



COB-2021-1010 FLIGHT SIMULATOR MODEL OF A SUBSCALE GENERIC FUTURE FIGHTER

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Abstract. *Linköping University designed and tested in flight a remotely piloted fighter, the GFF - Generic Future Fighter, with the intention of exploring the subscale technique. The technique of building and testing an aircraft on a reduced scale, respecting similarity conditions, is called subscale. The Swedish project of research Methods for Subscale Flight Test and Demonstration (MSDEMO) has the main objective of investigate the methods of subscale flight tests. This project also includes a partnership with the Aeronautics Institute of Technology. In this work, the GFF flight simulator built with wind tunnel test data is presented. The union of two methods, wind tunnel and system identification, provides a more accurate simulation model. In this same simulator a doublet maneuver is applied to the elevator to verify the aircraft's short period mode. Despite the input, the aircraft proved to be stable when it returns to the trimmed position.*

Keywords: *Lift estimation, Subscale, Flight Simulator, Rapid prototyping, Unmanned aerial vehicle .*

1. INTRODUCTION

The growth in the use of drones in recent years has encouraged the development of batteries with higher energy density and the development of smaller, lighter sensors. The application of remotely piloted aircraft has become cheaper and more resourceful for data acquisition and telemetry. Many universities have used remotely piloted aircraft as experimental testing platforms for research.

Linköping University has been testing a remotely piloted fighter, the GFF - Generic Future Fighter subscale aircraft and has been researching the limitations of subscale technique (Sobrón, 2018). The technique of building and testing an aircraft on a reduced scale, respecting similarity conditions, is called subscale. The use of remotely piloted fighters for research and development of new configurations has always been applied by NACA and NASA, since the F-4 Phantom project (Chambers, 2009).

Another example, is the X-29 fighter, which is an aircraft with negative swept wing. This aircraft was tested in a Nasa wind tunnel using a remote control with cable. The aircraft flew with six degrees of freedom, as in free flight, to determine control and stability characteristics (Chambers, 2009). A more recent subscale fighter development is the F/A-18, equipped with vectoring paddles. The purpose of the test was to verify control and stability at high angles of attack. The vectored thrust showed good control qualities for angles of attack above 30°. Later, this capability could be demonstrated on the manned F/A-18 full scale, (Bowers, 1998).

The GFF is a subscale aircraft built and operate at University of Linköping. The research process of this platform is being developed in partnership with Aeronautics Institute of Technology (ITA). While the University of Linköping tests the aircraft in flight, the ITA is responsible for developing a simulator for this aircraft. In this work, a GFF flight simulator developed by ITA, in Matlab software will be presented and analysis about control and stability of GFF will be evaluated.

2. Subscale GFF

The GFF is a research collaboration between Saab Aeronautics, the Swedish Defence Research Agency (FOI), Volvo Aero, Linköping University and the Royal Institute of Technology (KTH). In 2006 these institutions decided to develop a conceptual design of a hypothetical next-generation fighter with stealth, super-cruise and long range capabilities. Linköping University assumed the task of building a remote piloted 14% scale of GFF to study subscale flight test and to determine what information could bring to the project Jouannet *et al.* (2012).

The project of research Methods for Subscale Flight Test and Demonstration (MSDEMO) from Sweden has the main objective of investigate the methods of subscale flight tests. This project also contemplate a partnership with Brazilian universities, including Aeronautics Institute of Technology and Universidade de São Paulo. It is under a bigger project from a initiative related to the *Future Aircraft Design and Demonstration* (FADEMO). MSDEMO promotes the research collaboration between Brazil and Sweden in the aeronautics field. This project works with independent resources from

each university. From Swedish side, the project has investments from the National Program for Aeronautics Research, Lundström *et al.* (2016).

The Generic Future Fighter (GFF), figure 1, is a subscale stealth fighter operated and manufactured by Linköping University. It was developed with the aim of studying a scaled fighter (14%) and to serve as an educational platform at Linköping University.

