

Supporting Flight Dynamics, Parameter Identification and Simulation Teaching with a Flying Classroom

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Abstract: Cranfield University recently commissioned a modified Saab 340B airliner as a new flying laboratory classroom. The modifications are briefly described before the use of the flying classroom for flight test teaching is described. A flight dynamic model of the aircraft has been developed, and that, along with the data from the flight test programme are extensively used to support masters-level teaching in flight dynamics, flight simulation and flight parameter identification. Some examples of student results are also briefly presented.

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1. INTRODUCTION

An asset owned and operated by Cranfield University is the flying laboratory aircraft G-NFLB, a 34-seater Saab 340B twin turboprop commuter airliner, shown in Figure 1. The aircraft has been modified to serve as a flying classroom, and is used for teaching on both undergraduate and masters level programmes as well as supporting research programmes. The aircraft entered service for Cranfield University in 2021 and replaced a 15 seat British Aerospace Jetstream 31 aircraft (G-NFLA) that had served a similar purpose for over 20 years and was approaching its end-of-life. The aircraft is operated by a department of the university, the National Flying Laboratory Centre (NFLC), and is based at Cranfield Airport.



Fig. 1. Cranfield University Saab 340B twin turboprop flying classroom.

The Royal Aeronautical Society is licensed to accredit academic programmes at undergraduate and masters level. A

requirement of accreditation is that the programme should include a practical flight test course (Royal Aeronautical Society, 2024). Hence the NFLC provide sorties in the flying classroom that, supported by ground-based classroom teaching, form suitable practical flight test courses for around 1,700 students from over 20 universities as well as Cranfield.

Some other universities operate flying classrooms. For example, NLR and Delft University jointly operate PH-LAB, a Cessna Citation II, as an eight seater flying classroom. Students can experience real time the motions of the aircraft. Data is collected directly from the airplanes data buses and transmitted via wireless network onto tablet computers on which the students may see instruments in a similar format as seen by the pilot or graphs which provide real time information for the specific eigen-motions of the aircraft (Delft University, 2024). However the Saab 340B is unique in both its size and the range of applications it is used for.

The previous Cranfield University flying classroom, shown in Figure 2, was G-NFLA, a BAe Jetstream 31 sixteen seater twin turboprop airliner. Its use as a flying classroom is discussed by Daniels et al. (2023) where the experience and learning outcomes of a two sortie module of a part-time M.Sc. in Aircraft Engineering are reported upon. The paper includes a review of some of the other pedagogical studies of flying classrooms. The flight dynamics of the aircraft were also modelled (Cooke, 2006) and the resulting model used in teaching on the Cranfield M.Sc. in Aerospace Dynamics. In particular, the model was used to support modules on simulation and flight parameter identification. However, no pedagogical study of these has been reported in the literature.



Fig. 2. Cranfield University BAe Jetstream 31 twin turbo-prop flying classroom.

As well as being used for teaching, both G-NFLA and its predecessor, a Handley Page Jetstream, have been used for a variety of experimental work. For example, Mullen (2001) performed a study on the handling qualities of the Handley Page Jetstream during landing. Aerodynamic measurement and modelling techniques have been developed using the Jetstream 31 (Lawson et al., 2017). G-NFLA was used as a validation case for a study into system identification of uncrewed aircraft (Jameson and Cooke, 2015), for developing parameter identification techniques (Yusuf et al., 2017), and in a study of performance monitoring techniques (Sóbestor, 2021). The Jetstream 31 was used as a test bed for an icing-related decision-making system suitable for autonomous uncrewed aircraft (Armanini et al., 2016). The flight test data during icing conditions was also used to validate an icing accretion method based on super-twisting observers (Chen and Whidborne, 2023). A neural network approach to flight dynamics modelling was validated using recorded landings data for the Jetstream 31 (Antonakis et al., 2017). It has also been used to validate several CFD studies (Bennett et al., 2017a,b; Casadei et al., 2019; Könözy, 2021).

A flight dynamics model of the Saab 340B aircraft has been developed over the last few years. Makadia et al. (2023) developed a prototype model using Engineering Sciences Data Unit (ESDU) data sheets. System identification techniques are used by Millidere et al. (2023) to extract the aerodynamic parameters of the aircraft in the time domain from the flight test data. The study is extended by Millidere et al. (2024) using a swarm search technique to determine the most relevant set of independent variables for the data set. The aerodynamics data is fused with data from low-fidelity numerical methods to model, in particular, the impact of the flaps and elevators (Sahin et al., 2024). The model is in continuous development, so at present there is no ‘definitive version’, but the model is used on several research programs as well as for M.Sc. project work. Most importantly from an education perspective, it is used to support teaching on modules for the Cranfield University M.Sc. in Aerospace Dynamics. Hence the purpose of this paper is to describe the use of the Saab 340B flying classroom and its flight dynamics model in support of M.Sc. teaching at Cranfield University. The description of our utilization of the aircraft, models and data may provide lessons for other and future operators of flying classrooms.

