WIDE-SCALE USE OF LONG-RANGE MINIATURE AEROSONDES OVER THE WORLD'S OCEANS

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Abstract

On 20 August 1998 Aerosonde *Laima* took off from Bell Island, Newfoundland, headed east through a stormy night, and landed the next afternoon on South Uist in Scotland's Western Isles. She became the first unmanned aircraft to have crossed the Atlantic, and, at 13 kg gross weight, the smallest aircraft by far ever to have made such a flight. *Laima* crossed the Atlantic to demonstrate in dramatic style new opportunities for economical long-range deployment of lightweight instruments. Aerosondes have been designed especially for offshore weather reconnaissance, in which they have flown hundred of hours of field trials in various venues around the world. Air-traffic and regulatory policy is moving to accommodate these operations, and engineering development continues toward fielding of a much more capable, but equally small, "second generation". Thus robotic weather reconnaissance, and other applications involving lightweight payloads, are poised to become routine within the next few years.

Figure 1. Aerosonde *Trumper* leaves her cartop launch cradle at Bell Island, Newfoundland, for the first of four attempts on the North Atlantic made by Aerosondes in August 1998. *Trumper* didn't reach Scotland, but *Laima* crossed a few days later, landing on South Uist in the Hebrides. She covered 3270 km in 26 hr 45 min, and burned about 4 kg of 100LL avgas. Altitude was 1680 m (5500 ft) most of the way across, but for the final 150-odd km *Laima* flew low over the sea to qualify, under UK regulations, as a model aircraft! She hit every waypoint within a few minutes of estimate, thanks to a superb wind forecast by the US National Weather Service and careful routing by Cliff Mass and Scarlett Bendaña of the University of Washington. A map of *Laima's* route, overlaid on the satellite photo of the rainy enroute weather, can be viewed at http://www.insitugroup.com/. Photo by Keith Gosse.

Miniature robotic aircraft

Costs for certain airborne-sensing applications stand on the precipice: they are likely soon to tumble thanks to the advent of robotic aircraft with the following key attributes:

Aerosonde Operations 1995-1999

complete

proposed

Figure 2. Since its inception the Aerosonde program has emphasised early field trials with testbed aircraft. Our first trial was flown at the end of 1995, as part of the Maritime Continent Thunderstorm Experiment off northern Australia (McGeer 1996b), and since then we have deployed in diverse jurisdictions and climates in collaboration with the weather services of Australia, Canada, Taiwan, and the US. Principal results (as discussed by McGeer *et al.* 1999) are as follows:

- more than 900 flight hours since 1995
- deployment with relative ease (especially when we have traveled with aircraft, ground station, and launcher boxed up as airline luggage)
- 7 flights exceeding 24 hr; longest 30.5 hr
- flights in severe tropical thunderstorms (Western Australia; South China Sea 1998)
- flights in midlatitude icing (Vancouver Island, Apr 1998)
- fully automatic flight from takeoff to landing (Feb 1998)
- control of multiple aircraft from a single ground station (Vancouver Island, Mar 97)
- inflight transfer between ground stations, and enroute control-by-telephone from weather forecasting centres (Western Australia; Vancouver Island; North Carolina; Hawaii)
- first unmanned Atlantic crossing; 3270 km from Newfoundland to Scotland on 20-21 August 1998, in 26 hr 45 min using 4 kg fuel
- Aerosonde applications well understood and supported by weather and aviation agencies in Australia, Canada, UK, Taiwan, and the United States

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- small size, with attendant economies deriving from low costs of manufacture and use; easy shipment; assembly and operation by a single person; flexible basing on ship and shore; and independence of elaborate facilities;
- long range and endurance, sufficient to reach remote areas (particularly over the oceans) and to remain there for useful periods of time;
- autonomy, with automatic operation from take-off to landing, and only occasional messaging while en route, such that one person could manage several aircraft simultaneously;
- attrition that could be high (perhaps 10% of sorties flown) without making safety or

economics unacceptable. Miniaturisation of the necessary onboard components, particularly GPS and satellite-communications equipment, has created opportunity for development of such aircraft. Missions that can be flown with miniature instruments - as listed, for example, in Table 1- will be able to exploit them.

