Autonomous Soaring Project Phase Two

This SEAS DTC funded research aims to demonstrate autonomous soaring using a surrogate manned sailplane. This phase of the research follows from the Innovation Funded Research previously undertaken within the SEAS DTC. The demonstrations undertaken during this phase show the capability to predict and exploit orographic and thermal soaring opportunities within the local atmosphere. Correlation between prediction and demonstration measurement was achieved. The soaring opportunities predicted could be exploited by Autonomous Air Vehicles (AAVs) in order to improve range and endurance.

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Introduction

Phase 2 of the Autonomous Soaring Project follows on from the SEAS DTC Innovation Funded research undertaken in 2006. Phase 2 brings together the expertise of three organisations: MBDA, Met Office and Roke Manor Research. The objectives of Phase 2 were to build upon the paper study undertaken previously and demonstrate the capability to predict and exploit soaring opportunities within the local atmosphere, specifically orographic (ridge) lift and thermal lift. The former is based on a computational fluid dynamics (CFD) meteorological forecast of vertical air speeds at various altitudes above points on a chosen grid. The latter draws upon two sources of data; observation and automatic interpretation of clouds via a digital camera (cloudscaping) and tables of probability of thermals based upon land type and usage.

Trials have been undertaken using a surrogate manned sailplane operated by the Bristol and Gloucestershire Gliding Club (BGGC). The sailplane was fitted with a GPS receiver and a radio modem in order to receive ground-based observation data relating to cloud formation and evolution. Trials have involved an air-based system that takes into account not only the location of the sailplane and global weather conditions, but also orographic lift predictions and thermal lift predictions from cloudscaping results and thermal activity based on land type (modulated by cloud cover, time of day, etc.).

Note that it is equally important to predict regions of falling air in order to avoid them as it is to predict regions of rising air to exploit a soaring opportunity. It is foreseen that exploitation of soaring energy within the atmosphere can be of benefit to a number of autonomous air vehicles (AAV). Example military uses could include comms relay, observation platform, loitering munition or long-range weapon. An example civilian use could be an AAV tasked with undertaking a pipeline survey.

Trial site selection

To reduce the cost of the demonstration trials and remove the development cost of safety critical algorithms the decision was made at the start of Phase 2 to use surrogate-manned sailplanes rather than a fully autonomous sailplane; the surrogate sailplane pilot having full authority to abort the trial at any time. The site deemed most suitable for purpose was the Bristol and Gloucestershire Gliding Club (BGGC) located by Nympsfield in Gloucestershire.

The location of the BGGC airfield is on the edge of the Cotswolds by Birdlip escarpment and overlooking the Severn estuary. This location offers some very good orographic lift as winds channelled up the Severn estuary are forced up and over the escarpment. The locality also offers numerous examples of terrain usage from estuary and lake to forest, open fields, urban etc… These different terrains uses offer may opportunities for thermal activity. A visit to the BGGC provided lots of anecdotal evidence to support this.

Communication links

Data transfer between the sailplane and the ground station was achieved using COTS data modems; a pair of Warwick Wireless X8200 radio modems limited to 500 mW; in order to comply with regulations for unlicensed use. Reliable data transfer between the fixed ground station and the constantly manoeuvring sailplane using such a system proved problematic during demonstrations. The most satisfactory solution was achieved by the utilisation of a bespoke ground antenna. This antenna is shown in situ at BGGC in Figure 1.

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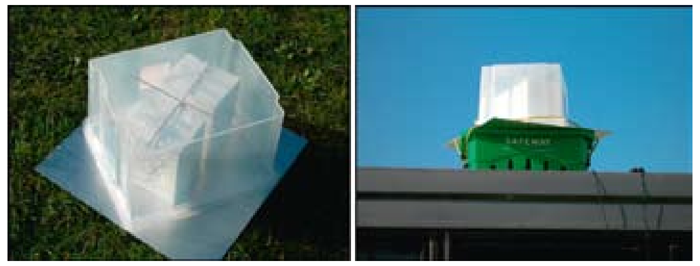

Bespoke antenna in situ at BGGC.