In the next section, the aircraft is described along with some details of its modifications for use as a flying classroom. In Section 3, the use of the aircraft for teaching flight test is described as well as the use of dynamic models of the aircraft and data from the flight tests in dynamics, simulation and parameter identification teaching at Cranfield University. Finally, some conclusions are drawn and the paper placed in context.

2. THE SAAB 340B AIRCRAFT

G-NFLB, a Saab 340B aircraft, is shown in Figure 1. The Saab 340B is turboprop with a maximum take-off weight of 13155 kg, and is powered by two GE CT7-9B engines with a maximum continuous rating of 1750 SHP. G-NFLB has been converted into a laboratory for in-flight experimental work by the installation of an instrumentation system and seat-back displays. The cabin layout in G-NFLB is configured to 33 seats, although the normal maximum seating capacity of 24 is used. The on-board instrumentation system consists of signal conditioning units, power supplies, an Inertial Management Unit (IMU) and a data acquisition system. The aircraft is not a fly-by-wire but it is equipped with a pitch rate feedback damper that can be switched off, and it does have an autopilot.

The original aircraft was modified to add instrumentation for use as a flying class room and laboratory. The forward galley was removed and replaced with an equipment rack containing computer, data acquisition unit and other on-board instrumentation shown in Figure 3. Within the sets of additional instruments there is a MEMS based IMU called Ekinox-D which is a tactical grade compact high end MEMS sensor. The INS/GNSS comes with one or two antennas and provides orientation, heave, and centimeter-level position. The Ekinox-D sensors are embedded with an 8 GB data logger for post-operation analysis or post-processing.

The aircraft is additionally retro fitted with 861CAR Rosemount AoA and AoS vanes shown in Figure 4. Two AoS probes are fitted, one on the left and one on the right side. The Curtis Wright KAM-500 is used for the analogue data acquisition of on-board instruments such as the Rockwell Collins AHRS 3000 IMU unit as well as for other aircraft parameters such as control surface deflections and control stick positions using the Commercial Standard Digital Bus (CSDB) protocol. The attitude and heading reference information obtained from the CSDB protocol is used as a reference for comparing the performance the proposed navigation algorithm.

3. TEACHING WITH THE FLYING CLASSROOM

The M.Sc. in Aerodynamics extensively uses the aircraft for teaching. Following the usual U.K. model, the M.Sc. is a 48 week full-time programme consisting of 50% teaching and 50% individual project work. Each student is required to follow a module entitled Experimental Flight Test which is 20% of the taught part of the course. The students then choose eight modules for the remaining 80%; these are wide-ranging, covering both aerodynamics and flight dynamics. The aerodynamics modules include options in theoretical, computational and experimental fluid dynamics as well as wing design. The flight dynamics modules