In order to determine a baseline for lift curve and other aerodynamic parameters, a wind tunnel test, with a 3.8% scaled GFF, was performed. On the table 1 is possible to compare the specifications of the GFF concept, the 14% subscale GFF and the 3.8% scale GFF tested in the wind tunnel.



Figure 1. GFF at Linköping University. Courtesy of Linköping University.

	GFF concept	14% Subscale GFF	3.8% subscale GFF
Take-off mass [kg]	15400	20	Not Applicable (NA)
Chord length [m]	4.48	0.627	0.170
Wing span [m]	10.5	1.47	0.402
Cruise altitude [m]	9000	0	NA

Table 1. GFF concept and GFF subscale

The Fig. 2 shows the systems inside the subscale GFF.

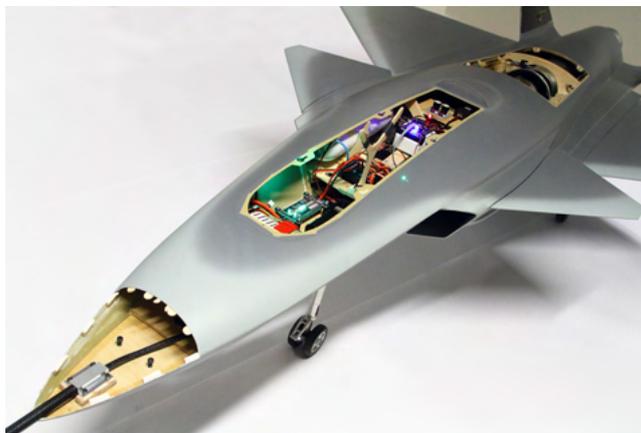


Figure 2. Electronic systems. Courtesy of Linköping University.

In 2017 and 2020, a flight testing campaign with data system acquisition was performed to acquire data to evaluate the stability and control of the subscale fighter. The subscale model, Fig. 2, shows the electronic systems used to operate the remote piloted aircraft. The engine is a jet turbine JetCat P160 capable of delivering a maximum thrust equal to 160 N. The radio control is a JetiModel DC-24. The data system acquisition used is a Pixhawk flight controller hardware, and

the software installed is the ArduPilot open-source with the version Plane (Sobrón, 2018). GFF taking off during a flight test campaign, Figure 3.



Figure 3. GFF taking off during a flight test campaign

3. GFF Wind Tunnel Test

The Wind Tunnel for Teaching and Research of ITA, is open circuit type and has a test section of 1 m high, 1.28 m wide (average) and 4 m long. The maximum speed of the wind tunnel is 80 m/s (280 km/h) and Mach number of 0.23. The fan is powered by 200 hp electric motor and has continuous speed control. Figure 4 presents the 3.8% scale GFF model at wind tunnel, manufactured on the 3D printer. And with epoxy finish to reduce surface roughness.



Figure 4. GFF at wind tunnel test

The wind tunnel has a Triumph Aerospace Force Measurement System (FMS) balance, designed specifically for this wind tunnel. The system fixes and directs the models throughout the range of tunnels operation and accurately measures the aerodynamic forces and moments. The single strut of the bayonet places the balance reference center at the center of rotation of the pitch/yaw system. The position control is done by computer and changes the angle of attack and the angle of sideslip during tests. The loads are calculated by load cell flexure strings.

The software that comes with the wind tunnel balance acquires the raw force data. The reference system of the balance is centered on the top of the model's fixing mast. The vertical force component is aligned with the mast, computing the lift of the aircraft. Which is perpendicular to the direction of the air velocity. With the lift force in hand, the lift coefficient

is calculated as follows

$$C_L = \frac{L}{0.5\rho V^2 S} \quad (1)$$

Where L is the lift force, C_L is the lift coefficient, ρ is the density of the air, V is the velocity of the air and S is reference area of the aircraft.

Due to the solid blockage effects present, they needed to be accounted for and estimated. Solid blockage is composed by wing blockage and body blockage. Solid blockage is the ratio of frontal area of an object to the stream cross sectional area, Barlow *et al.* (1999).

