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SUBSCALE FLIGHT TESTING OF A GENERIC FIGHTER AIRCRAFT

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Abstract

Recent technological advances in mechatronics enhance the possibilities of utilizing subscale flight testing as a tool in the development of aircraft. This paper reports the current status of a joint Swedish-Brazilian research project aiming at exploring these possibilities. A 13% scale fighter aircraft is used as a test bench for developing methods and procedures for data acquisition. The aircraft is equipped with an instrumentation system assembled from off the shelf components as well as open source hardware and software.

1 Introduction

Since the birth of aviation, downscaled models have played an important role in aircraft development. Initially, simple free-flying uncontrolled models were used to understand the physics of flight. It was not long until these models were put in wind tunnels, allowing easier quantification of characteristics, and it has since then remained the primary tool for aerodynamic studies. Nevertheless, the high operational cost of wind tunnels and the increase of available computational power are making engineers rely increasingly on simulations. However, simulations can be hard to verify, especially when applied to unconventional and unproven concepts. Nowadays, with the new capabilities of modern electronics, the interest in free-flying subscale models is rising again in the aeronautical community. With modern data acquisition tools and remote control (R/C) systems, subscale flight testing can provide aerodynamic information in a way similar to a wind tunnel. And more interestingly, it can be used for identification of flight dynamical characteristics during early stages of design, becoming a valuable input for risk reduction and for the design of flight control systems. This paper describes an ongoing research program, MSDEMO, in which the possibilities of subscale flight testing are explored.

1.1 Subscale Flight Testing

Testing of a scaled model in free-flight, equipped with some form of data acquisition system, is generally referred to as subscale flight testing (SFT). NASA is in many ways the pioneer of using subscale models in aircraft research. A good historic summary is given by Chambers [1]. Free-flying models have been particularly used for dangerous tests, such as high angle-of-attack flight or to study departure modes. Spin models for updraft wind tunnels have been a standard practice since the 1940s, but free-flight models have also been built for conventional wind tunnels such as the NASA Langley Free-Flight Facility [2]. Spin testing is also often carried out using remotely controlled unpowered models dropped from helicopters. In Sweden, this was used during the Saab Viggen test program [3]. More recent examples of how drop models have been used are the X-31 program [4] and Boeing F/A-18E/F [5]. Subscale drop models have also been used for studies of space vehicles such as the Lockheed Martin X-38 and Japanese HOPE-

X [6].

More advanced demonstrators are often powered by their own internal propulsion systems. Some examples are the Rockwell HiMAT [7], the NASA-funded McDonnell Douglas X-36 [8], the Saab SHARC UAV [9], the NASA X-43A-LS [10], the proposed Gulfstream Quiet Supersonic Jet [11], and the BAE Systems UAV technology research program FLAVIIR [12]. In all these cases the configurations are highly unconventional and there is thus a desire to demonstrate their feasibility without the cost or risk of a manned, full-scale vehicle.

Recently, the use of subscale flight testing has been extended to civil aircraft, as in the NASA AirSTAR research program [13], in which scaled models are used to explore an extended flight envelope for a civil transport aircraft.

Regarding blended wing body concepts, the X-48 program from Boeing and NASA has been using a scaled model to demonstrate the concept and obtain more data without going to full-scale [14]. An example of a pure research project with partners from both university and industry is the NACRE Innovative Evaluation Platform (IEP), in which a modular, dynamically-scaled aircraft is built to study environmental and safety issues [15].

2 MSDEMO Project

MSDEMO is a research project that investigates methods for subscale flight testing and demonstration, which also includes a research collaboration with the Brazilian universities Instituto Tecnológico de Aeronáutica (ITA) and University of São Paulo (USP). It is a subset of a larger initiative regarding Future Aircraft Design and Demonstration (FADEMO). The MSDEMO project as a whole is focusing on the following topics:

- Possibilities and limitations of subscale demonstrators in aircraft development,
- Dynamic scaling for development of control laws for unconventional configurations,
- Scaling methods depending on the issues to be addressed and the associated cost,
- Flight testing methods, repeatability and uncertainty issues,
- Implementations of an efficient avionic system for flight control and data logging.