Our particular interest has been in meteorology, which has a long-standing need for routine, inexpensive measurements - of pressure, temperature, humidity, wind, and icing - over oceans and remote areas. The Aerosonde was conceived in 1991 to address this requirement, and The Insitu Group was formed in 1992 to develop the concept with funding from the US Office of Naval Research and the Australian Bureau of Meteorology. In 1995 we were joined by Environmental Systems & Services, an Australian instrumentation firm, and in 1997 by the University of Washington. The weather services of Canada, Taiwan, and the United States meanwhile added their sponsorship. Trials with prototype aircraft began in 1995, and have proceeded through a series of venues and technical improvements as noted in Figure 2.

20 W-hr battery pack (1 hr power)
1.2 kg avionics set including
two 68332 computers
flight control sensors
UHF modem
L1, C/A code GPS
bladder for 5 kg 100-octane gasoline
pitot-static pressure ports
flap servo
GPS antenna
oil tank
ignition
engine and
generator
fixed-pitch
propellor
AEROSONDE
UHF dipole
antenna
in left tail
graphite/honeycomb
shell
graphite sandwich
inner panel
pods for pressure,
temperature,
humidity sensors
1 m
graphite tube tailboom
fibreglass tail
assembly joint
fiberglass sandwich
outer panel
AE
RO
S
O
NDE

Figure 3. An Aerosonde packs the fuel and equipment necessary for transoceanic flight into a 13 kg package small enough to fit on a tabletop.

The Atlantic crossing

Laima's Atlantic crossing was something of a culmination of the trials program, as it was the first Aerosonde flight to go more than 150 km or so from the launch site. We had previously excluded flights at longer range for lack of over-the-horizon communications. An Aerosonde-scale long-range system will not be useable until new low-earth orbiting networks (*e.g. Iridium*, *Orbcomm*, and *Globalstar*) are fully in-service for data transfer, later this year or in 2000. These will be essential for routine service, but we decided on an early demonstration *without* over-the-horizon communications in order to alert prospective users, air-traffic controllers, regulators, and the general public to the level of capability that was quickly coming to hand. We chose the North Atlantic, first because the historical significance of Atlantic crossings would ensure maximum attention, and second because the distance, and the prevailing winds, were just right for the Aerosonde at its current stage of development. The original plan was to fly from Newfoundland to Ireland, just as Alcock & Brown had done on the first nonstop Atlantic flight 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 offered by the Civil Aviation Authority, the Defence Evaluation and Research Establishment, and the UK Meteorological Office. (But while their support was truly

Table 1. Example payloads and applications for miniature aircraft

Payload	***Weight [gm]***	***Military application***	***Civil application***
Triple radiosonde instruments	70 gm	Ship -and shore-based weather reconnaissance	Wide-scale over-ocean soundings and tropical-cyclone reconnaissance
Nanotesla-level total-field and directional magnetometers	1 kg	Magnetic anomaly detection	Geomagnetic survey
Video, in visible or infrared, with TV or compressed-data downlink	< 2 kg	Battlefield reconnaissance; search	

and rescue
Fisheries reconnaissance,
search and rescue; fire
spotting; geodetics; law
enforcement
Synthetic aperture radar
"front end"
< 1kg
Over-the-ridge
battlefield
reconnaissance
Chemical or biological
sensors
< 1 kg
Battlefield toxin
detection
Pollution monitoring
Radio repeater
< 1 kg
Over-the-horizon/over-the-ridge data relay
Radio detector
< 1 kg
Signals intelligence;
search and rescue
Search and rescue

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exceptional, authorities elsewhere - in Canada, Australia, Taiwan, and the US - have likewise been, within clear bounds of safety and critical evaluation, very positive about finding practical ways to accommodate Aerosonde operations.)

Our launch site was Bell Island, near St John's, and we were able to monitor aircraft through our line-of-sight data link for about 40 km before losing contact. The subsequent lack of communication made little difference to our aircraft, which operates autonomously whether in contact or not, but for the crews on either side of the ocean it made for a long, anxious wait!

