RAVEN – A SUBSCALE RADIO CONTROLLED BUSINESS JET DEMONSTRATOR

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Abstract

A dynamically scaled model of a Business-Jet has been built and is undergoing testing at Linköping University. The goal of the project was to understand the difficulties of dynamic scaling and how to extract useful data from subscale flight testing. This paper presents the experience made during the project up to the time of writing, and includes details from manufacturing, ground testing equipment such as car top testing, in flight data acquisition system design, and preparations for the flight testing.

1 Introduction

The use of radio controlled models for validation and data acquisition in early stages of aircraft design is getting an increased interest in the aircraft industry around the world. Modern low cost electronics allows these types of tests to be carried out cost effectively yet providing valuable data for improving or validating a design.

One axis of the current research in aircraft design at Linköping University is focused on fast concept evaluation in early conceptual design stages. This covers multidisciplinary optimization using computational tools of different level of complexity [22] [23] [24], and low cost subscale flight testing. A methodology is under development to allow fast creation of subscale flying concepts. An important part of this methodology is to learn about scaling methods and the imposed requirements on manufacturing. To gain knowledge in this field a dynamically scaled demonstrator of an in-house designed business jet concept, has been manufactured. A lot of the work was carried out by master students within an aeronautical project course.

1.1 Subscale flight testing

Subscale flight testing is a mean of allowing a design team to evaluate the free flight characteristics of an aircraft design prior to building a full-scale prototype. It is a convenient way to investigate extreme, high risk portions of the flight envelope without exposing a pilot to risk or to danger an expensive prototype aircraft. There are several recent examples of this: the NASA funded McDonnell Douglas X-36 [6] [7], Rockwell HiMAT [8], Saab UCAV [9], NASA X-43A-LS [10] and proposed Gulfstream Quiet Supersonic Jet [11]. In all cases the configurations are highly unconventional and thus there is a desire to demonstrate the configuration's feasibility without the cost and risk of a manned, full-scale vehicle.

The testing of subscale free flying models is not a new concept. Particularly for high risk testing such as high angle of attack and to study departure modes, the restrictions imposed by a rigid connection as in the wind tunnel has been prohibitive. Spin models for updraft wind tunnels have been a standard practice since the 1940s and remotely controlled drop models from helicopters have often been used to complement spin tunnel testing. Free-flight models have also been built for conventional wind tunnels, such as the NASA Langley Free Flight Facility [13]. Also for fighter configurations, drop models have been widely used; recent examples being the X-31 [14] and F/A-18E/F [15]. Subscale drop models of space vehicles, such as the Lockheed Martin X-38 and Japanese HOPE-X [16], have also been employed. Recently the usage of subscale flight testing has been extended to civil aircraft such as the NASA AirStar research program [1], where a scale model is used to explore a larger then normal flight envelope for a civil transport aircraft. For the Blended Wing Body concept, the X-53 project from Boeing and NASA is currently using a scaled model to demonstrate the concept and obtain more data without going to full scale.

All the above mentioned projects are fairly complicated from a university perspective. The approach at Linköping University was to investigate what can be achieved with more common university funds and within educational programs.

1.2 The Raven Aircraft

The aircraft design that has been the objective for the subscale flight tests studies presented in this paper, is a university in-house design of a business jet/medivac aircraft called Raven (Fig.1). Raven is the result of an extensive design study carried out within a student project for Master of Science students in the 4th year of the aeronautical engineering education.

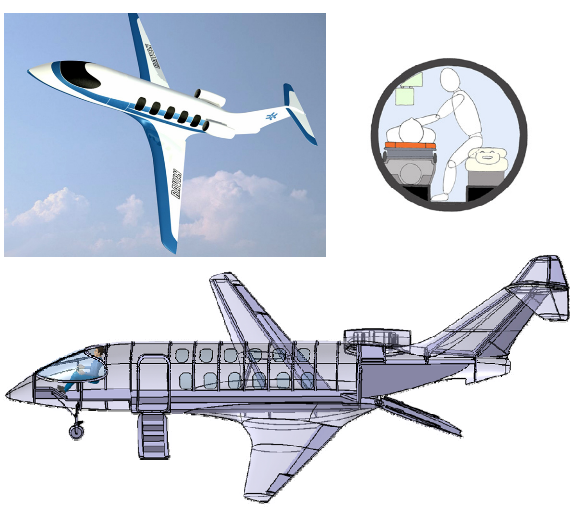

Fig. 1. Raven aircraft.