The airborne radio was fitted with a standard stub antenna mounted externally to the underside of the sailplane. This combination of antenna was still problematic but provided the best data transfer of the solutions trialled.

Orographic met model

Predictions of the atmospheric vertical velocity are made using a numerical model [1] for airflow over complex terrain. The model uses CFD to solve a set of equations (simplified in the interests of computational efficiency) which determines the vertical motion induced by the flow of air over the real terrain. Digital terrain data are used at the lower boundary of the model and vertical profiles of wind and temperature from the coarser resolution Met Office Global forecast model are used to represent the undisturbed atmospheric conditions at any given time. The model then predicts the vertical velocity field above the terrain as a gridded data set. Some convergence testing was undertaken to determine the required resolution of the grid. It was concluded that latitude and longitudinal resolution of 250m and 100m vertical resolution provided a pragmatic balance between orographic soaring opportunity predictions and volume of data generated. An example of and orographic prediction is shown in Figure 2.

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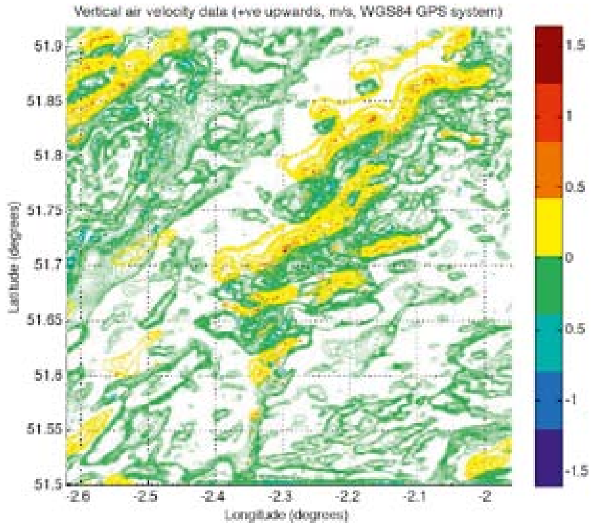

Example prediction of orographic lift in the vicinity of BGGC (data shown applicable for the period between 15:00hrs and 18:00hrs on the 10th September 2007).

To support the Phase 2 trials a prediction of the orographic lift specific to the BGGC trials site was undertaken every three hours by the Met Office at Exeter. This data could then be downloaded to the BGGC trials site for use on demonstrations relevant to the applicable time frame.

Thermal met model

A surface energy balance model has been run, driven by two years of observed atmospheric data, to predict the temperature variations of a number of different surface types (e.g. grassland, woodland, tarmac, urban). The average predicted differences between the temperatures of the different surfaces have then been presented as a function of season, time of day and cloud cover. For example the average temperature of a tarmac surface on a cloud-free day in summer is found to be 8 degrees warmer than that of a grass surface, but the differential decreases with increasing cloud cover or in other seasons.

Large-eddy simulations were performed to evaluate the likelihood of having a thermal above an isolated patch which is warmer than its surroundings. Both the temperature contrast and the size of the patch were varied. The results of these simulations were combined with those from the surface energy balance model, to produce probabilistic predictions of the likelihood of finding a thermal above a given surface.

These probabilistic predictions were presented as tables of probability based on types of surface and parameters such as time of day and cloud cover. The prediction tables were then applied to a map of the trials area in order to identify potential regions of lift or sink to be taken into consideration during thermal soaring trial flights.

Agent architecture

A multi-agent architecture has been developed that can receive data from a variety of sources and interpret it in order to plan a detailed sequence of waypoints to be flown.

The approach uses a reasoning system in which multiple agents communicate via a shared 'blackboard'. Conceptually, the blackboard can be regarded as a map onto which relevant information can be posted. The reasoning system consists of agents that cooperate. The agents can be physically distributed, with agent colonies existing on multiple airborne vehicles, and with agent interaction taking place between colonies on those airborne vehicles and also with agents on the ground, e.g. associated with ground-based sensor platforms.