A secondary objective of this project is to promote and facilitate research collaboration between Sweden and Brazil in the aeronautical field. This type of project is envisaged to be suitable in that sense, since the valuable data sets generated can also be used by other research groups not directly involved in this project. They can then also give feedback into the project, which can in this way form an enabler for further collaborative projects.

The MSDEMO project runs with independent financing on both sides. The Swedish side of the project, is funded by the National Program for Aeronautics Research with a budget of approximately 300,000 Euro for a two-year duration, with a plan for continuation.

The project has an strong focus on minimum-cost test techniques using as much off-the-shelf equipment as possible. There is an ongoing technological revolution in electronics and mechatronics. A good example is the Arduino and Raspberry Pi development communities, making it simpler than ever to fuse electronics and hardware. The hobbyist R/C and "drone" communities are another example where sophisticated electronics have raised the bar significantly in recent years. Components such as miniature gas turbine engines, powerful and precise actuators, robust and redundant data links, telemetry systems, and other advanced equipment are available at low cost. The open source community of autopilot systems such as Paparazzi [16], ArduPilot/APM [17] or PX4 [18], is yet an example of this revolution. MSDEMO intends to utilize this technological revolution to bring down the cost and maximize the technological benefit of subscale flight testing.

The project makes use of various platforms of different size and complexity. At Linköping University, the main research platform is an already existing subscale aircraft denominated Generic Future Fighter (GFF), shown in Fig. 1. At Instituto Tecnológico de Aeronáutica (ITA) research has commenced from different approach using a low-cost commercial kit of a BAE Hawk. Since there is an extensive database of this well-known aircraft, it is interesting to explore how accurately it can be understood using a simple low-cost model. However, this paper focuses on the research activities performed with the GFF platform.

Fig. 1 . The Generic Future Fighter demonstrator.

3 GFF Demonstrator

The Generic Future Fighter (GFF) was built at Linköping University in 2009 as a part of a research program concerning modern fighter aircraft design, financed by the Swedish Defense Materiel Administration. The university's part of the project was to investigate the capabilities of an absolute low cost remote controlled free flying demonstrator. The project budget for the manufacturing and initial test flight was about 60,000 Euro. The GFF demonstrator was built in order to investigate the feedback during the conceptual design phase. The design of the GFF is further described in [19], and some specifications are given below in Table 1. It should be emphasized that the GFF airframe was selected for the MSDEMO program purely for academic reasons. The aircraft is a generic design and, although it originated from a conceptual study at SAAB, it has no couplings to any current or future SAAB products.

The inertia of the GFF model has been measured using the pendulum and bifilar pendulum methods described by [20]. The aircraft was suspended in thin cables and put in pendulum motion. From the motion equations and the knowledge of the aircraft weight and centre of gravity (CG), the inertia is easily calculated. The same technique has also been reported to work well in other subscale projects [21] [22] [23].

Table 1. Main specifications of the GFF demonstrator.

Scale	13 %
Length	2323 mm
Wing span	1440 mm
Empty weight	15.0 kg
Engine	JetCat P160
Fuel capacity	3,5 liter
R/C system	Jeti Duplex
Servos	Futaba Digital

The CG, in all 3 axes, was measured using a precision scale put under each wheel. To get the z-axis CG the measurements were taken at two different angles, similarly as it is done on full scale aircraft [24].

The initial goal of flight testing the GFF is to see what parameters can be identified and to what repeatability. It is also of interest to learn more about data acquisition system limitations and eventual requirements.

The original GFF aircraft is designed to be longitudinally unstable, as any modern fighters. However, on the subscale model the CG is moved forward to achieve a stable aircraft that can be piloted in open-loop. An eventual goal is to perform system identification using the stable configuration and then, using simulation, to develop a flight control system that would allow it to fly unstable. Initial attempts show promising results of flying subscale models at the same or even higher level of instability than manned aircraft [25]. Existing commercial off-the-shelf (COTS) components, such as R/C servos and gyro systems are not a bottleneck.