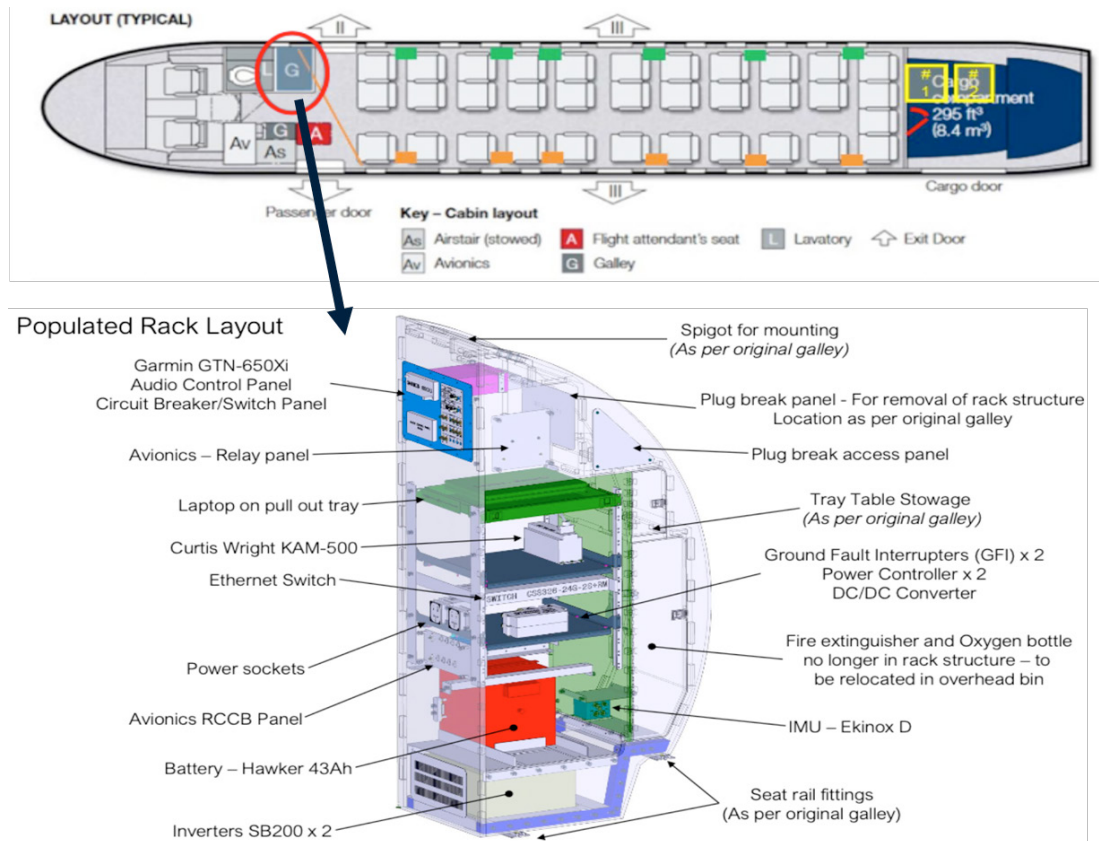


Fig. 3. Overview of the instrumentation on G-NFLB.

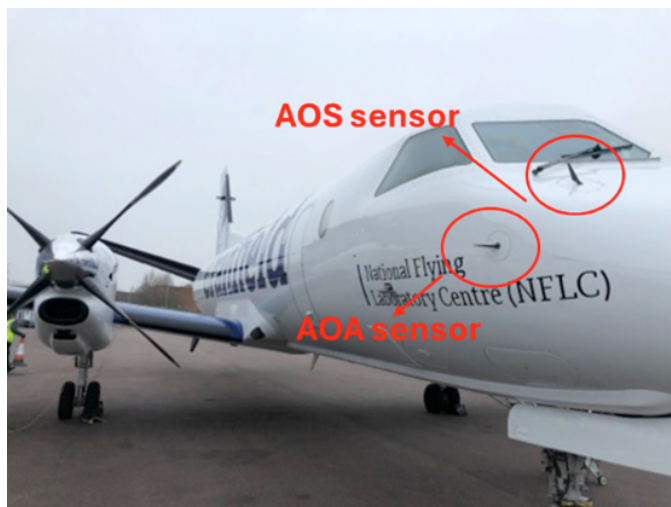


Fig. 4. AoA and AoS sensors on G-NFLB.

include Flight Dynamics Principles, Classical Control Design, Multivariable Control, Flight Control, Navigation and Sensing, Flight Simulation and Parameter Identification – thus covering most of the competencies required by a modern flight dynamicist or flight control engineer.

3.1 Experimental Flight Test

This is a unique module in the United Kingdom university sector. The aim is to provide an introduction to the performance, stability and control characteristics of a conventional aircraft. The module consists of ground school

lectures in flight test instrumentation and measurement, flight data analysis, aircraft performance, aerodynamics and flight dynamics. The syllabus covers the following

- air data systems, standard atmosphere and pressure error measurement;
- basic aircraft aerodynamics of lift and drag;
- cruise and climb performance;
- static equilibrium and trim;
- longitudinal static stability, trim, pitching moment equation, static margins and manoeuvre margins;
- lateral-directional trim and static stability;
- introduction to dynamic stability and modal analysis;
- and certification specification requirements and compliance assessment.

The students also have 7 sorties on the aircraft which support the theoretical knowledge given in the above list of aspects of aircraft assessment. Each sortie lasts about 60 minutes. For example, the objectives of the first flight are

- (1) Estimate the lift and drag coefficients and compare with wind tunnel test and other historical data.
- (2) To estimate the best lift/drag ratio for the aircraft.
- (3) Assess the effect of undercarriage and flap deployment on the lift and drag characteristics.
- (4) Estimate the pressure error corrections (PECs) for airspeed and altitude using the GPS method.