The Raven aircraft was designed with its main role as a business jet and secondary role as an ambulance/medivac aircraft. The aircraft was designed according to FAR23/EASA23 rules, around two Williams FJ-33 engines, with short take-off and landing performance for rural operation in mind. The design incorporated several innovative features in order to fulfill the requirements of both an exclusive business jet as well as a rugged ambulance aircraft. The most striking is a rear bulkhead door that allows a practical way to load and unload patients. The main geometrical characteristics of Raven are the following:

- Wing span 14,4 m
- Overall length 13,4 m
- Wing Area 21,8 m2
- AR 10
- M_{cruise} 0,55 at 40 000 ft
- Cross section 1.6 m diam.

The design of Raven is described more in detail in reference [3].

1.3 Dynamically scaled model.

Within aircraft design student projects, it has been a tradition at Linköping University to “close the loop” by building and flying a small scale demonstrator. For the Raven project it was decided to extend this effort into also producing a dynamically scaled demonstrator. That is to scale an aircraft not only according to its dimensions but also to its weight, inertia and control system response, so that the dynamic properties of the model correspond to the full scale. The dynamic scaling approach was inspired by the work performed by NASA within the AIRSTAR program [1]. The main goal was to acquire experience and understanding on building and flying dynamically scaled models.

Froude scaling and the work presented in by Wolovicz et.al [2] were used as reference for the downsizing of the full scale aircraft. Based on practical considerations on size and weight restrictions on the model, the scale factor was decided to be 14%. The model weight is determined from full scale aircraft weight and altitude accordingly to the following equation:

$$W_M = k^3 \cdot W_{fs} \cdot \frac{d_M}{d_{fs}} \qquad (1)$$

where k is the scale factor, W is the weight and d is the air density. Annotations "fs" means full scale and "M" means model. As given by the equation, the weight of the model can represent different combinations of aircraft weight and altitude. In order to keep the landing speed down without needing complex high lift devices on the scaled model, it was decided to only simulate dynamics of sea level flight. However other altitudes could be simulated by adding weight to the model. It should also be pointed out that already when simulating sea level flight, the wing loading of the Raven subscale model becomes as high as 25kg/m^2. This is right at the upper limit of what is allowed for radio controlled models in Sweden.

Mass moments of inertia of the model are related to the inertias of the full scale aircraft by a factor of k^5.

Once the details of the model were set (weight, inertia etc), the CAD model of the full scale Raven was downscaled to 14%. Using the outer surfaces as guide, a new structure adopted for the demonstrator was modeled, as well as all the components that were to be placed inside (Fig. 2).

Fig. 2. Structure of Raven demonstrator.

The CAD software used was Catia V5. The built-in inertia measuring function of Catia was of great help to position all components in order to insure that target inertias could be met.

Fabrication of the airframe was completed using composite material. Negative moulds for each composite part were milled directly from RenShape™ 5460 blocks, using exported 3D models from Catia (Fig. 3).

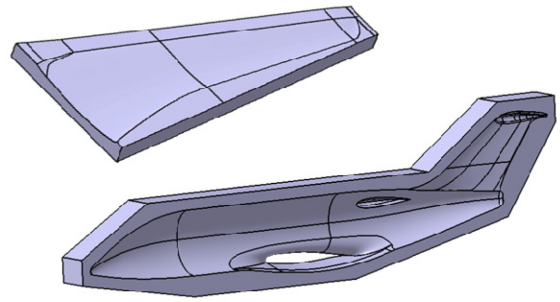

Fig. 3. Moulds for composite fabrication.

The fuselage was laminated as a sandwich in glass fiber and Herex™ foam. Internal structure was cut from traditional aircraft plywood. The wings were fabricated using a glass fiber and balsawood sandwich. A sturdy wing spar of unidirectional carbon fiber serves to carry the bending loads. Vacuum technique was used for minimizing excess matrix material and maximizing bonding strength during curing. The composite parts were spray painted with its base colors directly in the moulds prior to laminating. This minimizes weight and also work time since little effort is left to do on finishing once parts are released from the molds. Most of the fabrication was completed in the university lab by students, but under the authors' supervision. The pictures in Fig. 4 show a few stages from the manufacturing.