The corrections due to wing blockage effect at wind tunnel is described below. For the estimation of the solid blockage some parameters of the aircraft and the wind tunnel need to be described. The wing of GFF has an average thickness of:

$$t_a = \frac{0.08 + 0.04}{2} = 0.06 \quad (2)$$

The wing tip has a 0.08 thickness (t/c) and the wing root has a 0.04 thickness (t/c). From Figure 10.3 of reference Barlow *et al.* (1999), the constant k_1 used to calculate the blockage effect, is equal to 0.94.

The ratio of model span to tunnel breadth is:

$$r_b = \frac{0.402}{1.28} = 0.3104 \quad (3)$$

Where, 0.402 is the wing span and 1.28 is the tunnel breadth.

The ratio of tunnel width to tunnel high, B/H , is equal to 1.28. According to Figure 10.3 of reference Barlow *et al.* (1999), using r_b and B/H , is obtained τ_1 equal to 0.84. The wind tunnel area is 1.28 m^2 . The volume of wings (left and right) is equal to $1.45 \times 10^{-4} \text{ m}^3$. Thus, the solid blockage of the wing is:

$$\epsilon_{sbW} = \frac{0.94 \cdot 0.84 \cdot 1.45 \cdot 10^{-5}}{1.28^{1.5}} = 7.91 \cdot 10^{-5} \quad (4)$$

The blockage due to body is function of the effective diameter of the body, equal to 0.111 m and the length of the aircraft, 0.6 m. The ratio of the effective diameter to the length is:

$$\frac{d}{l} = \frac{0.111}{0.6} = 0.185 \quad (5)$$

From the figure 10.3 of reference Barlow *et al.* (1999), the constant k_3 is equal to 0.94. The volume of the body of the aircraft is equal to 0.001370 m³. Therefore:

$$\epsilon_{sbB} = \frac{0.94 \cdot 0.84 \cdot 0.00137}{1.28^{1.5}} = 7.47 \cdot 10^{-4} \quad (6)$$

The total solid blockage is:

$$\epsilon_t = \epsilon_{sbW} + \epsilon_{sbB} = 7.91 \cdot 10^{-5} + 7.47 \cdot 10^{-4} = 8.26 \cdot 10^{-4} \quad (7)$$

The dynamic pressure corrected is equal to;

$$q_c = q_a(1 + \epsilon_t)^2 = q_a \cdot 1.001652 \quad (8)$$

Where q_a is the wind tunnel dynamic pressure. The dynamic pressure corrected, q_c , was used to calculate the coefficients from wind tunnel test.

4. Model

The body coordinate system that was adopted is shown in Figure 5. The x -axis passes through the center of gravity and is parallel to the longitudinal direction of the aircraft, the positive direction points to the nose of the aircraft. The z -axis is on the plane of symmetry of the aircraft, perpendicular to x -axis and exiting through the bottom of the aircraft. Finally, the y -axis axis completes a right-handed trihedron.

The state variable equations for the simulator was defined as follows:

$$\dot{V}_T = \frac{F_T \cos(\alpha) - \bar{q} S C_D}{m} - g \sin\gamma \quad (9)$$