The ability to modify with ease the physical distribution of agents has been employed in this project. For initial data-link shakedown trials, sensors were connected directly to a UHF wireless modem for communication down to the agent colony running on a laptop computer on the ground. In subsequent data collection trials, the majority of the agents were airborne, running on a laptop, with cloudscaping results data being up-linked to the sailplane.

Agent technologies allow for the implementation of very loosely-coupled software objects. Those objects are able to communicate requests, commands and data using standardised protocols, such as those specified by the Foundation for Intelligent Physical Agents.

Agent-based route planning

An agent known as a *planner*, working with a mission *requirement agent*, implements route planning and plan monitoring.

The planner determines a 'high-level' plan of what the AAV is to do next. This agent considers the current AAV status and the 'global picture' maintained by the blackboard agent, and generates a set of goals. These goals are broken down in more detail, specifically into a set of waypoint sequences. The goal breakdown may propose a number of possible plans and reports these to the high level planner. As the high level planner ultimately it proposes a current plan – an ordered list of the current goals. Each goal is associated with a validity – i.e. the criteria which must be true for the goal to be applicable, including the time by which the goal must be realised. The planner continually monitors the applicability of the current proposed plan by reviewing the applicability of the current goals, the addition or deletion of lift regions, and significant deviations from the current plan.

Note that the tactical planner agent does not itself fly the AAV; rather it generates a detailed waypoint sequence which can be presented, via the waypoint manager agent, to the sailplane pilot or to a AAV flight management system.

Algorithms for the strategic and tactical planner agents have been prototyped and successfully demonstrated prior to their inclusion into the multi-agent reasoning system. The planner agent was implemented from the prototype during extensions to the project undertaken after trials.

Trials results

Limited flight trials were undertaken during the very wet summer of 2007; demonstrating the opportunistic nature of autonomous soaring! These limited flight trials were also hampered by problems obtaining satisfactory performance from the COTS data modems.

Flight trials using sailplanes were undertaken: firstly to validate data collection and air-ground communications and secondly to test whether orographic lift and sink were found where predicted. The trials configuration is shown in Figure 3.

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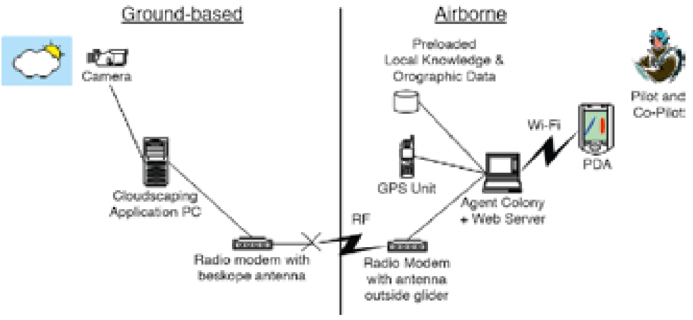

Flight trials configuration.

Video cloudscaping data was collected and correlated against measured sailplane behaviour on a number of occasions. Whilst opportunities for thermal soaring were limited, nevertheless good opportunities arose for trialling the orographic-soaring elements.

A cloudscaping image processing application, running on a ground-based PC, used this comms arrangement to communicate thermal region information to the agent colony. However, the weather conditions on trial days were not always conducive to thermal lift detection within the limits of the cloudscaping application.

The trials were flown in a two-man sailplane, with a laptop in the air connected to a stand-alone GPS receiver. In order for the trials engineer to view the output from the agent colony, web-pages were generated on the fly and delivered over WiFi to a PDA incorporating a transflective screen for good visibility in bright sunlight.

An agent in the laptop was configured to output a map to the PDA's web-browser showing regions of interest (Figure 4) together with a table giving distance and bearing to promising regions of lift (and sink) for the trials engineer to read and convey to the pilot. In general there was good correlation between predicted areas of lift and sink and those encountered by the sailplane during its trial flights (predicted lift is shown in Figure 5 and the corresponding recorded flightpath is shown in Figure 6, see next page).