Fig. 4. Different stages in manufacturing.

Through out the design most of the hardware components have been obtained commercially from the RC hobby industry. Typical RC servos have been used for control surface actuation. Two Funsonic FS70 turbine engines are used for propulsion. Each turbine has a maximum thrust of 70N which is a great deal more then what is needed, but the FS70 turbines were favored due to an attractive price and because they are among the smallest turbines on the market. Maximum thrust can be electronically limited for flight testing. Table 1 summarizes the equipment used in Raven.

Engines:	2x Funsonic FS70 Typhoon turbine (70N class)	
Servos:		
-	Elevator	2 x Futaba S9650
-	Aileron	2 x Futaba S9650
-	Rudder	1 x Futaba S9650
-	Nose wheel	1 x Futaba S3050
-	Flaps	2 x Futaba S9156
-	Elevator trim	1 x Futaba S5050
Receiver:	Weatronic Dual Receiver 12-20 R	
Landing gear	Behotech pneumatic retractable	
Transmitter:	Graupner MC24 (35Mhz)	

Table 1. Traditional RC equipment used in Raven demonstrator.

The final aircraft is shown in Fig. 5 below.

Fig. 5. The finished aircraft.

The inertia was measured by mounting the aircraft in a cradle that is put in a pendulum motion. Using equations of pendulum motion the aircrafts inertia was computed based on the period time averaged over a number of cycles. The result is shown in Table 2.

	Target values	Catia predictions	Measured
I roll *(kgm^2)*	0,54	0,3	0,24
I pitch *(kgm^2)*	1,65	1,2	1,46
I yaw *(kgm^2)*	2,09	1,4	1,59

Table 2. Raven inertia.

As can be seen the difference from Catia predictions were at a maximum approximately 20%. This was due to uncertainties in the cad model and inaccuracy in the weight prediction of composite fabricated parts. The numbers are however acceptable since all inertia values are lesser then target values. By adding weights to both wings and fuselage it was possible to reach proper inertia values without overshooting the total weight budget. A conclusion is that using common model aircraft building techniques leads to aircrafts with inertias less then what is required for dynamic scaling. Fig. 6 shows the aircraft in the inertia measuring cradle.

Fig.6. Raven inertia measuring.

2 Car top Testing

Before the Raven subscale model will commence flight testing it will be thoroughly tested on a captive carry test rig, or what is more conveniently called "car top testing". Car top testing involves mounting a subscale aircraft on top of a moving ground vehicle thus simulating real flight. Several aerodynamic properties can be evaluated this way. Aerodynamic forces and moments can be measured in methods very similar to what is used in wind tunnel testing. Due to less control on the surrounding environment the measuring accuracy can never reach the same level, but at a fraction of the cost this technique should provide far better result than theoretical predictions.

For subscale flight tests, and in particular the Raven project, car top testing is a sensible way to test the aircraft in low risk environment, ensuring that there are no unknown characteristics prior to first flight. For instance trim conditions, stability, control, cross coupling effects etc can be examined.

2.1 Equipment

Preliminary work on a car top test rig was carried out at Linköping University in 2002. A detailed report from this experience can be found in [4]. In this work vibration analysis and flow field studies around a moving car were completed both analytically and experimentally. It was found that the flow above a moving car can be considered to be smooth and uniform in Z direction and with a region of streamlines parallel to the direction of the moving car large enough for an aircraft to be located. A mechanical rig for car top testing was built and several experiments were carried out on a research aircraft. The results were encouraging but the rig had several flaws compromising the validity of the results. Especially the force measuring sensors lacked resolution and there were problems with electromagnetic interference. With the result from these experiments a new improved car top test rig has been designed and built for the raven aircraft. The rig is displayed in Fig. 7.

Fig. 7. Raven mounted on car top test rig.

The aircraft is mounted on top of a Volkswagen Caravelle minibus using roof racks. The aircraft is attached on a 2m portable tripod. A support column protrudes from the tripod through an opening in the airframe and mounts with a gimbal in the aircrafts exact center of gravity. When designing the airframe, care had to be taken so that structural integrity was not affected by this installation. A special wing spar had to be designed leading the bending forces around the opening (Fig. 8).

