STAG

(The Stratosphere Troposphere Atmospheric measurement Glider)

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Abstract

STAG is a small glider (≈1.5m wingspan) equipped with a set of meteorological measurement sensors which, after prototyping, will be launched from a meteorological balloon at altitude. STAG will make measurements of pressure, temperature, relative humidity, wind speed and direction, and ozone concentration which will be telemetered back to a ground station in a similar fashion to a standard rawinsonde. However, the system will be able to autonomously guide itself back to the ground station using information from a digital compass, GPS data and a set of accelerometers processed onboard by a network of task-specific microcontrollers. This ability will allow measurements of atmospheric parameters to be made inexpensively and on the up- and down-legs of the flight. The autonomous guidance ability of a powered version of the glider is currently under test at low altitudes. An initial description of the prototype and discussion about the guidance performance to date is detailed. The stages of prototyping to be performed will also be discussed. The possibility of using the powered version of STAG for low–level pollution studies and air-quality monitoring is to be considered.

Figure 1: The current powered prototype of the STAG instrument.

Background

Rawinsonde observations are generally considered to be the most important input to Numerical Weather prediction models. These rawinsondes are generally expendable packages which are attached to a helium or hydrogen-filled weather balloon. The data retrieved by these instruments generally includes pressure, temperature, relative humidity and many now have some form of GPS-based wind speed and direction measurement ability. The aim of the current project is to examine the possibility of producing a recoverable rawinsonde sounding system. The benefits of a recoverable system are –

•more accurate calibrated sensors can be utilised which could not be used in an expendable platform because of cost and time constraints.
•measurements can be made on the up- and the down-leg of the mission.
•the use of a recoverable rawinsonde package could significantly reduce the cost of routine observations by meteorological services and thus may be important in increasing the amount of atmospheric information measured. The cost-effectiveness of such a system may be of significant use in increasing the number of launches made in third world countries.

Another benefit of such a system which is under consideration is the ability of the system to loiter over a specified area, defined by a set of waypoints, this may be of significant use in mesoscale model studies. A prototype powered version of the current STAG design is indicated in Figure 1.

Mission

The final STAG system should allow the following operations to be performed–

- •Record pre-launch information, which includes pressure, temperature, relative humidity and a launch position based upon GPS data.
- •Launch by a helium or hydrogen-filled meteorological balloon
- •Ascend to the balloon burst altitude (or to a user-specified altitude at which point a release servo will be activated) while transmitting data to the ground station via an on-board UHF transmitter. Onboard memory will also allow the measurements to be downloaded at a later date if the data is not received at the ground station.
- •Travel under autonomous control to an area above the launch point. An algorithm examines the current GPS position and the launch point position and calculates whether this is possible based on the gliders aerodynamic parameters (the glide slope being the most important parameter). If the launch point can not be attained (which is likely in high wind conditions) a secondary landing site should be targeted.
- •Once the glider is above the launch position (or the secondary landing site) the glider should either circle the launch point or define a path between a set of pre-defined waypoints until a lower altitude is reached. At this point a servo is triggered which releases a parachute. A homing signal is also activated at this point which allows the STAG instrument to be recovered.

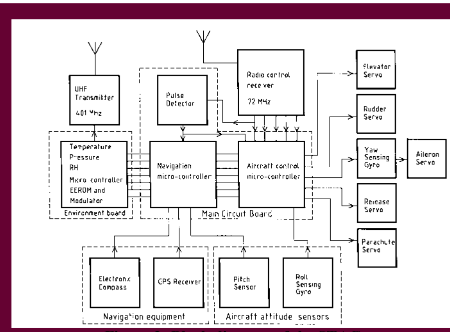

Figure 2: Block diagram of the STAG control and environmental measurement systems.

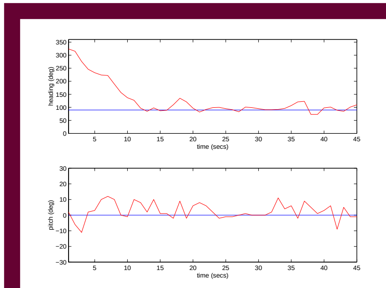

Figure 3: Compass headings and pitch measurements, derived from accelerometer data, made during a test flight (red lines) and navigation commands (blue lines).

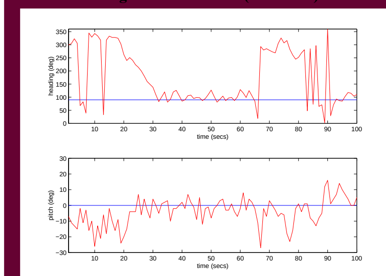

Figure 4: Compass headings and pitch measurements, derived from accelerometer data, made during a test flight (red lines) and navigation commands (blue lines).