During the flight, the students can view the data on a tablet computer in either flight instrument format (see Figure 5, for example), or as traces. The students receive

the data after the flight. The students are assessed by a flight test report which is written to industry standards. It is done as a group exercise, each student will analyse and report on one aspect of the aircraft resulting in a complete assessment of the aircraft.

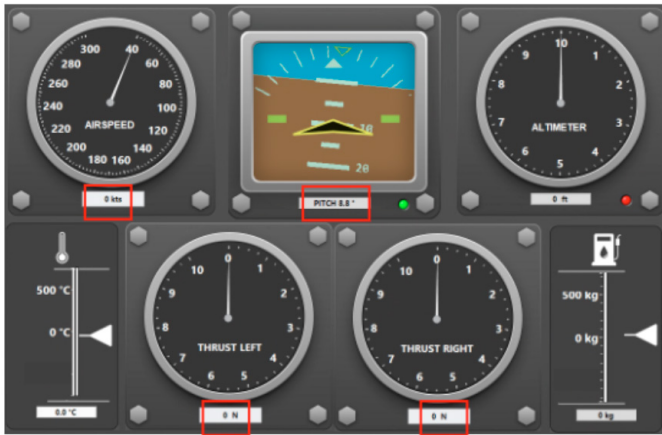


Fig. 5. Example of flight data display on tablet computers.

3.2 Flight Dynamics Principles

The Flight Dynamics Principles module aims to describe and demonstrate methods for analysis of the linear dynamics, stability and control of fixed-wing aircraft and their interpretation in the context of flying qualities. The module is a pre-requisite for subsequent flight control, simulation and identification modules. Upon completion the students should be able to:

- (1) Apply small perturbation theory to derive and solve the equations of motion for a conventional fixed-wing aircraft.
- (2) Compare the effects of aerodynamic derivatives on the aircraft static and dynamic characteristics.
- (3) Assess the flying qualities of a fixed-wing aircraft using the Certification Specifications/Standards,
- (4) Recommend and design simple stability augmentation system strategies to rectify flying qualities deficiencies.

The module is assessed via an individual problem-solving based course work where the students are given a unique flight condition. The students are required to use empirical modelling techniques using ESDU datasheets to calculate the longitudinal and lateral-directional state-space representation of the Saab 340B aircraft dynamics. Afterwards the students are required to perform modal analysis and assess the flying qualities using industrial standards. Depending on the assessment the student is required to design a simple pitch rate feedback damper to meet the specified flying quality. Figure 6 shows an example case for a pitch damper designed by a student.

3.3 Air-Vehicle Modelling and Simulation

Another module of the M.Sc. in Aerodynamics is Air-Vehicle Modelling and Simulation. The aims of this module are to provide the student with the skills and knowledge necessary to model, simulate and then critically analyse the resultant non-linear motion of modern air vehicles

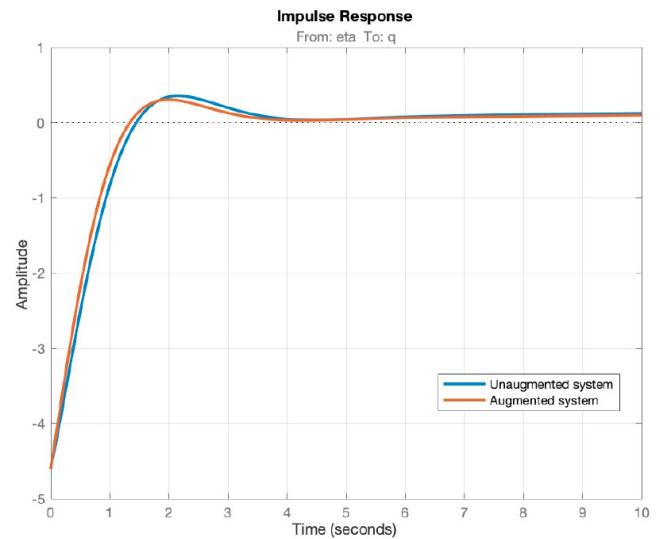


Fig. 6. Pitch damper effect on pitch rate (q) from elevator (η) for short-term response.

using advanced design and analysis software tools. On completion, a student should be able to:

- (1) Recognise, implement and apply selected numerical integration routines for model simulation using modern software tools.
- (2) Describe air-vehicle dynamics as a set of ordinary differential equations, and define and implement example air-vehicles in terms of their aerodynamic, control, mass and inertia characteristics. Evaluate and critically compare the resultant motion.
- (3) Identify the requirements for model testing, verification and validation, and demonstrate their application to an air-vehicle model.
- (4) Define mathematical trim conditions, how they relate specifically to air-vehicles and validate an air vehicle using trim data generated for a range of flight conditions and vehicle configurations.
- (5) Define mathematical linearization, how it relates specifically to air-vehicles and validate a non-linear air-vehicle model using the linear model equivalents generated at a range of flight conditions.