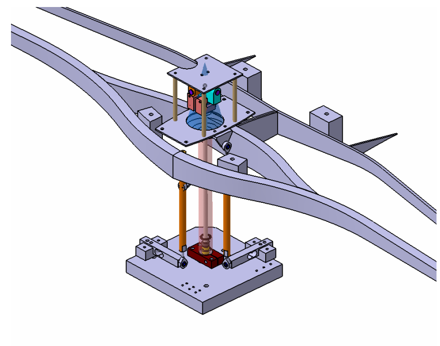

Fig. 8. Gimbal attachment and wing spar design.

The gimbal allows the aircraft to freely rotate in all axes. For each axis a potentiometer is keeping track of the precise angle. Most of the planned tests will be completed with the aircraft in a freely pivoted configuration. For measuring pitch, roll and yawing moments, the possibility exists to lock the aircraft in a given position, where moments are measured using pushrods and conventional beam type load cells. Fig. 9 shows the support column principle.

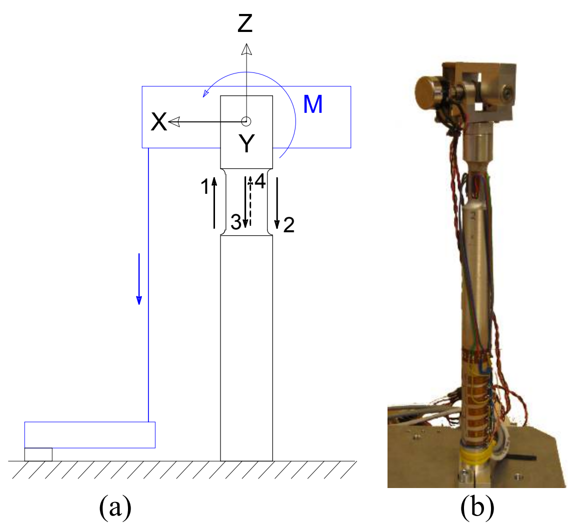

Fig. 9. Car top testing support column. (a) Principle of force measuring. (b) Picture of actual support column.

Lift, drag and side forces are measured with 4 strain gauges mounted as described in Fig. 9a. Differential strain at 1 and 2 is proportional to force X. Differential strain at 3 and 4 is proportional to force Y. For Z axis forces, i.e. lift force, measuring is done by averaging the sum of all 4 strain gauges. The support column is carefully dimensioned so that the maximum strain that is safe to reach will correspond to the maximum forces that are expected to be induced during testing. Each strain gauge is connected in a quarter Wheatstone bridge configuration. The output signal from each Wheatstone bridge is fed through an amplifier and signal conditioner module. A 2 pole Butterworth filter smoothens out any potential electric noise on the strain signal.

Airspeed is measured using a pitot tube and a differential pressure transducer. This is mounted on the support tripod where it always remains facing the oncoming air. Additionally temperature and ambient pressure is measured by a hand held device, but not actively logged during tests. This information is used for correction of data to standard atmosphere conditions.

The data capture system used to record information during car top testing is a Picotech ADC-24 USB data logger [17]. The ADC-24 is a portable, 16 channel, 24 bit resolution analog input data logger with a maximum input signal level interval of ±2.5 V. A laptop running Picotechs Picolog software is used to display real time data as well as storing data to hard drive. The ADC-24 is powered directly from the laptop's USB port. Additional power is needed for the strain gauge amplifiers which run on 12V DC. This is taken from a small 14,8V lithium polymer battery running a linear 12V DC/DC converter.

2.2 Test setup

The car top testing will be used both for measuring aerodynamic forces, as well as observing if there are any unexpected flight behaviors. The latter is the more important objective since many of the aerodynamic measurements will be done also during later free flight tests. Below is a summary of the points that will be tested.