The tension was all the worse because mechanical reliability was marginal for long flights. Our emphasis on early field trials had called for some engineering shortcuts, and a number of problems remained to be fixed especially in the powerplant and fuel system. These had cost us several aircraft in earlier trials, and we lost three more into the Atlantic.

At US$25,000 per aircraft the associated cost was not insignificant, but a gamble is worthwhile when early results of novelty and significance are at stake. Of course the high stakes made for a tense game, but *Laima*, the third Aerosonde to make the attempt, had luck on her side. (She was named for the ancient Latvian deity of good fortune.) She popped up on the Scottish end right on time, making contact with the South Uist station at a range of 57 km. An elated trio of University of Washington engineers brought her in with a gentle plop onto the tall Hebrides

3300 km
8200 km

4 km
5.8 km

54 kt at sea level
78 kt at sea level

40 MHz floating point computer

1000 flight-hour target

$40K expected in 1999
$20K target

$500/flight hour in small-scale operations
still-air
range
onboard
processing
service
ceiling
maximum
level speed
average
lifetime
life-cycle
cost
total
flight-hour
cost

FIRST **SECOND**

1.5 days
5 days
sea-level
endurance

Figure 4. *Laima*, and her stablemates (Figures 2, 3), are relatively unrefined "first-generation" Aerosondes developed for early field experience. They will continue to expand meteorological and other applications over the next couple of years, but upcoming designs will offer substantially better reliability, economics, and performance.

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grass, and in due course they joined their British hosts in making full use of Benbecula's two public houses. *Laima* returned to Seattle by air freight, and is now on display at the Museum of

Flight on Boeing Field. McGeer & Vagners (1999) give an account of the Atlantic demonstration.

Toward routine service

The festivities that followed *Laima's* flight celebrated not just her own safe arrival, but moreover the long-awaited arrival of the Aerosonde concept. Where previously the idea of long-range operations by miniature robotic aircraft had been a bit of conceptual esoterica, the

Figure 5. An important application for Aerosondes is targeted meteorological reconnaissance, for example over the northeast Pacific. The NORPEX program in 1998 demonstrated that such reconnaissance can substantially improve weather forecasting (*e.g.* Szunyogh *et al.* 1999), and Aerosondes offer about the only fiscally practicable method in prospect for routine operations. This would involve cycling several aircraft continuously though bases in Hawaii, the Aleutians, and the West Coast (to take best advantage of prevailing winds). First-generation aircraft can begin to nibble at the edges, but second-generation aircraft will be able to reach, loiter, and communicate wherever observations are of greatest value. For non-meteorological missions, the second generation will likewise have improved flexibility for trading range against payload.

1200 km typ. operating radius
for 1st generation Aerosonde
3000 km typ operating radius
for 2nd generation Aerosonde;
>10,000 km missions with
tailwind

0
2000
4000
6000
8000
10000
0
2
4
6
Payload [kg]
Ran
g
e to zero fu
el
in
s
t
ill a
i
r [
k
m
]
2nd
gen Aerosonde
1st
gen Aerosonde

Atlantic crossing made it a well-known fact on the ground. And the set of field trials as a whole have pretty well answered the fundamental questions of feasibility. Certainly aircraft of this scale are capable of flying long distances and durations - indeed much longer than has been achieved by our "first-generation" prototypes (Figures 4, 5). They can be operated autonomously. They can fly in, and retrieve data from, severe weather - including conditions comparable to those in tropical cyclones (Figure 7), which are prospective Aerosonde targets of especially great interest to the sponsoring weather services (Holland *et al*. 1992; McGeer 1993). Furthermore Aerosondes can be operated safely and accommodated by air-traffic and regulatory agencies, as we will discuss presently.