3.1 Instrumentation

The GFF platform is equipped with an onboard low-cost data acquisition system. Initial work on an onboard logging system at the university started in 2008 using a Diamond Systems PC board "Athena" with a Pentium III class processor running a streamlined Linux kernel as operating system [26]. The resulting system was however slightly oversized for some platforms, and it was affected by timing problems caused by the non-real-time operating system.

Taking into consideration the experience gained it was decided to develop a new system based on microcontrollers without any operating system. This reduces the hardware to an absolute minimum and therefore the cost, size and power consumption. The new system, based on a 32-bit Atmel microcontroller, reached a fairly mature state as described in [27]. Everything, including the ground-station and data-links, was programmed from scratch. It was therefore labor intensive to work with, and it also presented a limited number of input and output channels. Although it proved capable, during the initial test campaign of the GFF this solution was put aside in favor of a more compact, modular system partially based on low-cost COTS components. As explained in [25], the new generation of hobbyist-type open-source flight controllers based on 32 bit microprocessors offer excellent data processing capabilities and are able to log multiple channels at sample rates that seem sufficient for flight-dynamics system identification.

The hardware currently in use is the Pixhawk board [18], an open-source project started by the Computer Vision and Geometry Lab in ETH Zürich, supported by the Linux Foundation Dronecode community and the private company 3D Robotics. The widespread APM multiplatform autopilot firmware [17], also open-source, is used to sample and log sensor data. This firmware has also been modified in order to increase the logging rate of some variables of interest, such as pilot commands. The sensors already in-built in the Pixhawk board are inexpensive and not certified for professional flight testing, but have proved robust in harsh environments with vibration and large temperature variations such as those usually found in hobbyist-type operations. The main board comprises two different inertial measurement units (IMU) with an integrated magnetometer, and a barometric pressure sensor. These are complemented by an external GPS antenna, a remote magnetometer, and various additional peripherals as described below.

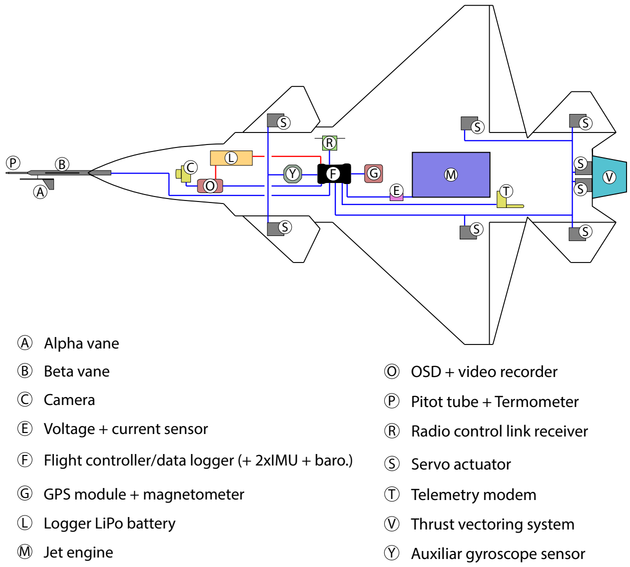

Fig. 2 . Layout of the main components and sensors on the GFF platform.

3.1.1 Nose-boom

The most important custom component of the measurement system is the nose-boom, Fig. 3. It was designed and built at the university and is based on a 12 mm outer diameter carbon fiber tube. In the tip it houses a pitot-static system designed following general pitot tube recommendations by Gracey [28]. On the sides two vanes are mounted for flow steam measurements. The two vanes are pivoted on ball bearings and the position readout occurs contact-less through the use of hall sensor encoders. These encoders were initially planned to be assembled from Austrian Microsystems AS5X sensors, but a more practical solution was found by scavenging parts from a BlueArrow "DMS28013MG" R/C servo. That particular servo houses a magnetic induction rotary encoder complete with a stabilized voltage regulator and a linear analogue output of 0-3V.