- Stability: One of the most important objectives is to verify that the aircraft has a proper stability margin. There is no easy way to measure the exact neutral point. What will be done is to ensure that the aircraft, with its current center of gravity, has a predictable and linear pitch to elevator response. For instance it must be examined that the forward swept wing does not induce any problematic pith up at higher angles of attack.
- Trim: For each flight phase the trim conditions will be tested. For instance different flap positions, power settings etc.
- Flap positions: Raven is equipped with large flaps for reducing takeoff and landing speeds. Flap positions must be verified not to cause any complications.
- Stall speed: Knowing the stall speed for the first test flights will be crucial for reducing risk during landing. Although an experienced RC pilot easily recognizes when an aircraft approaches stall speed, the high wing loading of the Raven aircraft will likely lead to characteristics more critical than conventional RC aircraft. For safety a telemetry system with stall warning will be used.
- Control response: Preliminary control surface deflections have been configured on Raven, but needs to be verified before first flight. Especially making sure that pitch authority is enough to level out at low speeds with full flaps.
- Lift and drag: C_l alpha and C_d alpha will primarily be determined in flight, but car top testing will be useful to get a true measurement for lower speeds. This will be used to compare with later flight test data.
- Turbine thrust: A simple model for turbine thrust as a function of velocity exists, but this needs to be verified with

experimental results. By conducting test runs with turbines at different throttle settings both fuel consumption and thrust curves can be tested.

It should be mentioned that car top testing will only be performed in speeds of up to approximately 30m/s. Beyond this point data will be extrapolated. The raven aircraft is expected to fly in speeds up to 100m/s.

2.3 Results.

Unfortunately, at the time of writing, it has not been possible to carry out the car top testing due to unforeseen changes in personnel working with the project. All the hardware is however completed and testing is scheduled to be performed under July 2008.

3 In flight data acquisition hardware design.

The rapid development of low cost and miniaturized electronics has been a key enabling technology to the development of subscale vehicles. In order to extract data from the test flights a custom data acquisition system has been designed. Key drivers in the layout of the instrumentation system were minimum cost and simplicity, such that a minimum amount of time would be required to integrate the hardware and to build the software. The basic system layout used in this work is given in Fig. 10. All electronic hardware is commercial off the shelf (COTS).

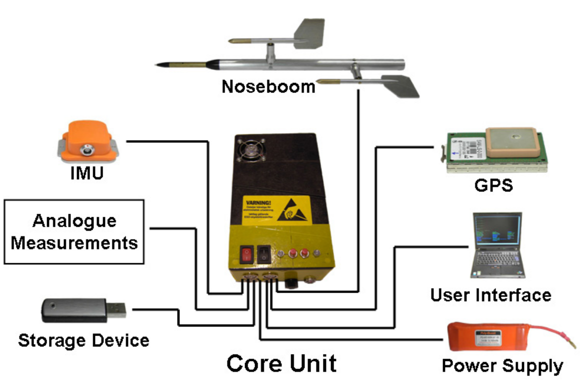

Fig. 10. Data acquisition system.

3.1 System configuration

The data acquisition system consists of the following components.

- CPU board with data logging capability
- Attitude and Heading Reference System (AHRS)
- GPS receiver
- Potentiometer at all control surfaces
- Alpha and Beta vanes
- Dynamic and static pressure sensors
- Temperature sensor
- Turbine motor interface
- Telemetry with stall speed warning for the pilot

All components except the telemetry system are connected with the CPU board, which retrieves and stores all data. The system assembly is divided into a core unit and a nose boom unit. The core unit, a box with dimension 195x115x60 mm, includes the CPU board, an electric power supply board (10V, 5V, 10V and 3,3V) and connection interfaces for the analog and digital inputs. The nose boom unit contains the sensing elements for the alpha and beta angles, air temperature, static pressure and dynamic pressure. The core unit is installed in the nose of the aircraft (Fig. 11) and is designed to easily be moved between different platforms.

Fig. 11. Core unit installed in airframe.

The system is driven by a 14,8V/3.1Ah Lithium Polymer battery. Its average current consumption is approximately 0.8A.

3.2 Component features

The data acquisition system components can be divided into three parts. The main board, “high level” sensors, and “low level” sensors. High level sensors refer to digital sensors that have their own data processor and “low level” sensors summarize all analog sensors without built in processor. Each component will be described more in detail below.

