J8.9 AEROSONDE OPERATIONS IN 1998

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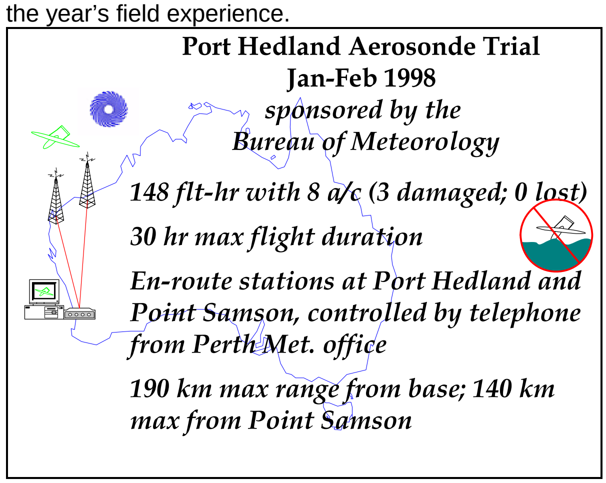
Early in the afternoon of 21 August, Aerosonde *Laima* - having doubtless been shepherded by her namesake, the ancient Latvian deity of good fortune - landed into a brisk wind on South Uist in the Hebrides, and so became the first robotic aircraft to have crossed the Atlantic. Its flight, from Newfoundland, was a key advance in the burgeoning development of unmanned aircraft, but moreover it was a significant milestone for weather forecasting. The Aerosonde has been designed from the outset for long-range meteorological reconnaissance, with the objective of affording operations on a scale sufficient to fill the chronic data voids over the world's oceans. The Atlantic crossing demonstrated - to meteorologists, air-traffic authorities, regulators, and indeed to the public at large - that long-range operations by these aircraft will be practical in the near future, and has contributed materially to facilitating their introduction to routine service.

Aerosonde Milestones in 1998

- ~400 flight hours (~800 hr total since '95)
- 5 flights >24 hr duration; longest 30.5 hr
- 8 aircraft lost (all to remediable technical faults; none to weather)
- flights in severe tropical thunderstorms
- flights in midlatitude icing
- fully automatic flight from takeoff to landing (*i.e.* with no manual control)
- use of multiple ground stations, and enroute control-by-telephone from forecast centres
- first Atlantic crossing by an autonomous aircraft; 20-21 August, 3270 km in 26h 45m on 4 kg fuel.
- Aerosonde applications well understood and supported by weather and aviation agencies in Australia, Canada, UK, Taiwan, and the United States.

However *Laima's* flight was only the most publicised of a diverse set of exercises which, in aggregate, have shown exciting promise for meteorological applications. These exercises - including programs in Western Australia, the South China Sea, and off Vancouver Island - encompassed flights in severe thunderstorms and icing; integration with and segregation from other air traffic; control-by-telephone from forecast offices; and acquisition of high-quality upper-air data. Attrition has been unacceptably high for routine service - we have lost 8 aircraft this year in about 400 flight-hours - but the responsible technical faults are understood and will be fixed in the course of further engineering development. We expect to complete this work, with an associated twofold improvement in range and endurance, over the next three years or so. It is on this timescale that wide-scale service can commence.

A few illustrated examples will allow us briefly to review the year's field experience.



1998 trials began with a six-week exercise in Western Australia. The objective was to do routine reconnaissance along the northwest coast, and in order to range further than was possible in previous trials - within the constraint of using terrestrial line-of-sight communications - we developed a system for relay via either of two stations. These could be controlled remotely via telephone, and this allowed us to do much of the enroute control from Perth. The arrangement is discussed in an accompanying paper by McGuffie (1999).

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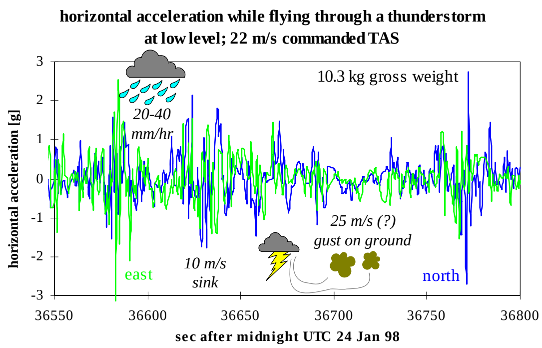
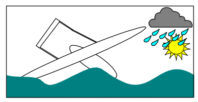
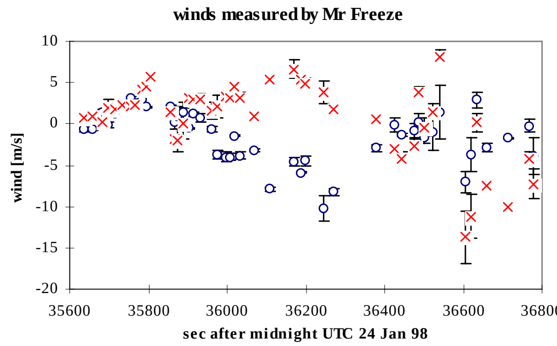