3.1.2 Control surfaces

Control surface position is an important parameter to log. However installing position encoders on every control surface is complicated and not necessarily needed. Considering that a modern servo has very little deviation from commanded position to actual position, it was decided to only

Fig. 3 . Airdata nose-boom with alpha and beta transducers installed on the GFF platform.

log the servo signals and not the actual servo position. Each control surface has been carefully mapped up as shown in Fig. 4. Additionally, to further reduce the uncertainty between commanded position and actual position, the response of the servos has been characterized in a specific test rig. Future plans also includes installing a custom position encoder on a selected control surface purely to investigate in flight the validity of this assumption.

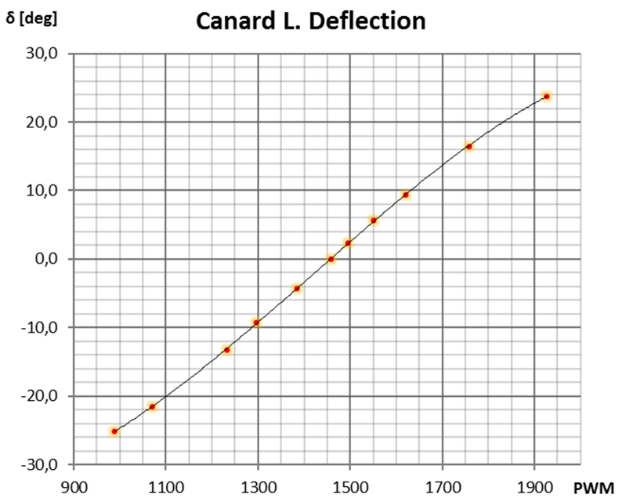

Fig. 4 . Example of the deflection angle calibration performed on the control surfaces. The nonlinearity between servo input and control surface output is caused by the geometry of the servo linkage.

3.1.3 Fuel consumption

The influence of the fuel quantity on the weight of the aircraft is not negligible, and considering that the fuel is burned at a relatively high rate this must be logged during flight. This is estimated by measuring the power drawn by the jet-engine fuel pump using voltage and current sensors. After appropriate calibration, the accumulated current draw of the fuel pump is considered as proportional to the burnt fuel.

3.1.4 Video camera

Light micro-cameras are placed on the aircraft in order to record phenomena of interest. Since the flight controller is able to export data in real time, flight information can be directly overlaid on the video using an on-screen-display (OSD) microcontroller. This can also be done through the ground-station, or afterwards during post-processing from saved video and data files. This is a valuable tool for verifying the accuracy of the IMU and its estimation of the aircraft's angular position in space, i.e. the accuracy of the autopilot's artificial horizon. An example is shown in Fig. 5 where flight data are overlaid on the video from a nose mounted camera on the GFF.

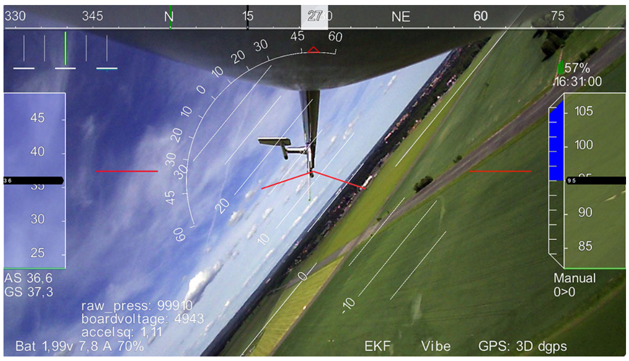

Fig. 5 . GFF demonstrator performing sustained high-g turns to test the robustness of the attitude estimation. Flight data are superimposed on real video using the open-source ground-station software Mission Planner [29].

