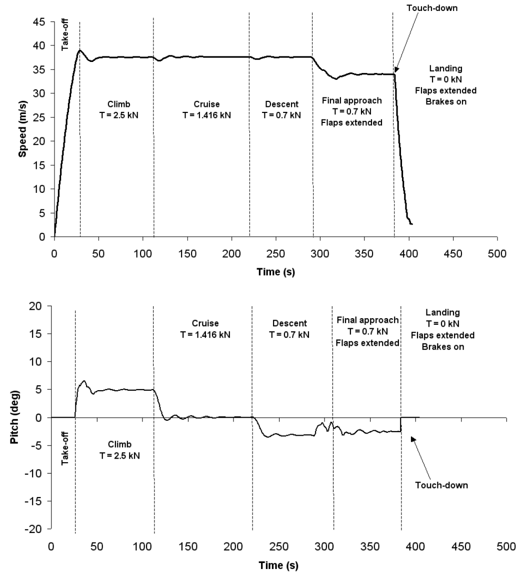

Figure 4. Plot of speed and pitch vs. time.

From the plots of Fig. 4, describing the whole flight, we may see that the aircraft behaves like a stable dynamical system: in each phase a steady-state configuration, represented by an equilibrium value of the couple speed-pitch, exists. These states are characterized by about the same speed and by a positive, zero and negative value of pitch during climb, cruise and descent-landing respectively.

Conclusions

Physics of flight as well as many physics topics require formal reasoning, ability to break problems into manageable components and to extract general principles from specific ones. Many studies [1,2] have pointed out that using dynamic visual representations can both speed and facilitate learning and that supportive software involving simulation tools can support this process. The computer tools we have used to model the behaviour of physical systems can bridge the gap between graphical, symbolic, and visual representations.

References

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[4] BAUMANN, R. and SCHWANEBERG, R. Interpretation of Bernoulli's Equation. *The Physics Teacher,* 1994, vol. 32, pp. 478-488.

[5] See the website http://www.krev.com