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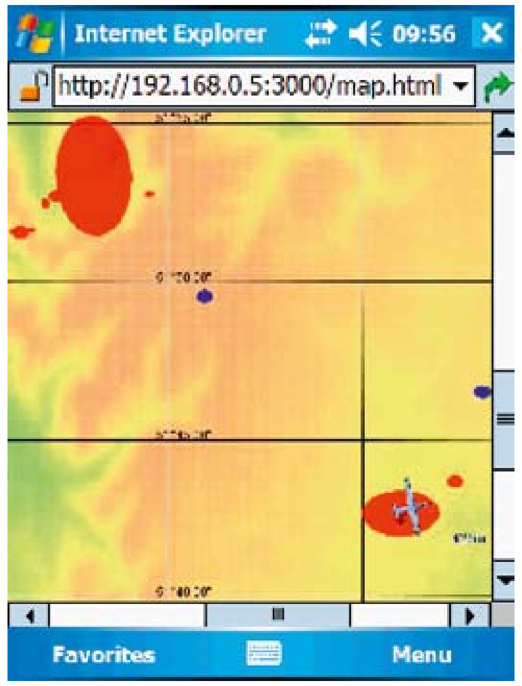

PDA display.

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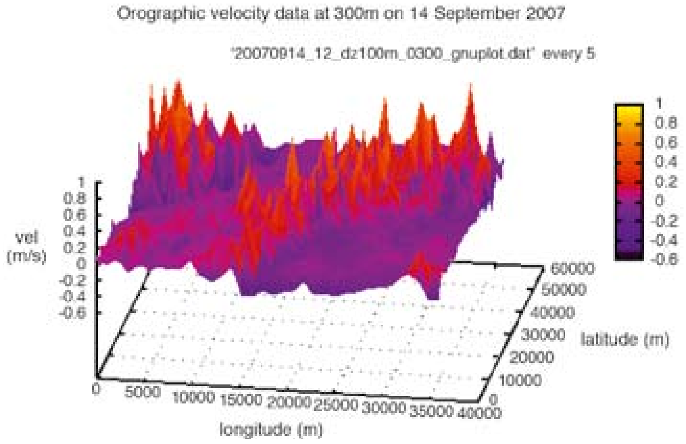

Orographic lift prediction.

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STREPLA visualisation of flightpath.

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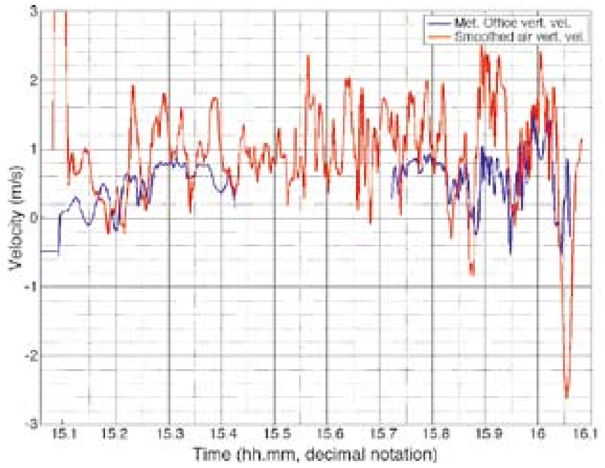

Comparison of predicted and measured vertical velocity.

The sailplane was fitted with an altimeter and also a 'variometer' which indicates whether the sailplane is gaining or losing energy. The trials engineer on board noted that there was good agreement between the areas where lift was predicted and the behaviour of the altimeter and variometer displays. Furthermore, local pilot instructors commented that the predicted areas of lift were consistent with their experience. This was confirmed mathematically by comparison of the predicted total energy of the sailplane against the output of the variometer. The total energy can then be converted into a comparison of predicted and measured vertical velocity. Such a velocity comparison is shown in Figure 7.

Further developments

It was found that the PDA's transflective display was easy to read in the air and that the tabular display was easy to assimilate. Further trials could therefore be undertaken in single-man flights with the PDA placed next to the sailplane pilot showing recommended areas in which to seek lift and to avoid sink.

Additional development was undertaken under RAO ADD032 funding. The planning agent implementation was completed, which could be used in trials to present proposed routing so as to maximise time in rising air and minimise time in sinking air.