3.2.1 Main board with the CPU

The central part of the data logging system is a PC104 computer, “Athena”, from Diamond Systems. The Athena board is equipped with a 400MHz Pentium III “Coppermine” processor. In conjunction with 128MB RAM it provides a calculation capacity much grater then what is needed for data collection. The extra computational power however could be useful for future upgrades, such as onboard data filtering, automatic control etc. The Athena board was chosen primarily for its integrated analog to digital converter. It provides a 16 channels single ended (or 8 channels differential) A/D converter with a selectable input range between 1,25V to 10V and with a maximum sampling rate of 100kHz. A 64MB flash memory is used to run the onboard operating system as well as the logging software. The log data is saved directly to a USB storage device.

3.2.2 High level sensors / Digital devices

Attitude and Heading Reference System

For logging accelerations and angular positions an AHRS from Xsens Technologies B.V./Netherlands [18] is used. This system, called “MTi”, encloses tree accelerometers, three rate of turn sensors and a three axis magnetometer. The unit runs its own processor and provides a drift-free 3D orientation as well as calibrated 3D acceleration, 3D rate of turn and 3D earth magnetic field data. Both filtered and raw data can be obtained from this unit. The filtered data can be optionally retrieved in Euler angels, quaternion or as rotation matrix. To reduce the storage space and ensure fast computation, in this project the quaternion are logged. The MTi uses RS-232 for communication.

Global Position System Receiver

The GPS receiver used is a “SAM-LS” 16 channel all-in-one GPS device from Ublox/Switzerland. The power consumption of this device is less than 0,4W with an input voltage of 3V. This unit provides calculated GPS data with a maximum update rate of 4Hz via serial protocol. The device is connected with the RS-232 connection of the main board with the help of an interconnected RS-232 receiver (Maxim 3232) that transfers the 3V low level signal to the default 13V level of the Athena board’s serial interface.

Turbine ECU interface

During flight tests it is vital to log turbine engine parameters. Data such as rpm and fuel consumption is needed for computing turbine thrust and to correct data for the aircrafts instantaneous weight (accounting fuel burn). The Electronic Control Unit (ECU) of the Funsonic turbines monitors this information, but unfortunately there is no easy way to interface the ECU to the Athena board for direct logging. Currently there is no solution to this problem, but in contact with Funsonic it has been revealed that a new ECU with rs232 interface is soon to be released to the market. This will likely be used in the future. In the meantime a possible workaround is to log the turbines input signal from the RC receiver and fuel pump voltage. The RC receiver “throttle” signal can be mapped versus rpm, and the fuel pump voltage can be mapped to fuel consumption.

3.2.3 Low level sensors / Analogue sensors

All low level sensors are connected to the A/D converter. In total 13 single ended channels are used (7 control surfaces, 1 RC receiver reference voltage, 1 temperature, 2 vanes, 2 pressure indicators). Care has been taken to adjust signal levels of each sensor so that maximum resolution of the A/D converter is used.

Control surface positions

In order to log control surface deflection an angular encoder, or potentiometer, is needed at each control surface. To avoid the extra work of installing custom potentiometers it was chosen to use the information from each actuators internal potentiometer. On 7 actuators, or servos, extra wiring has been added allowing its position data to be read by the A/D converter. Additionally the output level of the power supply is logged to detect any voltage alterations during operation.

Apart from logging the actual control surface position, the control signal to each servo is logged internally in the RC receiver. This was never a requirement but is a neat function of the Weatronic 12-20R RC receiver.

Alpha and beta vanes

The alpha and beta-vanes are in-house designed and mounted together with the Pitot tube in the nose boom. The wanes are pivoted with ball-bearings and the position read out comes from frictionless hall sensors (Honeywell HMC 1501) in a Wheatstone bridge configuration. A high precision differential amplifier (AD620A) with a gain factor between 35 and 50 is used to amplify the hall sensors signal. In order to ensure that the output signal relates itself to only positive values the reference of the instrumentation amplifier is connected to an additional amplifier, which raise the reference voltage to approximately +2,5V. Within this adjusted reference voltage, it is possible to read out the signal of one Hall sensor with only one single-ended A/D channel. The Hall sensor is driven by a high accuracy 5V power supply and the amplifiers are directly connected with the 10V power supply circuit, provided from the core unit.