Autonomous Control and the Environmental Measurement System

A block diagram which indicates the major components of the STAG electronic systems is shown in Figure 2. The system can be separated into five sections, these are –

- •Enviromental measurement unit
- •Navigation microcontroller
- •Aircraft control micro-controller
- •Navigation and aircraft attitude sensors
- •STAG Servos

It should be noted that because of the difficulty and expense of frequent balloon launches' a powered design has been used to test the autonomous control system. The use of a powered design requires the glider to be controlled from the ground at take-off and landing and a standard radio-control receiver has been integrated into the onboard electronics to allow this function to be performed. The heart of the environmental measurement unit is a microcontroller, the readings from the atmospheric sensors (pressure, temperature and relative humidity) are passed via an analog to digitial converter to this mircocontroller. Digital data from the GPS unit is then integrated into a data stream in the microcontroller. The microcontroller codes this data stream for input to the on-board UHF transmitter which transmits the data to the ground, this data stream also being passed to onboard memory which will allow the measurements to be downloaded at a later date if the data is not received at the ground station. Navigation commands are derived in the Navigation microcontroller from the current compass heading and current GPS location relative to those required to reach the launch site. The command, consisting of a compass heading, is passed to the aircraft microcontroller which interprets the navigation command and produces the modulated signal used to control the aileron, rudder and elevator servos. It should be noted that in the powered prototype these servos can also be controlled via a standard model aircraft radio-controller. Navigation commands defining a set of predefined waypoints can also be downloaded to the navigation microcontroller pre-launch, this ability has been of particular use during the prototyping and testing phases of the autonomous control system where the glider can be set to autonomous control then commanded to perform a loiter manoeuvre. Currently, a signal from the radio-control transmitter is used to tell the aircraft microcontroller to relinquinsh control of the glider servos so that the powered aircraft can be landed under human control. It should be noted that the range of the radio-control system is relatively limited (less than 2km) and this has limited test flights to relatively short test periods for the autonomous control system in order to ensure that the glider can be placed under human control at any time.

Figure 5: The environmental chamber which is used to test the glider and calibrate the atmospheric measurement sensors.

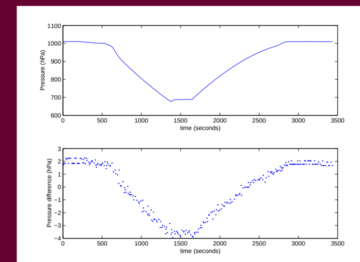

Figure 6: Absolute pressure measured using the enviromental chamber's Barocell (top figure) and the pressure difference observed between the Barocell and the atmospheric measurement systems pressure sensor (bottom figure).

Initial Flight Tests

Initial flight tests have proven to be successful and data from the electronic compass and pitch measurements, derived from accelerometer data, for two separate periods where the aircraft was under autonomous control are shown in Figures 3 and 4. In Figure 3 the glider was commanded to proceed directly East (90 degrees) for a period of 45 seconds and remain level. The blue lines indicate the commands made by the navigation microcontroller, the red line indicates the achieved pitch and compass headings. During this test flight the aircraft was initially moving on a North-West heading, after approximately 12 seconds of autonomous control the powered glider was achieving the correct heading and flying level. It should be noted that in this case the glider behaved particularly well. Figure 4 shows the effect of large wind gusts on the compass headings and pitch of the powered glider. These wind gusts can be observed as large variations in the pitch at approximately 10 and 67 seconds. During both these events the glider lost control for several seconds. However, in both cases the required course is regained which is encouraging at this early stage of the prototyping.

Initial Environmental Chamber Tests

Figure 5 displays an environmental chamber which has been designed to simulate the conditions in the troposhere and stratosphere and will be used to calibrate the atmospheric sensors to be used onboard STAG. In addition, the environmental chamber has and will continue to be used to test that the materials and the electronics are robust enough to cope with the extreme conditions at high altitudes. An initial calibration run which indicates the pressure inside the chamber measured by a precise Barocell and the difference between that measurement and the pressure sensor to be used in the STAG environmental measurement unit is shown in Figure 6. It should be noted that a constant pressure difference between the two instruments associated with poor initial calibration of the STAG pressure sensor has been removed. The errors observed in Figure 6 are associated with random error and calibration errors and show that the enviromental chamber will be of significant use in calibrating the various STAG atmospheric sensors.

Conclusions and Further Work

A brief description of the STAG instrument has been made and encouraging data from initial flight tests and a purpose-built environmental chamber have been detailed. However, a great deal of further work is needed to realize a system which can perform the mission outlined. The first step of further work planned is to study and improve the autonomous control algorithms of STAG. In addition testing and calibration of the various sensors utilised in the environmental measurement unit needs to be standardized. In the near future, tests using a tethered kite or balloon-borne system are to be performed to examine the robustness of the system in real conditions.

Acknowledgements

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