

Cessna Citation X Aircraft Global Model Identification from Flight Tests

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ABSTRACT

During an aircraft development, mathematical models are elaborated from its characteristics, physical laws and modeler prior knowledge of the system. Once the aircraft built, those models (mainly linear models) are tuned with flight test recorded data. Regulation authorities define the precision needed for such models.

The purpose of this paper is to build an aircraft global model complying with regulation authorities' accuracy requirements with minimal prior knowledge of the system. A professional D level simulator has been used as a flight test aircraft. More than 1,000 experimental flight tests were made with numerous configurations in speed (140 to 240 kt), altitude (10,000 to 46,300 ft), mass (24,000 to 33,000 lb) and the center of gravity position (17 to 34 % of the mean aerodynamic chord).

Aircraft's global model is built by identifying linear models at flight points within aircraft flight envelop and the center of gravity limits. Those models are then interpolated to provide a linear model within all the aircraft flight envelop and the center of gravity limits.

Linear model identification and interpolation provide accurate results for aircraft's short period mode. To our knowledge, it's the first time a study on this subject is conducted from flight test realization to model identification.

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INTRODUCTION

While developing an aircraft, mathematical models called white box models are frequently used for aircraft behavior and performance analysis. During flight tests, the mathematical models are improved from measurement identification. It then allows to take into account non-linear phenomenon like aeroelasticity, which would be difficult to determine otherwise.

The model is respectively named black box or gray box because it is respectively totally or partially obtained from system's dynamic measurements.

LINEAR MODELING

Aircraft study is commonly separated in two dynamic domains [1]:

- Longitudinal
- Lateral

Figure 1 shows this separation according to aircraft inputs and outputs.

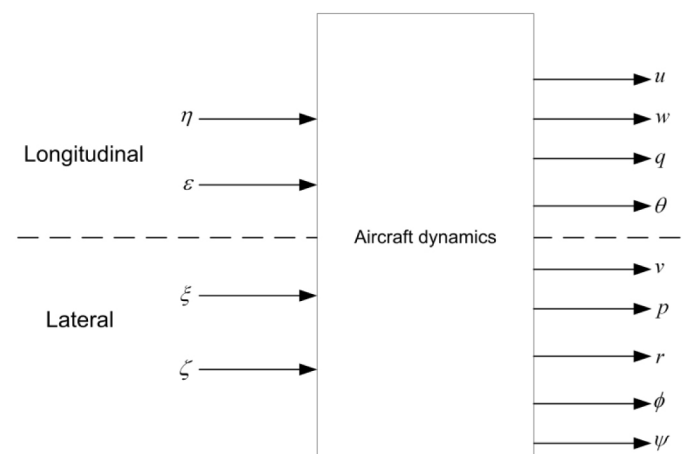


Figure 1. Input/output aircraft relationship.

In general, we study the aircraft model in the case where engine thrust (represented by the throttle lever angle ϵ) is kept constant. This allows simplifying aircraft dynamic equations.

On one hand, the steady state representation of the aircraft describing small variations around the equilibrium for longitudinal dynamics is [1]:

$$\begin{bmatrix} \dot{u} \\ \dot{w} \\ \dot{q} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} x_u & x_w & x_q & x_\theta \\ z_u & z_w & z_q & z_\theta \\ m_u & m_w & m_q & m_\theta \\ 0 & 0 & 1 & 0 \end{bmatrix} \times \begin{bmatrix} u \\ w \\ q \\ \theta \end{bmatrix} + \begin{bmatrix} x_\eta \\ z_\eta \\ m_\eta \\ 0 \end{bmatrix} \times \eta \quad (1)$$

On the other hand, lateral dynamic equations are given by the following steady state representation [1]:

$$\begin{bmatrix} \dot{v} \\ \dot{p} \\ \dot{r} \\ \dot{\phi} \\ \dot{\psi} \end{bmatrix} = \begin{bmatrix} y_v & y_p & y_r & y_\phi & y_\psi \\ l_v & l_p & l_r & l_\phi & l_\psi \\ n_v & n_p & n_r & n_\phi & n_\psi \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \end{bmatrix} \times \begin{bmatrix} v \\ p \\ r \\ \phi \\ \psi \end{bmatrix} + \begin{bmatrix} y_\xi & y_\zeta \\ l_\xi & l_\zeta \\ n_\xi & n_\zeta \\ 0 & 0 \\ 0 & 0 \end{bmatrix} \times \begin{bmatrix} \xi \\ \zeta \end{bmatrix} \quad (2)$$