Pressure sensors

The static and the dynamic pressure are measured with signal conditioned, high precision pressure transducers of the BSDX series from Sensortechnics/Germany [19]. These sensors comes pre calibrated and with a signal voltage ranging from 0.5V to 4.5V. The static pressure sensor has a range of 800 to 1100mbar witch theoretically allows performing flight testing up to 1950m (ISA conditions). The sensor for the pitot tube is a differential pressure sensor with a pressure range from 0 to 50mBar. This enables a measurement of a maximum speed up to 99 m/s (ISA; 0m). For higher velocities, this sensor can be replaced to a sensor with 100mBar range. Alternatively the GPS data can be used for high velocity measurements, neglecting wind speed.

Temperature sensor

To calculate the density of the air, a temperature sensor is placed under the fuselage in the free air flow. This sensor is a LM334A precision temperature sensor from SGS-Thomson. It operates as a 2-terminal Zener diode and the breakdown of the voltage is proportional to the absolute temperature at 10mV/°K. This sensor is connected with an adjustable constant current source and an offset trim-pot with the 10V supply voltage from the core unit. The constant current source is set to 1mA to ensure both a failure-save operating and a minimum of self heating of the sensor.

3.2.4 Telemetry.

For performing flight tests effectively a telemetry link transmitting key information such as speed, altitude etc, to a ground station is valuable. It was desired to integrate a telemetry link with the data acquisition hardware, but since it required a lot of extra work in both software writing as well as hardware design, a simpler off the shelf solution was chosen. An Eagletree Systems Pro recorder [20] has been acquired. This is a low cost data logger built for hobby or UAV applications and is shipped with a 2,4 GHz data link and ground station software. Although not a particularly elegant solution it will be used in parallel with the Athena board solely for transmitting in flight data. An audible alarm will be used for stall warning.

3.4 Programming

At the beginning of the project, Linux was chosen as the operating system on the Athena board because of the following benefits:

- (soft) real time performance
- minimal processor load → high system performance (time)

- small disk space (only 64MB)
- freeware, open source
- maximum flexibility in order to extend the program later on (e. g. with filtering and controlling functions)

The logging software is mostly written in C language, only the direct communication with the GPS device is performed in C++. This is because a the freeware program “GPS logger 1.8” from the Naval Research Laboratory is used to retrieve the GPS data and store it in the Random Access Memory (RAM)

The logging software includes four parts: the core logging module and three data retrieving modules. The logging module includes the user interface, the initialization of the devices and the file managing for the logging files. The three interface modules (one for the IMU, one for the A/D converter and one for the GPS receiver) perform the communication with the external devices and write the received data into the RAM, from which the logging module fetches and stores the data to a USB memory. The logging frequency of the A/D converter is set to 100 Hz, the IMU is set to 50 Hz and the GPS frequency is limited by the GPS receivers maximum update rate of 4Hz.

A problem in the current condition of the logging program is the absence of time synchronization between the retrieving modules: The A/D converter is controlled over an interrupt routine with a fixed, during the initialization defined, sampling rate. In contrast, the data updating frequency of the IMU is itself performed by the inbuilt IC. In future, a program with a central interrupt routine for all devices should be developed to synchronize these units. But even in this case, is it not easy to get real simultaneous measurements, since each device has a system specific time delay. This delay is insignificant for the A/D converter, very small and constant (for a special type of output mode and interface settings) for the IMU (about 0.5ms), but very big and variable for the GPS device (100-200 ms, depending on the number of tracked satellites).

3.5 Discussion

The amount of work and cost needed to build an in-flight measurement system depends highly on the requested accuracy of the measured values. The total hardware costs in this project accounts to approximately 4000€. Building a low cost system such as this is mainly possible thanks to the availableness of commercial of the shelf strapdown inertial measurement systems. These electromechanical sensors in combination with a digital data processing afford high accuracy at reasonable cost, weight and power consumption, which is not possible with the older, gimbaled, mechanical systems.

A disadvantage with the current hardware is that the 64MB flash disk, used for running the Linux system on the Athena board, is not big enough to allow debugging and compiling directly on the target system. To avoid the cross compiling, the flash disk will be replaces to one with enough space to allow debugger, linker and compiler to run directly on the target system.