The module consists of lectures and MATLAB/Simulink exercises in simulating non-linear dynamic systems, Simulink model building, and numerical trimming and linearization in Simulink. The module is assessed via an assignment, where a partially complete Simulink model of the Saab 340B is provided to the students, and their tasks include completing the model, performing numerical trimming and linearization, performing a modal analysis, and validating the model using data from the sorties of the flying classroom. Figure 7 shows an example from a student analysis of a yaw rate comparison.

3.4 Fundamentals of Aircraft System Identification

System identification is essential in the aerospace field for extracting aircraft dynamics models from flight test data, thereby supporting both fundamental and applied research. Cranfield University is among the few institutions globally that offer an M.Sc. course and short course specif-

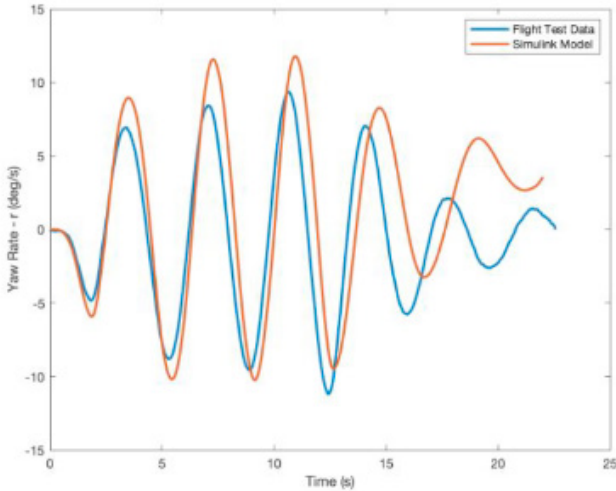


Fig. 7. Example of validation by yaw rate comparison for a Dutch roll manoeuvre.

ically in the area of aircraft system identification. This module aims to provide a comprehensive understanding of the analytical methodologies and flight test techniques used to derive linear and nonlinear mathematical models of various aircraft, including fixed-wing, rotary-wing, and UAVs. Upon completion, students should be able to:

- (1) Apply various classical and state-of-art system identification tools to derive qualified flight dynamic models from flight test data.
- (2) Plan a flight test sortie to obtain flight test data and conduct data compatibility analysis to create a reliable dataset most suited for system identification.
- (3) Determine the appropriate structure model and estimate the model parameters validated by suitable approaches.
- (4) Describe and categorise methods of system and parameter identification based on the desired mathematical model.
- (5) Apply system identification tools to explore and better understand nonlinear aerodynamic phenomena.

The module comprises lectures and MATLAB/Simulink exercises focused on parameter identification. The integration of the Saab 340B flying laboratory aircraft provides students with practical experience in critical areas such as flight test preparation, data kinematics consistency checks, and the application of analytical tools to real flight test data—elements often lacking in similar courses at other universities. The exercise includes

- (1) Conducting a consistency check to ensure the quality of flight test data, including identifying any erroneous or missing data points.
- (2) Applying system identification techniques to determine key stability and control derivatives from the flight data.
- (3) Evaluating the accuracy of the models in replicating the true aerodynamic behaviour of the Saab 340B.

Figure 8 presents an example from a student paper that compares G-NFLB flight test data with predictions from

an estimated lateral-directional model, utilizing a time-domain output-error identification procedure.