With questions of feasibility substantially addressed, the main question remaining is one of timing - or perhaps of funding, which is roughly the same thing. Wide-scale service within five years is a practical possibility. Indeed even the current Aerosonde design, although developed as a testbed rather than a production system, has some capacity for service in the near term; a

rough annual costs
for routine Aerosonde reconnaissance

$0
$2,000,000
$4,000,000
$6,000,000
$8,000,000
0
50,000
100,000
150,000
200,000
annual flight-hours
t
o
t
a
l annual c
o
st
[
U
S$
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0
25
50
75
100
125
dialy soundings @ 4 flt-hr/sounding
3 bases/1 control station
600 flt-hr average A/C life
US$30K lifetime A/C cost
1200 flt-hr average A/C life
US$20K lifetime A/C cost

Figure 6. A reconnaissance program along the lines illustrated in Figure 5 would cost a few million dollars per year, depending upon the scale of operations and the aircraft lifetime

actually achieved. A few tens of millions of dollars per year would fund a set of such programs extending cyclone reconnaissance and targeted observations over the oceans worldwide. The figures here bracket the likely range of costs and lifetimes. To determine actual average lifetime - and to optimise it - there is really no alternative to extensive service experience.

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new company, Aerosonde Robotic Aircraft (http://www.aerosonde.com/), has been formed in Australia to explore its potential. Meanwhile Insitu and the University of Washington are moving on to development of "second-generation" Aerosondes (Figures 4, 5), offering the reliability, economics, and performance necessary for routine long-range operations in meteorology and other applications. The full development program through field testing and setup for production could be completed in about two years at a cost of about $4M dollars. A subsequent annual expenditure of a few tens of millions of dollars per year would be sufficient to maintain comprehensive sampling over the world's oceans. This level of expenditure looks fiscally realistic compared with current weather-balloon spending of about $100M annually.

Mission characteristics in routine service

We envision that, in routine weather reconnaissance over the oceans, Aerosondes would fly about 10^6 flight-hours per year worldwide. At a loss rate of, say, one aircraft every ten missions, there would be about 100 Aerosondes flying weather reconnaissance at any given time. Likely characteristics of these missions are as follows.

horizontal acceleration while flying through a thunderstorm
at lowlevel; 22 m/s commandedTAS
-3
-2
-1
0
1
2
3
36550
36600
36650
36700
36750
36800
sec after midnight UTC 24 Jan 98
ho
ri
zo
nta
l
a
ccel
era
ti
o
n
[g
]
east
north
10.3 kg gross weight
20-40
mm/hr
10 m/s
sink
25 m/s (?)
gust on ground

Mr Freeze at Port Hedland

winds measured by Mr Freeze
-20
-15
-10
-5
0
5
10
35600
35800
36000
36200
36400
36600
36800
sec after m idn ight UTC 24 Jan 98
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Figure 7. Hurricane reconnaissance has been a major objective of Aerosonde development since early in the program (Holland *et al*. 1992, McGeer 1993). There was some early scepticism about the theoretical case for survivability, but actual experience has been reasonably convincing. The plots here illustrate one of several encounters with severe thunderstorms during 1998 field trials, this one by Aerosonde *Mr Freeze.* With the aircraft orbiting just a few hundred metres above the launch site in Western Australia, we 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 very small-scale gusts, 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* - only to be struck down in the end by water ingestion through the carburettor. An intake shield fixed that problem for a subsequent storm encounter over the South China Sea.

□ **supervisory control from a remote station via a low-rate data link**

In routine oceanic operations, the current line-of-sight link for enroute control would be replaced by a low-rate satellite link. Data would be routed by telephone from satellite gateways to a central station, which would be responsible for supervisory control of many aircraft simultaneously. This station would pass position and other data to air-traffic services, and weather data to users. Data would be in the form of brief messages sent a few times per hour,

2000
4000
6000
8000
10000
12000
86500
87500
88500
seconds after midnight UTC 23 April 1998
icing sensor frequency [H
z
20
40
60
80
100
120
relative hum
idity [
%
base frq
(bare &
dry)
0.5mm ice
ice chips lodged
on edge of
membrane?
melting
<base frq due to
water loading
0.2mm rapid
accretion in climb
above freezing level
base frq
(bare & dry)
slight frq drop due
to mass loading by
a few supercooled
droplets?
comm fade
2000
4000
6000
8000
10000
12000
86500
87500
88500
seconds after midnight UTC 23 April 1998
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attempt to
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due to icing rate
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clim b above icing
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2000
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87500
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d
[
m
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]
overspeed in
turbulence
high speed for
rapid descent
minimum speed
for best clim b