The exploitation of further atmospheric phenomena offering soaring opportunities could be exploited. For example, lee waves, atmospheric standing waves which form under certain meteorological conditions on the lee side of mountain ranges and offer high altitude soaring opportunities. A global lee waves prediction tool is already in use within the Met Office. This prediction tool could easily be used in conjunction with a developed cloudscaping application extended to detect lee waves. Some lee wave integration, with data from the Met Office, was conducted under the RAO ADD032 funding. The data was received as files covering north central England – unfortunately no data covering Nympsfield was available. However, this allowed the lee wave data to be integrated and an improvement to region inference algorithms to be implemented. Figure 8 shows lee wave data over the Pennines, and Figure 9 shows the corresponding regions inferred by the autonomous soaring software. There is a pleasing correlation between the region locations/orientation and the areas of strong activity shown in the plots.

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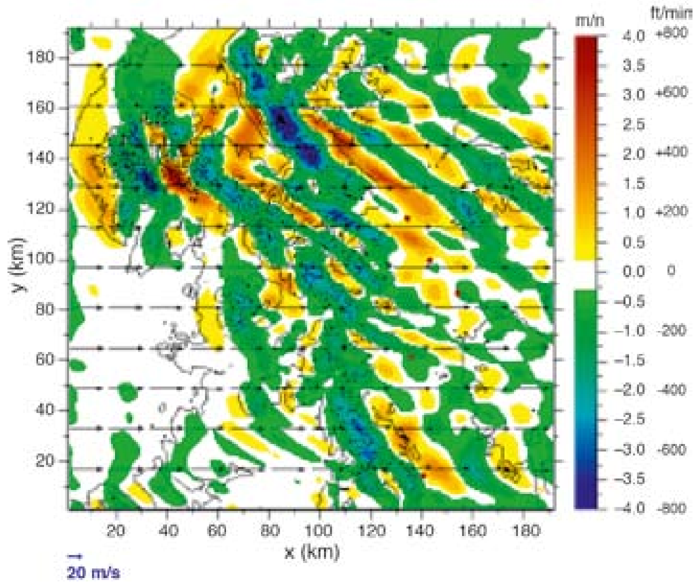

Lee wave forecast over Pennines.

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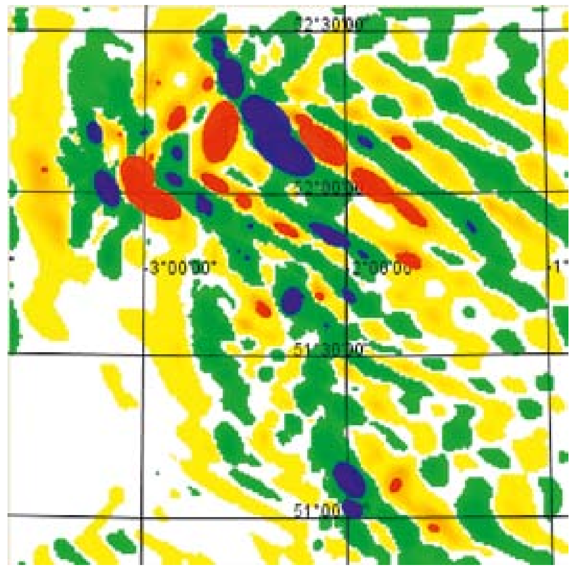

Inferred lee wave regions over Pennines (autosoaring S/W plot).

Exploitation of these further atmospheric phenomena could be undertaken using surrogate manned sailplanes. However, as the autonomous soaring techniques are envisaged as being deployed on AAV platforms a further logical step would be to undertake demonstrations with an AAV. Such AAV demonstrations are likely to be prohibitively costly. If such AAV demonstrations are to be realised then opportunities for sharing the costs of such trials should be explored within the realm of the SEAS DTC as multi-thread demonstrations. For example the problematic COTS datalink used in Phase 2 could be replaced with a military specification datalink and used to demonstrate some research being undertaken within the SEAS DTC on novel communications.

References

1. Vosper, S, *'Development and Testing of a High Resolution Mountain-Wave Forecasting System'*, 2002, Meteorol. Appl. 10, 75–86.

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