Mr Freeze at Port Hedland





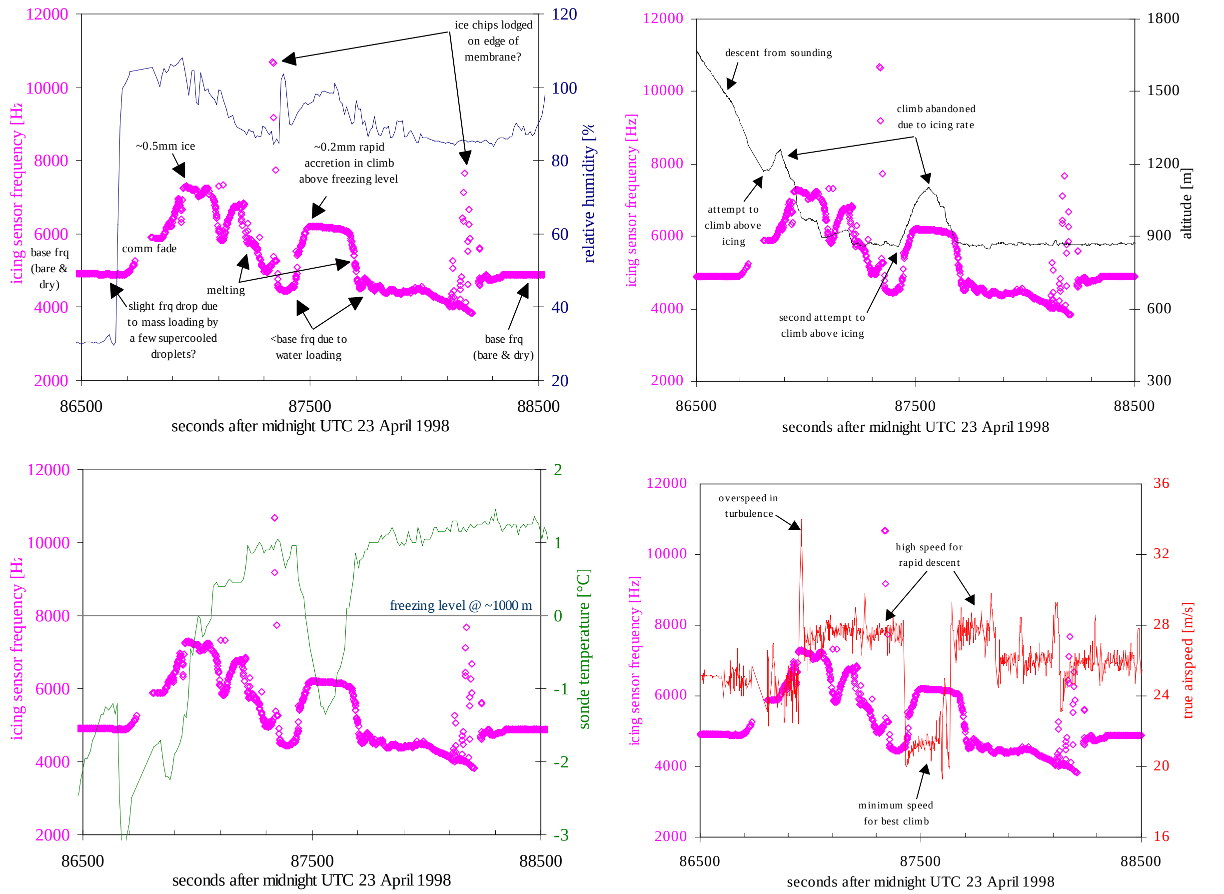
Despite the "cyclone alley" venue, weather during the Port Hedland trial was generally benign albeit with the odd exception. In the evening of 24 January, *Mr Freeze* was caught in a thunderstorm over the launch site. Unable to land and afraid to run, we kept the aircraft in a circuit about 200 m overhead, and were treated to a harrowing ten minutes of rapid climbs and descents, phenomenal overspeeds up to 45 m/s, and dizzying accelerations - indicated here, somewhat qualitatively, by finite-differences of N/S and E/W groundspeed. The Aerosonde's windfinding-by-maneuver algorithm (McGeer 1996a) gets confused in gusty conditions, so the reported winds (o for S, x for W) are suspect, but certainly they were strong. At one point there was a sudden *WHOOSH* while our ground-station shed, weighing a tonne or so, jumped sideways in a microburst. Thankfully we survived the ride, as did *Mr Freeze* - until, with the storm finally abating, its engine failed, apparently due to ingestion of a great deal of water into the exposed carburettor (not previously thought to be a problem based on ground tests, but later fixed by an "umbrella"). *Mr Freeze* came down, undamaged by the storm - but unfortunately in a saturated salt pond, which did its internal components no good at all.