Figure 8. Attrition in Aerosonde field trials has been high, but mainly because of design weaknesses which will be eliminated in a version for routine service. We believe that icing will then remain as the dominant factor in attrition, as it was (we suspect) for the two losses to date that cannot be attributed to technical faults. Those two might have been saved had they been fitted with icing sensors, as were Aerosondes flown off Vancouver Island in a 1998 trial for Environment Canada. Here the sensor - a peizoelectric membrane ringing at its natural frequency - measured rapid accretion on Aerosonde *Fester.* (This occurred upon descent into cloud, as indicated by the jump to 100% humidity in the upper-left-hand plot.) The

information was used to alert the ground controller, but aircraft in routine service would have to respond on their own with some combination of reversing course, changing altitude, and then trying the original course again. Appropriate techniques will be worked out through simulation and trials in the second-generation development program.

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or otherwise when triggered by events on the aircraft or by the need for a command from the ground.

 round-robin basing

Aerosondes are slow, with a cruise speed of 40 kt or so, and consequently can cover much more ground when routed downwind than otherwise. Consider for example reconnaissance in the NE Pacific, which is of considerable interest to the US National Weather Service. Aircraft flying out-and-return from the west coast would usually face strong headwinds on the outbound leg, and so be relatively limited in operating radius. A more attractive possibility would be to circulate aircraft among bases on the west coast, Hawaii, and the Aleutians (Figure 5). Typical winds are such that the whole NE Pacific would usually be within reach of aircraft flying this circuit; out-and-return and reverse-circulation missions would only be used infrequently.

 automatically-generated diverse routings

Areas of most interest to weather forecasters vary from day to day. Contemporary forecast models can calculate the sensitivity of a forecast to data from any given area (*e.g.* Szunyogh *et al.* 1999), and Aerosonde routes would be varied from day to day to maximise the value of data returned. We envision that these routes would be planned automatically (on the ground), using optimisation algorithms accounting for forecast sensitivities, aircraft performance, icing, and air-traffic constraints.

 altitude cycling

To afford a significant forecast benefit, Aerosondes would have to collect data through the atmospheric column rather than at a single level. Hence flight profiles would often involve continuous cycling from minimum altitude (say 200 ft to stay clear of ship masts, icebergs, *etc.*) to 20,000 ft or so, and in some applications perhaps to more than 40,000 ft. These cycles would be constrained by air traffic and icing.

 autonomous re-routing (within specified bounds)

Aircraft would have some limited ability autonomously to adjust routes, for example upon encountering icing or a strong headwind. In the case of icing, the re-routing would entail some combination of a backtrack and altitude change before proceeding en route (*cf.* Figure 8). Another routing problem would arise in tropical-cyclone reconnaissance. Aircraft flying cyclone reconnaissance would be programmed to keep station relative to the storm using their onboard wind measurements. Stationkeeping might be done in the eye or while orbiting the storm at some radius. (McGeer 1996b, Tyrrell *et al.* 1999)

 the "Aerosonde rain"

We noted earlier that high attrition would be expected in routine service, that is, most aircraft would be lost at sea after a few missions (mainly due to icing, we suppose). One would have to ensure that the associated hazard to ships, *etc.*, would be acceptably small. It turns out (McGeer 1994, Vagners *et al.* 1999) that, with a "rain" of 1000 Aerosondes per year, the collision rate

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with ships in the open sea would be about one every 200 years or so. This seems acceptably small relative to other oceangoing hazards.

Regulatory issues

Aerosonde operations, like operations proposed for other new unmanned aircraft, raise novel issues of regulatory policy, and discussions of these issues in various jurisdictions over the last decade have yet to lead to firm standards. The concept of acceptably small risk, in our view, should serve as a point of departure.

Familiar manned-aircraft regulation is designed essentially to achieve an acceptably small risk to people and property

- onboard the aircraft;
- in other aircraft;
- on the surface.