3.1.5 Telemetry and ground-station

The pilot's R/C system in the 2.4 GHz band already integrates a telemetry downlink which displays the most safety-critical variables, such as control-signal strength and onboard voltage levels. In addition to this, bi-directional radio modems in the 433 MHz band are used to transmit other sensor data in real time to the ground-station computer, where they are displayed and recorded (for redundancy in the case of mishap) using the open-source ground-station software Mission Planner [29].

3.2 Certification

In order to operate the GFF demonstrator within Swedish airspace, it is certified as a Class 2 UAV accordingly to the Swedish Transport Agency. All operational procedures are driven by these rules. Flights and maintenance are kept in log-books and the pilot needs a UAV operator certification. By these rules, the GFF is limited to fly only over unpopulated areas and only within line of sight of the ground operator. The latter is an important limitation for flight testing design. Technically, it would be simple to extend the operational range by adding a long range data and video link and piloting from the ground-station. Hobbyists typically do this kind of piloting illegally using R/C and video links for the FPV (first person view) hobby. However, in order for the transport agency to allow such activities, a restricted airspace would be required and such cost is far beyond the budget of MSDEMO.

4 Flight Testing

Flight testing is generally divided between performance flight testing and parameter identification flight testing. With the GFF the intention is to look at both types of testing although the latter part is prioritized.

Flight testing is ongoing at the moment and different flight testing techniques are currently being evaluated. Comparison is made to manned flight testing where methods and flight test maneuvers are well established. A limitation with the line-of-sight requirement is that some of the traditional flight testing maneuvers are difficult to execute. Consequently, most testing needs to be carried out within a race track or figure 8 flying pattern. The testing is done on the straight legs of those patterns. Once turning into a straight line, the pilot has very little time to stabilize the aircraft and perform the maneuver before it is required to turn again. An additional challenge is that in every turn the increased drag tends to slow down the aircraft. If throttle is left in a fixed position the aircraft decelerates in turns and accelerates through out every straight path. For tests requiring a constant speed the pilot need to actively work the throttle in turns in order to compensate for the increased drag. Due to these circumstances a skilled pilot is essential. The telemetry data are helpful to aid the pilot in adjusting the test speed and altitude. These parameters are either called out by the ground-station operator or by the in-built bi-directional telemetry function of a modern R/C system: on the R/C transmitter used here, a Jeti DC 16, the aircraft speed for instance can be presented to the pilot as an audible signal, or called out as a synthetic voice.

A flight test typically involves three people. One pilot, one ground-station operator, and one safety director. The test site is a closed military airfield near the university campus, and it allows testing to be carried out on a flexible schedule.

Most flight testing maneuvers are flown manually, but to trigger dynamic motions for parameter identification, automated control pulses are used. This has been initially solved by using pre-programmed control sequences in the R/C transmitter, which the pilot triggers from a momentary switch. If the sequence needs to be aborted the pilot simply releases the switch. This works for simpler excitation signals with the default R/C transmitter software. Fig. 6 shows an example of a simple doublet input on the canard surfaces made with this technique. For more advanced excitation signals such as sinusoidal or harmonic inputs, a different solution is needed. A method to generate excitation signals from an external computer and pass it through the R/C transmitter is currently under development.

Although the flying of the GFF has been fairly uneventful, some experiences are worth mentioning. When making an unstable aircraft design stable by moving the CG forward, the main landing gear location should ideally move forward an equivalent distance. When the GFF was built this was not possible since the retractable landing gear would not fit in a more forward position. Consequently, the weight distribution between the main and nose landing gear is significantly out of the norm. This leads to poor ground handling characteristics and difficul-