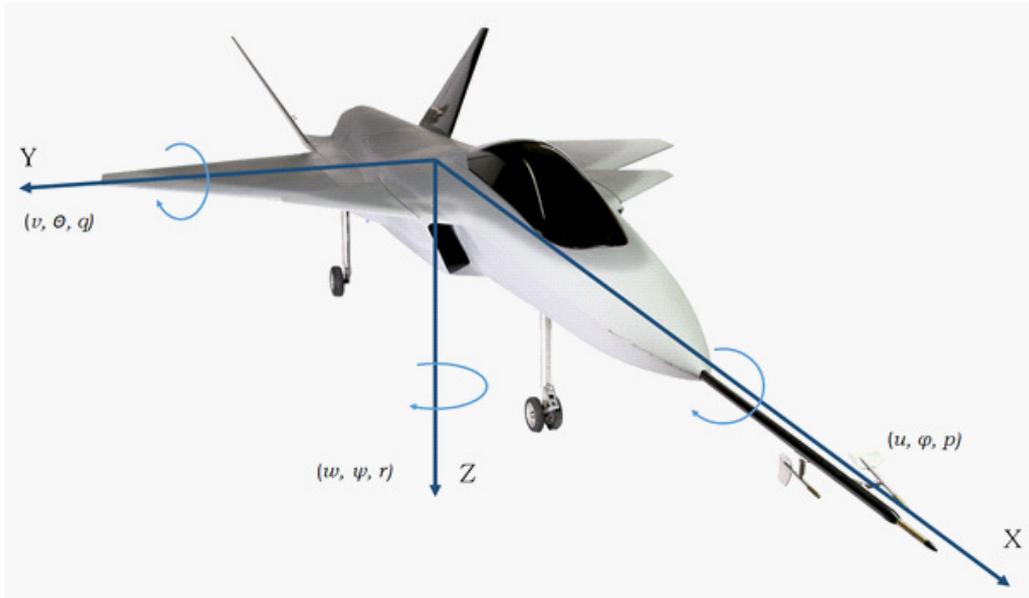


Figure 5. Reference System of GFF body

$$\dot{\alpha} = \frac{F_T \sin(\alpha) - \bar{q} S C_L + m(V_T q + g \cos(\gamma))}{m V_T} \quad (10)$$

$$\dot{\theta} = q \quad (11)$$

$$\dot{q} = \frac{\bar{q} S \bar{c}(C_m + D) + F_T Z_E}{I_{yy}} \quad (12)$$

$$\dot{h} = V_T \sin(\gamma) \quad (13)$$

$$\dot{x} = V_T \cos(\gamma) \quad (14)$$

Where V_T is the true airspeed, F_T is the thrust force, α is the angle of attack, \bar{q} is the dynamic pressure, S is the reference wing area, C_D is the drag force coefficient, g is the gravity, γ is the flight path, m is the mass of the aircraft, C_L is the lift force coefficient, q is the pitch rate, \bar{c} is the mean aerodynamic chord, C_m is the pitching moment coefficient, Z_E is the distance of the thrust force in z axis with respect to center of gravity, I_{YY} is the moment of inertia about y axis, h is the altitude and x is the position about x axis.

The dynamic pressure \bar{q} are defined as follows

$$\bar{q} = \rho \frac{V^2}{2} \quad (15)$$

Where ρ is the air density.

The pitch damping D is described as follows,

$$D = \frac{1}{2} \bar{c} \frac{C_{mq} q}{V_T} \quad (16)$$

Where C_{mq} is the pitch moment coefficient change due to pitch rate q .

The lift, drag and pitching moment coefficients are described as

$$C_D = C_{D0} + \frac{C_L^2}{\pi e AR} \quad (17)$$

$$C_L = C_{L0} + C_{L\alpha} \alpha \quad (18)$$

$$C_m = C_{m0} + C_{m\alpha} \alpha + C_{m\delta} \delta e \quad (19)$$

Where C_D is drag force coefficient, C_L is lift force coefficient and C_m is pitch moment coefficient.

5. Results

5.1 Wind Tunnel Results

Based on the data acquired in the wind tunnel test and applying the Eq. 1, the lift coefficient values were estimated. The angle of attack during the test was varied from approximately 0° to 16° . These values can be seen in the graph of the Fig. 6.