We had two similar thunderstorm encounters during the South China Sea Monsoon Experiment in May. These bear witness to the ability of Aerosondes, by virtue of their small size, to manage in turbulence which would put larger aircraft at some substantial risk. Cyclone reconnaissance by Aerosonde has been much discussed (Holland *et al.* 1992, McGeer 1996b), and survivability in the associated rain and turbulence has been a matter of some debate; here is practical evidence that such operations will be feasible.

The Port Hedland operation involved a lot of droning around in boring weather, but we had a few moments of excitement. One was during the thunderstorm encounter discussed above. Another came near midnight of 29 January when *Lex Luthor* lost its generator belt about 50 km off Port Hedland. Loss of the generator is a serious matter, since battery capacity is about 30 minutes - and that, coincidentally, was roughly the amount of time required to fly home. The crew undertook some fast work, culminating in our first fully automatic landing. This *almost* worked - but the engine was cut a second or two early, and *Lex Luthor* bounced off some boulders short of the runway before skidding to a stop on centreline. (Fortunately the damage was not too expensive.) A successful autoland followed in February with *Nixon* at Camp Roberts, California, on a flight which also included an automatic takeoff. More development is required to make these features satisfactorily robust, but the foundation is there for a level of autonomy that will be essential for economical operations.

South China Sea

More tropical weather came in May on remote Dongsha Island, where a crew of three from ES&S joined staff from the Taiwan Central Weather Bureau for the South China Sea Monsoon Experiment. The party was hosted graciously by the local military, and not-so-graciously by the island's ubiquitous dogs and rats, but despite the privations and ferocious humidity the crew chalked up about 90 flying hours in 17 days. These included two more thunderstorm battles. The first occurred over the launch site, as at Port Hedland, except that the rain rate reported by ground instruments was higher. Again there was an engine failure, but, at 2000 m, *Ming* was high enough for recovery on the runway. (Indeed that initial problem was to get the aircraft down through convection.) Maurice Gonella lined it up while David Hobby, pilot's console in hand, strained into the rain and murk for visual contact. *Ming* emerged on target with only seconds to spare, and was put down manually in a spectacular sheet of spray. The meteorological data from the flight are thought to be a very valuable complement to those collected simultaneously by the BMRC C/POL radar - and the engineering lesson led to the "umbrella" modification.