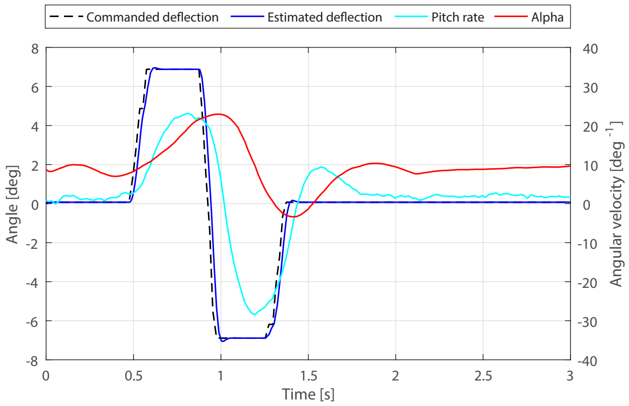

Fig. 6 . Doublet input on the canards at an airspeed of 48 m/s. The final control surface deflection is estimated from the calibrated command-signal through the simulation of the servo actuator.

ties to rotate during take-off: a high speed and full deflection of the control surfaces are needed to get airborne. Furthermore, the wheels on the retractable main landing gear are relatively small due to limited internal space in the aircraft. This was not identified as a problem initially since the tires, made for R/C jets, met the weight of the aircraft. However, due to the high take-off speed needed, these wheels reach more than 8,000 rpm at rotation speed. At one point the tires were actually launched off the rims due to the high centrifugal forces. The lesson learned is to spin the wheels in a test rig before first flight, as well as not to neglect the rpm at which they actually spin. Special fiber reinforced rubber inlays had to be molded for the tires.

4.1 Flight Data Analysis

All flight data and video recorded onboard are downloaded into the ground-station computer immediately after each flight. A MATLAB script has been develop to uncompress, visualize and analyze any desired variables directly in the ground-station, allowing quick decision-making before the next flight. This is specially useful when trying to progressively expand the flight envelope. An example of data handling is given in Fig. 7 for a minimum-speed maneuver, as part of the investigation of the high angle-of-attack region and stall behavior of the platform. A three-dimensional animation tool has been integrated in the script in order to assist the flight examination as well as to visually compare the response of the simulation model against recorded data.

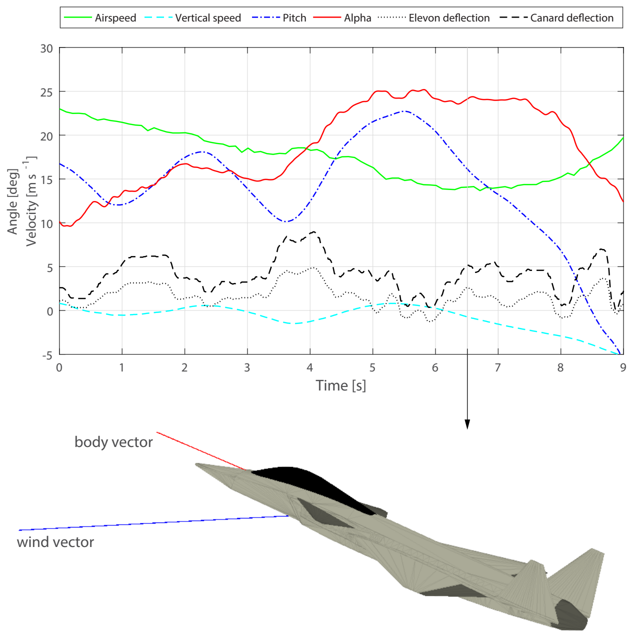

Fig. 7 . Example of a minimum-speed maneuver intended to investigate the high angle-of-attack region and stall behavior. Data is analyzed and presented by the MATLAB script, which also includes a 3-D visualization tool.

Additionally, other commonly available software such as the open-source simulator FlightGear or Google Earth can be used to plan or to visualize flight tests in first- or third-person view, as shown in Fig. 8.