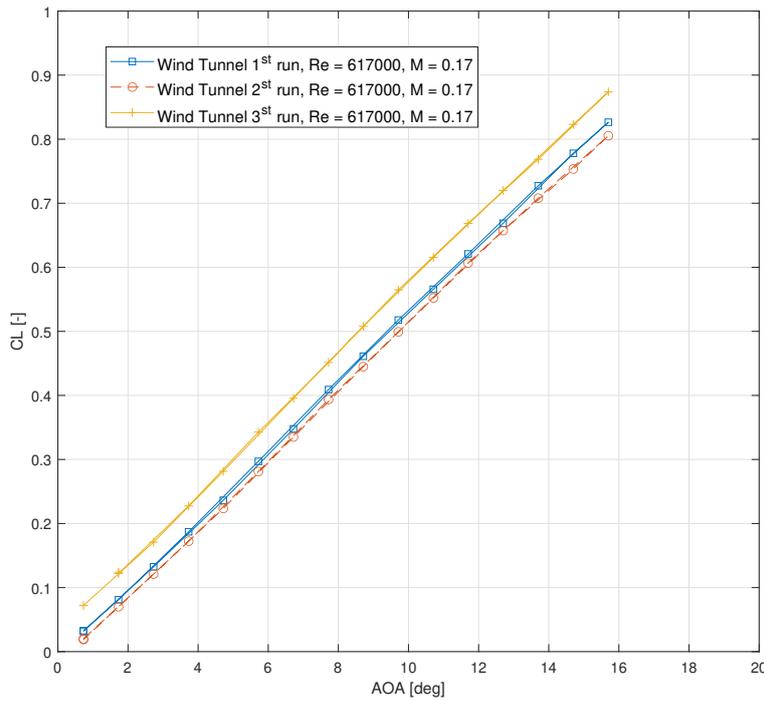


Figure 6. Lift Coefficient

Three tests in the wind tunnel were run. The third test, Fig. 6, has a slightly higher coefficient, probably due to some adjustment in the balance setup at the beginning of the test. These results of lift curve were used as input to the simulation model described in the subsection 5.2

5.2 Flight Simulator Results

The model was built based on the wind tunnel lift curve and with the estimated aerodynamic coefficients from flight test data, Sobrón (2021). These parameters can be seen in the table .

Table 2. Estimated Parameters

Parameter	C_{D0}	C_{L0}	$C_{L\alpha}$	C_{m0}	$C_{m\alpha}$	C_{mq}	$C_{m\delta e}$
Value	0.0250	-0.0100	2.8648	0.0424	-0.0121	-1.5600	-0.3000

The data from a simulation with the coefficients from the table 2 and with the state equations 9, 10, 11, 12, with the aircraft in a stabilized condition is shown in the graph below 7.

In the Fig. 7 are plotted the state variables, true airspeed V , angle of attack α , theta θ , pitch rate q and altitude h .

Another simulation was done, but with a doublet input in the elevator surface Fig. 8.

The doublet input on the elevator is a two sided step and is simple and adequate to excite the short period of the aircraft. Despite the input, the aircraft is stable and returns to the steady state condition.