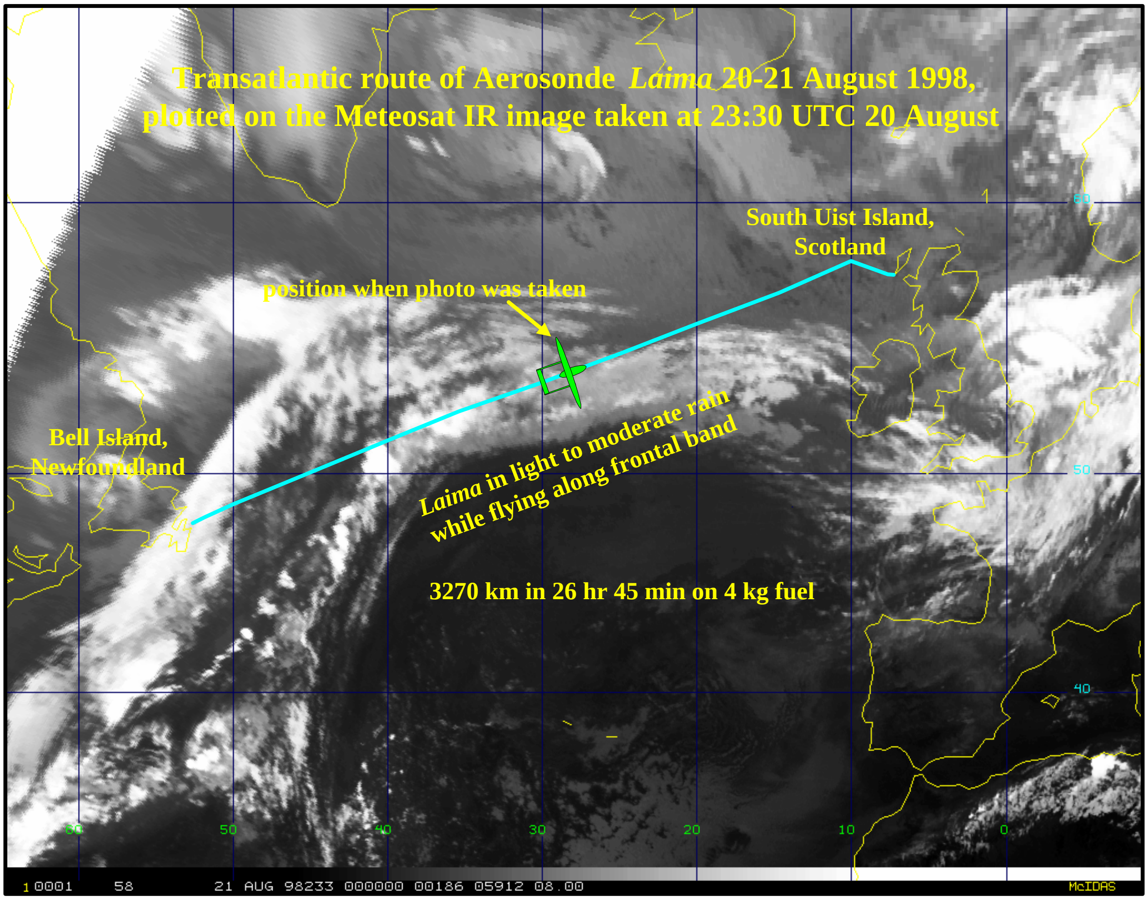


In April we flew off Vancouver Island for two weeks in a trial sponsored by Environment Canada. We were particularly interested to test an airframe-icing sensor developed by our colleagues at Hood Technology (Hood River, Oregon). We had a few instances of icing, including this case of rapid accumulation on *Fester* upon descent into cloud (indicated by the jump to 100% humidity in the upper-left-hand plot). The icing sensor is essentially a piezo membrane made to ring at its natural frequency. A film of ice across the membrane mainly adds stiffness and so increases that frequency. Water, or isolated drops of ice, instead adds mass and so lowers the frequency; hence the lower-than-base frequency while the ice melts (or when flying in rain). The experience off Vancouver Island demonstrated an ability to detect ice with a lightweight sensor. Here the information was used to alert the ground controller, but aircraft in routine service would have to take avoiding action on their own.

The Atlantic crossing

Until August our operating radius had been restricted to 150 km or so, for lack of over-the-horizon communications. To do longer-range operations routinely we await new satellite services, *e.g. Iridium*, which will not be available until 1999. But in February we conceived the idea of doing an early long-range demonstration *without* enroute communications. The North Atlantic was the obvious place to go, first because the historical significance of Atlantic crossings would ensure maximum attention, and second because the distance, and the winds, were just right for the Aerosonde at its current stage of development. We knew, in view of our lingering reliability problems, that it would be a gamble - and indeed *Trumper, Piper, and Millionaire* wound up in the Atlantic - but the gamble has paid off manyfold.

The original plan was to fly from Newfoundland to Ireland, just as Alcock & Brown had done in 1919. However the Irish Aviation Authority decided, rather late in the day, that in view of the lack of position reporting enroute it could not authorise our flight. Perhaps that was for the best, since it led to an exhilarating few days in August when we switched our planning to Scotland and, from a cold start, obtained all of the necessary approvals from the authorities in the UK. We are very grateful indeed for the extraordinary assistance and enthusiasm from the Civil Aviation Authority, the Defence Evaluation and Research Establishment, and the UK Met Office. But while their support was truly exceptional, authorities elsewhere - in Canada, Australia, and Taiwan - have likewise been, within clear bounds of safety and critical evaluation, very positive about finding practical ways to accommodate Aerosonde operations.



Laima's track on 20-21 August took it south of the great circle to pick up favourable winds along an occluded frontal zone; the photo shows the frontal cloud and aircraft position at midnight UTC. *Laima* flew through enough rain to get past our seals and accumulate (for lack of a drain hole!) in the fuselage. The route was planned using winds from the NCEP aviation model, and these turned out to very well forecast: *Laima* arrived within minutes of estimate, and its logged winds matched the NCEP analyses precisely. Steve Lord was instrumental in making the wind forecasts available for flight planning, and is particularly to be thanked for frenetic late-night work to recover from a disc crash in time for *Trumper's* attempt on 17 August.

Acknowledgments

We have had the privilege of enjoying wonderful support from a great many people in the course of the Aerosonde project. Here we would like to thank our hosts in the various field operations, who have been invariably cheerful and helpful despite our shameless impositions; our colleagues at Insitu, ES&S, the Bureau of Meteorology, and the University of Washington; and the air-traffic and regulatory services which have willingly risen to the Aerosonde's new challenges. We are delighted also to acknowledge the project's sponsors, including Environment Canada, the Taiwan Central Weather Bureau, the US National Weather Service, the Department of Energy, Boeing, L3 Communications, and above all, the Australian Bureau of Meteorology and the ONR Office of Marine Meteorology, who have remained steadfast supporters from the project's earliest days.

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