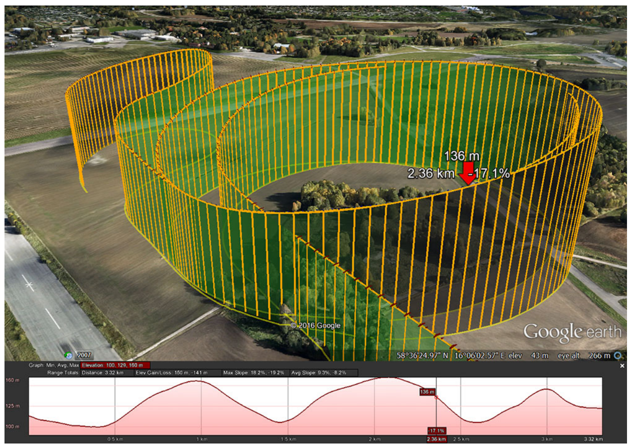

Fig. 8 . The freely available software Google Earth is also helpful for flight analysis and planning. The reconstructed trajectory is imported using the open-source ground-station software Mission Planner [29].

5 Discussion and Conclusions

The project is running at the moment of writing this paper, and the first flight test data have just started to be produced and shared among the partners.

One of the goals is to see what can be achieved with a limited budget and how a collaborative project of these characteristics can be effectively conducted over a long geographic distance. This type of project seems to be suitable in that ways, since data produced at one location can be easily shared and analyzed by other partners. Considering that the generation of experimental data is a relatively costly part of a project, it is effective to involve more parties to work on the data. In addition, various platforms with different degrees of fidelity and complexity are produced by the different research groups.

On the flight testing procedures and processing of flight test data there are many open research questions. It remains to be seen what results can be achieved towards the end of the project. It's clear that traditional testing methods, as used in full scale, will not work directly.

The low-cost Pixhawk flight controller has been working satisfactorily in the testing. For the time being, it has only been set up as a passive data acquisition unit although it has the capacity to also do closed loop control. It would be interesting to use this capability to semi-automate the testing procedures. For instance, it would help to have functions such as an automatic speed hold, or altitude hold. Some of the limitations of the Pixhawk as a data acquisition system are that it has a limited amount of analog inputs and also relatively limited logging rates of about 50 Hz. It is probable that for some of the tests a separate external computer or an additional logging system may be needed. New solutions based on real-time Linux-based platforms such as Navio2 and Raspberry Pi are being studied at the moment.

References

[1] Chambers J R. *Modeling Flight: The Role of Dynamically Scaled Free-Flight Models in Support of NASA's Aerospace Programs*. 1st ed. NASA, Washington, DC, USA, 2009.

[2] Hahne D E, Wendel T R and Boland J R. Wind-Tunnel Free-Flight Investigation of a Supersonic Persistence Fighter. Tech. rep., NASA, 1993.

[3] Henriksson K. Spin Testing the Viggen Aircraft. Tech. rep., Society of Experimental Test Pilots, 1974.

[4] Klein V and Noderer K D. Aerodynamic parameters of the X-31 drop model estimated from flight-data at high angles of attack. AIAA, editor, *Guidance, Navigation and Control Conference*, pp. 174–181. AIAA, Hilton Head Island, SC, USA, 1992.

[5] Croom M, Kenney H, Murri D and Lawson K. Research on the F/A-18E/F using a 22 percent-dynamically-scaled drop model. *Atmospheric Flight Mechanics Conference*, pp. 117–131. American Institute of Aeronautics and Astronautics, Denver, CO, USA, 2000.

[6] Yanagihara M and Munenaga T. High Speed Flight Demonstration Project. *24th Congress of International Council of the Aeronautical Sciences*. INTERNATIONAL CONGRESS OF THE AERONAUTICAL SCIENCES, Yokohama, Japan, 2004.

[7] Deets D A, DeAngelis V M and Lux D P. HiMAT Flight Program: Test Results and Program Assessment Overview. Technical Memorandum 86725, NASA, 1986.

[8] Walker L A. Flight Testing the X-36 — The Test Pilot's Perspective. Contractor Report 198058, NASA, 1997.

[9] Duranti S and Malmfors V. Flight testing of saab uav sharc technology demonstrator. *Proceedings of SETP/SFTE European Symposium*. Royal Aeronautical Society, London, England, 2004.