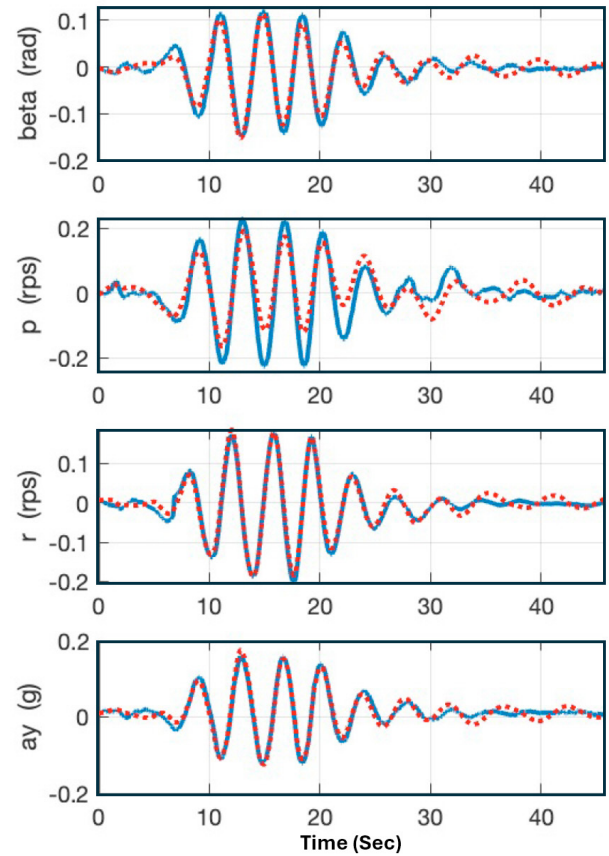


Fig. 8. Comparison of predication of identified lateral-directional model predication and flight test data at 150kts.

4. CONCLUSIONS

The paper describes the use of the Cranfield University Saab 340B flying classroom for teaching for an M.Sc. in Aerospace Dynamics. The paper is largely descriptive, an pedagogical analysis of the effectiveness of the classroom remains for future work. However, anecdotal evidence shows that the students generally appreciate the value of the aircraft and the use of data that is more representative of what may be experienced in industry.

The flight dynamics model (Makadia et al., 2023; Millidere et al., 2023) will be implemented into the Cranfield University Future Systems Simulator (Korek et al., 2024) and used for project work by the students as well as to provide a simulation facility to enhance their experience in the Experimental Flight Test module and other modules. In a modified form, this model may be made available to other university courses who use the flying classroom.

The main aspect of flight dynamics that is not described in this paper is that of flight control. The Saab 340B is a commuter airliner, and as such, has very benign dynamics and large stability margins. The pitch rate dynamics are augmented by a pitch-rate feedback damper, and the aircraft does have an autopilot, but in terms of flight control, the designs of neither are particularly challenging

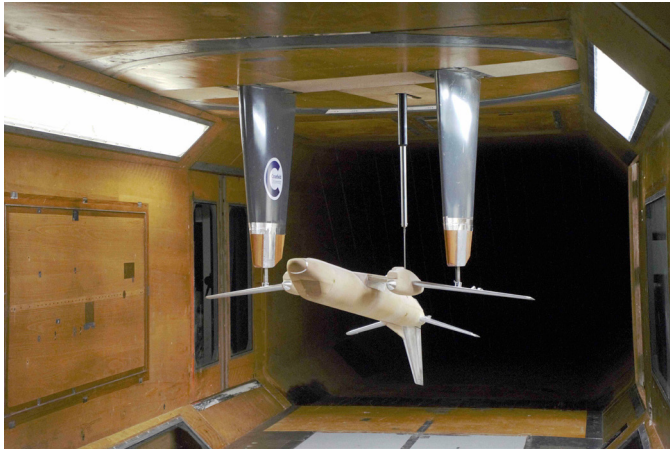


Fig. 9. Saab 340B model in the Cranfield 8ft × 6ft Low Speed Wind Tunnel.

compared to, for example, fly-by-wire combat aircraft or rotorcraft. Hence the flight control modules of the M.Sc. programme do not make extensive use of the aircraft or its flight test data. That said, the planned implementation the Saab 340B model in the Future Systems Simulator could be used for flying qualities assessment of fly-by-wire transport aircraft control designs (e.g. C* controllers) and this may also be done in the future.

This paper has concentrated on the use of the aircraft for flight dynamics M.Sc. teaching, but the aircraft is also used for other M.Sc. programmes at Cranfield, namely the Aerospace Vehicle Design and Airworthiness. Furthermore, a wind-tunnel model of the aircraft has been constructed (see Figure 9) and is being used for project work by for the M.Sc. in Aerospace Dynamics. The results will be used to improve the flight dynamics model of the Saab 340B.

In much engineering teaching, examples and exercises given to students are ‘toy’ problems, without all the ‘real-world’ problems of noise, uncertainty, missing data, and so on. In using data measured from the G-NFLB, the assignments are given a problem that is much closer to the industrial-scale problems that most students will encounter in their working lives and hence prepare the students for the realities of working with real problems.

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