Longitudinal modes are:

- Short Period mode
- Phugoid mode

Lateral modes are:

- Spiral mode
- Roll Response mode
- Dutch Roll mode

Those modes are detailed more in depth within the experimental framework part.

The orders of the steady state representations of the aircraft are the only prior knowledge used for the system identification part.

EXPERIMENTAL FRAMEWORK

The experimentation was conducted on a SimFinity flight simulator from CAE. The simulator flight dynamic model is

of FAA's D level, which ensures great model accuracy [2]. Thus, the SimFinity simulator behavior is considered as the reference for our study.

In order to obtain a model of the Cessna Citation X, the selected solution was to mesh the flight envelop (Figure 3) and the center of gravity limits (Figure 2). For each point of this 4 dimensions mesh, 5 flight tests were conducted (one for each longitudinal and lateral aircraft mode).

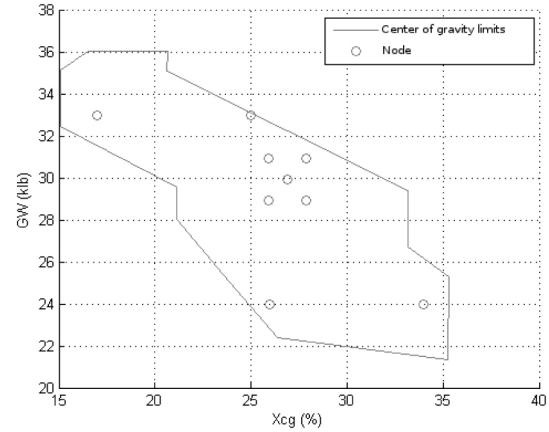


Figure 2. Center of gravity limits mesh.

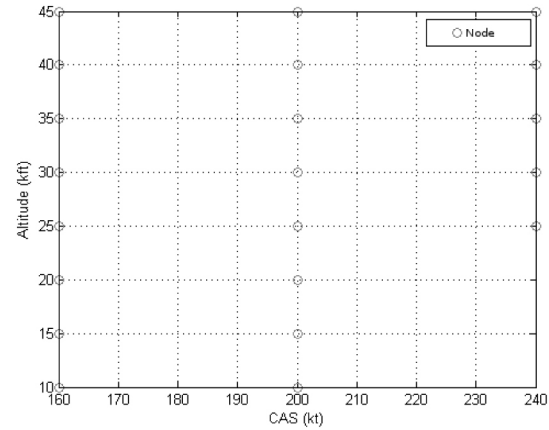


Figure 3. Flight envelop mesh.

Considering 9 points inside the center of gravity limits, 21 points in the flight envelop, we should have 945 flight tests in the flight test database. Some extra flight tests were conducted in order to provide validation points. Adding those validation points, the total number of flight test is 1,033.

Two methods were available to conduct flight test: automatic flight tests and manual flight tests.

Automatic flight tests are made using simulator side scripts.

Manual flight are made by two operators, one pilot and one instructor.

Repartition of automatic and manual flight test per flight test mode is given within the database is given in Table 1.