[10] Gibson C, Neidhoefer J, Cooper S, Carlton L and Cox C. Development and flight test of the x-43a-ls hypersonic configuration uav. *1st AIAA UAV Conference*. Portsmouth, VA, USA, May 20-23, 2002.

[11] Warwick G. Gulfstream unveils concepts for supersonic business aircraft. *Flight International*, vol. 158, No. 4751, 2000.

[12] Yarf-Abbasi A, Clarke A, Lawson C and Fielding J. Design and development of the eclipse and demon demonstrator uavs. *26th International Congress of the Aeronautical Sciences*.

Anchorage, AK, USA, Sept. 2008.

[13] Jordan T L, Foster J V, Bailey R M and Belcastro C M. AirSTAR: A UAV Platform for Flight Dynamics and Control System Testing. *25th AIAA Aerodynamic Measurement Technology and Ground Testing Conference*. American Institute of Aeronautics and Astronautics, San Fracisco, CA, USA, 2006.

[14] Risch T, Cosentino G, Regan C, Kisska M and Princen N. X-48B Flight Test Progress Overview. *47th AIAA Aerospace Sciences Meeting*. Orlando, FL, USA, 2009.

[15] Schmollgruber P, Jentink H W and Tuinstra M. Iep : a Multidisciplinary Flying Testbed for New Aircraft Concepts. *27th International Congress of the Aeronautical Sciences*. Nice, France, 2010.

[16] École nationale de l'aviation civile and Paparazzi develpers community. Paparazzi project, open-source autopilot system, 2015. URL `http://wiki.paparazziuav.org/`

[17] Dronecode Project Inc a Linux Foundation Collaborative Project. APM:Plane open-source autopilot firmware, 2016. URL `http://plane.ardupilot.com/`

[18] Computer Vision and Geometry Lab at ETH Zürich 3D Robotics Inc and PX4 developers community. PX4/Pixhawk open-hardware autopilot project, 2015. URL `http://pixhawk.org/`

[19] Amadori K, Jouannet C and Berry P. Development of a subscale flight testing platform for a generic future fighter. *27th Congress of International Council of the Aeronautical Sciences*. Nice, France, 2010.

[20] Miller M P. An accurate method of measuring the moments of inertia of airplanes. Tech. Rep. NACA-TN-351, NACA, 1930.

[21] McClelland W A. Inertia Measurement and Dynamic Stability Analysis of a Radio-Controlled Joined-Wing Aircraft. Thesis, Department of Aeronautical Engineering, Air Force Institute of Technology, 2006.

[22] Bussamra F L d S, Montestruque Vilchez M C and Santos J C. Experimental Determination of Unmanned Aircraft Inertial Properties. *Brazilian Symposium on Aerospace Eng. & Applications*. Campos, SP, Brazil, 2009.

[23] Seanor B A. *Flight testing of a remotely piloted vehicle for aircraft parameter estimation purposes*. Ph.D. thesis, West Virginia University, 2002.

[24] Ward D T, Strganac T W and Rob N. *Introduction to Flight Test Engineering, Vol. 1*. 3rd ed. Kendall Hunt Publishing, 2006.

[25] Sobron A, Lundström D, Staack I and Krus P. Design and Testing of a Low-Cost Flight Control and Data Acquisition System for Unstable Subscale Aircraft. *30th Congress of the International Council of the Aeronautical Sciences*. Daejeon, South Korea, 2016.

[26] Lundström D and Amadori K. Raven – a Subscale Radio Controlled Business Jet Demonstrator. *26th International Congress of the Aeronautical Sciences*. Anchorage, AK, USA, 2008.

[27] Staack I and Lundström D. Subscale Flight Testing at Linköping University. *27th Congress of International Council of the Aeronautical Sciences*. Nice, France, 2010.

[28] Gracey W. Measurement of Aircraft Speed and Altitude. Reference Publication 1046, NASA, 1980.

[29] Oborne M and Dronecode Project Inc. Mission Planner open-source ground station software, Version 1.3.37, 2016. URL `http://ardupilot.org/planner/`

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