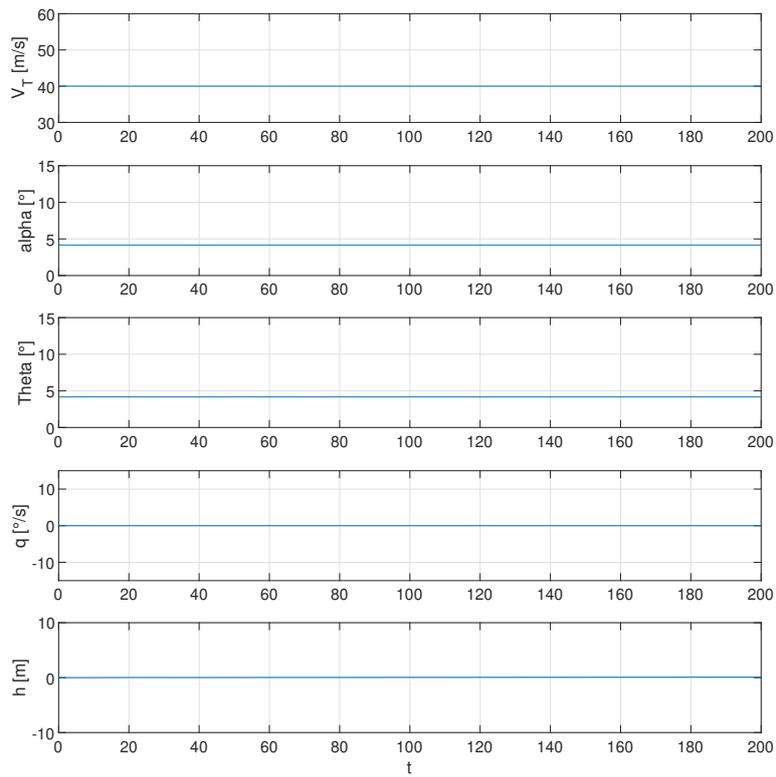


Figure 7. Simulation with steady state

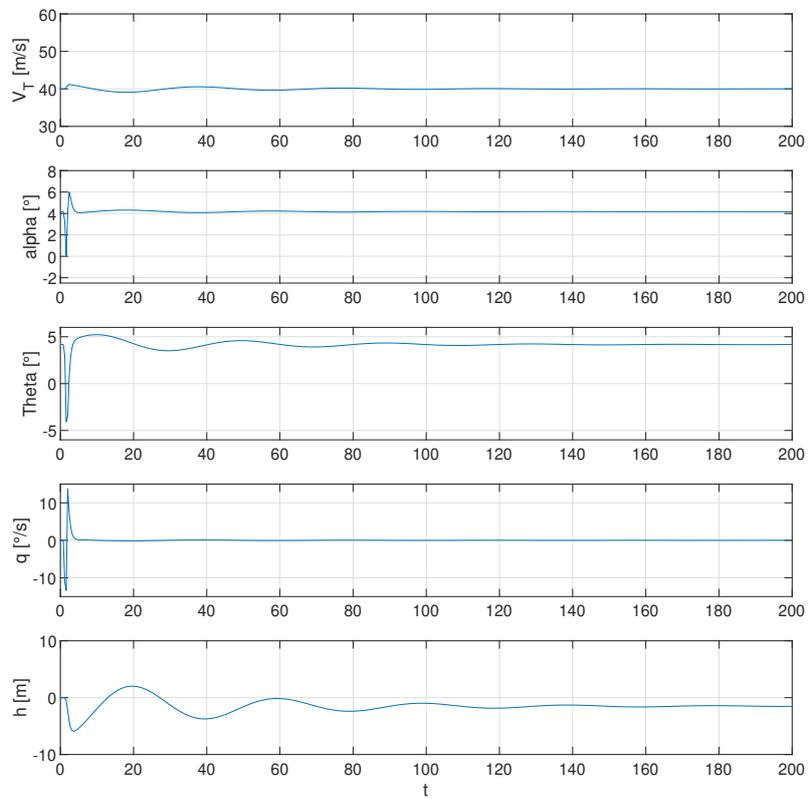


Figure 8. Simulation with doublet input in elevator surface

6. Discussion

The lift curve slope obtained in the wind tunnel is very close to the system identification presented in Sobrón (2021). The system identification process uses flight test data to estimate aerodynamic derivatives. However, initial values of derivatives need to be provided to start system identification. Justifying the use of the wind tunnel.

The wind tunnel can be used as a reference for comparing and validating the system identification using flight test data. It is also possible to fix the values of the derivatives, which have already been estimated in the wind tunnel, so that the system identification can estimate the other values. For example, dynamic derivatives that are not estimated in conventional wind tunnels. Because they demand a specific balance to acquire values of force and moment varying over time.

The other coefficients in the table, in addition to the lift curve, also come from the system identification method.

7. Conclusion

The use of wind tunnels for estimating derivatives guarantees more accuracy, but is limited, it does not estimate dynamic derivatives. On the other hand, an identification of systems makes it possible to estimate dynamic derivatives, such as the c_{mq} .

The union of the two methods, wind tunnel and system identification, provides a more accurate simulation model. The simulation model, in turn, allows an analysis of the aircraft's dynamic behavior in a theoretical and numerical way, without the interference of in-flight test noise, such as turbulence.

Wind tunnel data continues to be processed, such as momentum and drag force, to be compared to system identification. And thus obtain a more accurate simulation model of GFF.

8. REFERENCES

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