Table 1. Automatic and manual flight tests repartition

Flight test type (mode excited)	Manual	Automatic
Short period mode	32 %	68 %
Phugoid mode	48 %	52 %
Spiral mode	100 %	0 %
Roll Response mode	100 %	0 %
Dutch Roll mode	0 %	100 %

Mode Excitation

Short period mode

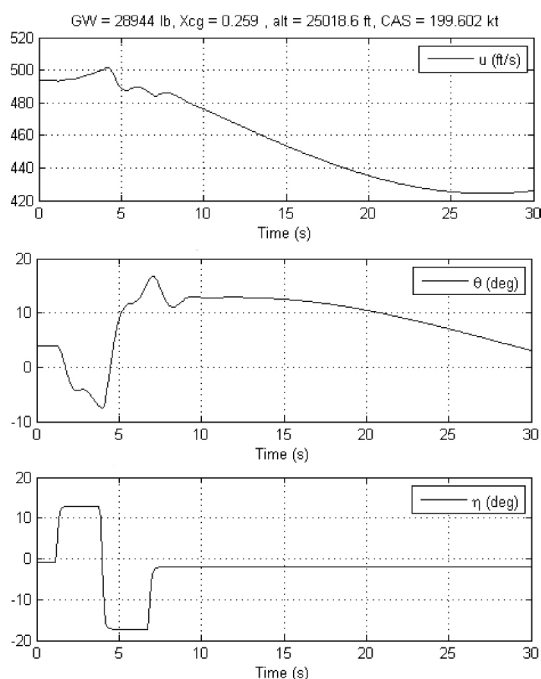
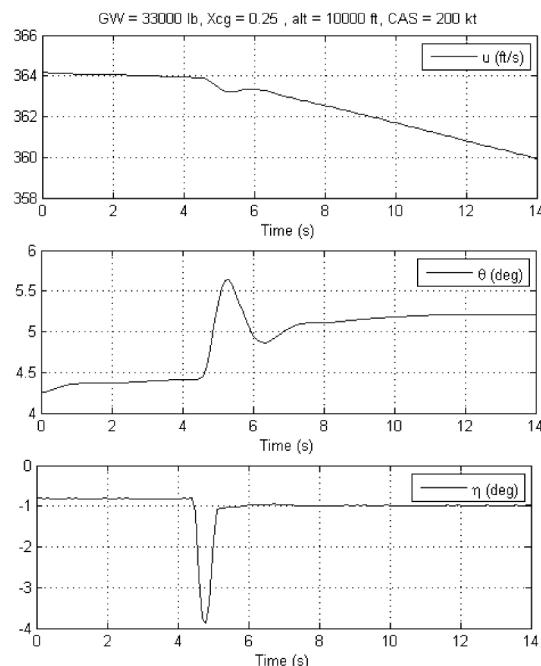
The short period mode is a rapid oscillation in pitch following an elevator input η . Its frequency is about 2.5 rad/s.

The input applied is different between automatic and manual flight tests. When conducting the flight test manually, the elevator input is two tablets of opposite sign (Figure 4). When conducting the flight test automatically, the elevator input is an impulse (Figure 5).

Two tablets are more easily applied to the aircraft by the pilot because he only needs to push-pull the joystick from the max elevator input stop to the min elevator input stop. However, this input presents a drawback: it also excites the phugoid mode which is slower but less damped than the short period mode. Moreover, the measurements may be polluted by the phugoid mode influence.

The only drawback of the elevator impulse is to be more complex to apply than the two tablets input.

Measurements show that the aircraft behavior is similar to a second order model, with a typical oscillatory behavior following the pitch angle θ [1].

**Figure 4. Manual short period mode flight test record.****Figure 5. Automatic short period mode flight test record.**

Phugoid mode

The phugoid mode is a slow and low damped aircraft's mode, mainly influencing u , θ and h [1]. Its frequency is about 0.1 rad/s.

Phugoid excitation mode can be done with a small longitudinal speed perturbation [1] applied to the aircraft in equilibrium. It consists in applying a small amplitude input on the elevator nose-down or nose-up. We apply this input until the longitudinal speed of the aircraft increases or decreases of 15 kt. When we reach this longitudinal speed variation, we release the elevator into equilibrium position.

Flight test records must contain at least three oscillations' period. From our test analysis on the Cessna Citation X, we observe three periods in 300 s.

As phugoid mode excitation flight tests are about 300 second; long, parasite lateral movements may appear during the flight test. Those lateral movements come from initial equilibrium defaults and need to be corrected [1] by either the pilot if the flight test is manual or a PID controller if the flight test is automatically done.

Only phugoid mode flight tests with a bank angle less than 5 degrees were accepted.