The Athena board holds considerably more computational power than what is needed for data logging. If one would design a system from scratch, a better solution could be to use microprocessors. Building as system using microprocessors would require much smaller dimensions, significantly lower energy consumption (no problem with cooling), ready and cheap sensor application with special microprocessor interface protocols (such as I2C) and an easy time management given by fixed rates of the processor. The disadvantage of this solution is the programming in machine code and the system fixed features after the chip-selection.

The next step in this project should be the implementation of a Kalman filter, fusing together GPS information with MTi data, in order to improve the position update rate and accuracy. A custom telemetry system transmitting the aircrafts position and AHRS information is also on the timetable, although not a high priority.

4 Flight test preparations

The primary focus for the initial flight testing will be to test the data logging system and to evaluate different flight testing techniques. The fist goal will simply be to get experience in flying a dynamically scaled model and to acquire accurate log data. From there on, it will be decided how to continue. One of the first exercises will be to identify classical aerodynamic properties such as C_l, C_d and C_m in relation to angle of attack. Since the model will be flying at Reynolds numbers significantly lower then its full size counterpart, this data will not be representative. However from a flight test point of view it is interesting to investigate how accurate such parameters can be acquired from a free flying remotely piloted vehicle.

All the flight testing will be done remotely piloting the aircraft, using a conventional RC transmitter and only within line of sight. With a dynamically scaled, and hence heavy and fast aircraft, this leaves little time flying in a straight flight path before visual range is exceeded. Part of the experiment will be to see what aerodynamic parameters can be retrieved within such confined flight space.

4.1 Correction of data

Important aerodynamic and flight mechanical parameters, for example lift and drag, cannot be measured directly during flight tests and need to be calculated using raw data from the aircraft's instruments and measuring systems – barometric pressure, airspeed, air temperature, thrust, weight etc. These, on the other hand, are affected by various factors, including measurement errors, atmospheric conditions, and decrease of weight due to fuel consumption. Different methods will be tested to correct for these errors. Much of the initial testing will be used to calibrate and verify sensor accuracy.

Pressure measurements must be corrected for instrument error and position error. Position error is the error induced by the aircrafts adjacent pressure field changing depending on the aircrafts state. Regarding instrument errors, the pressure sensors used are pre-calibrated from the manufacturer and with a documented error margin. Accordingly to Ward et al. [5], total pressure measurements using a pitot system, such as the nose boom on Raven, can be considered to be without position error for flow inclinations of up to 20 degrees. Pitot static systems, on the other hand, are more sensitive to the aircraft's state. The static pressure orifices, two in total, are located on the nose boom on opposite sides relative to the centre line. Ward describes a number of different techniques to account for position error. Again it is unclear what is realistic to achieve with a remote controlled aircraft. Several techniques will be tested and compared.

Air temperature is usually measured by bringing the air to rest relatively to the aircraft. The resulting compression causes an adiabatic increase in temperature that has to be accounted for. Since the Raven aircraft will fly at airspeeds much lower then full size aircraft, it was chosen to simplify the air temperature measurement by simply mounting a probe in the free stream air and neglecting any possible temperature increase due to local compression effects.

5 Summary and conclusions

With a typical low university-budget, a dynamically scaled model of an in-house designed business jet, Raven, has been built and is being prepared for flight testing. Much of the work has successfully been combined with education programs in aeronautical engineering.

Building the model to meet the requirements on weight and inertia did not cause any complications.

A light weight, low cost, data acquisition system has been designed and will be used as a modular system for both current and future subscale research projects at Linkoping University. The flight testing of Raven will focus at exploring limits and possibilities of subscale flight testing using conventional radio control within visual range.

Due to delays in the project the Raven aircraft has currently not been flown. It was originally scheduled to fly during fall 2007, but various delays, many of which related to people joining and leaving the project, first flight is scheduled to happen during late summer 2008.

The capability being built up at the University will in the future be used both for educational and research purposes. Subscale flight testing may be an excellent low cost method to provide students with a practical understanding of flight testing principles and data reduction methods. From a research perspective the acquired knowledge is hoped to open up doorways for future collaborative projects with aerospace companies.

The work being done in this project is an example of a low cost university approach to subscale flight testing. Total budget for the Raven project has been 20’000€, excluding work hours by supervisors.

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