The majority of existing regulation addresses the safety of people onboard, and in taking care of them it takes care of those on the surface as well. But with autonomous aircraft the onboard problem vanishes, and consequently a lot more diversity is possible than with manned aircraft. That is, with a manned aircraft you have to build to the same standard no matter what is underneath you, but among unmanned aircraft, acceptable safety for flights exclusively over oceans can be achieved with rather more rickety machines than would be fit to fly over a city. Hence the abundance of possibilities which everyone recognises and is struggling to manage. Diversity calls into question the conventional approach of mandating specific design techniques, load cases, redundancy levels, equipment, and so forth. An alternative might be to specify instead acceptable *levels of risk*, while being receptive to diverse solutions for achieving those levels. The authorities in Canada[1] and Australia[2] have circulated preliminary ideas consistent with this concept. Over the next few months, we contemplate developing a thorough risk analysis for Aerosondes to serve as a test case and model (Vagners *et al.* 1999). This analysis would aim to define limits on density of aircraft and surface "targets", below which operations could be conducted with acceptable safety.

Elementary midair collision risk and mitigation

We have mentioned a surface-hazard result from an elementary risk analysis. We can also add some elementary midair collision results (McGeer 1994). It turns out that if Aerosondes were distributed through some region at the density of radiosonde balloons now flying over the continental US - and distributed *at random*, that is, with absolutely no effort at separation - then from the point of view of a transiting aircraft the collision probability would be (as it is now for radiosondes) about 10^{-8} per flight-hour. Meanwhile for transport-category aircraft a

[1] Minutes of Non-Piloted Aircraft meeting chaired by Arlo Speer, Chief, Recreational Aviation & Special Flight Operations, Transport Canada, Ottawa, 22 May 1998.

[2] *Guidance for unmanned aerial vehicle (UAV) operations, design specification, maintenance and training of human resources.* Civil Aviation Safety Authority draft, September 1998.

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catastrophic-failure probability worse than 10^{-9} per flight-hour is generally considered

unsatisfactory, so 10^{-8}/flight-hour collision risk is too high - but only by an order of magnitude.
The necessary order-of-magnitude improvement - plus several orders of magnitude more - can readily be achieved by making the Aerosonde distribution non-random.
The basis for effective separation is precise knowledge of aircraft position, which is continuously determined onboard by GPS. At present it is also reported continuously to the ground station. Reporting will be reduced to several short messages per hour on long-range missions with satellite relay, but the ground-station software will run an estimator during the intervals between messages. Flexibility of operation will depend upon how effectively the position information is applied. We foresee application in three levels:

- **Avoidance of busy airspace**

Aerosondes are primarily required over oceanic and remote areas, where low-altitude traffic is essentially nil, and high-altitude traffic operates on well-defined IFR routes. These routes can be avoided reliably, without undue complication or restriction in flight planning. Operations near coastal bases are likely to be more constrained, but, as in our work to date, bases can be sited where activity is light and transit corridors easily arranged.

- **Data communication with ATC**

A real-time data link for position reports and traffic advisories can be established between the Aerosonde ground station and the ATC computer network. Aerosondes could then be controlled much like manned aircraft, and separation reliably maintained in areas wherever ATC tracks the large majority of traffic.

- **Independent surveillance**

The definitive technical solution will be active collision avoidance independent of ground control. A Swedish system has demonstrated mutual avoidance based on local broadcasting of GPS position (Nilsson 1992), and similar work is underway in the US (Proctor 1999). The technical and economic strengths of such an approach make a compelling case for universal adoption. (The cost might be a few hundred dollars per aircraft, and arguably it would be economical for government, or industry, to pay for installation on every aircraft flying rather than to spend large sums on maintaining TCAS or developing an alternative system.) Such a system will not be operational for some years, but once in place it should allow operations almost everywhere.

Safety benefits from wide-scale use

In weighing an acceptable level of risk for Aerosonde operations, one must also consider the risk of *not* doing operations. In particular, we are now suffering a safety penalty - not least in aviation, but also in many other fields - through lack of offshore data for weather forecasting. Thus if, for example, it was proposed to exclude Aerosondes from some oceanic airspace due to some potential for traffic conflict, the risk of conflict would have to be compared with the risk associated with loss of forecast data from that region. Similarly, if a regulatory proposal were made with implications for higher costs (and hence reduced operations) then again it would be

necessary to compare the effects on collision risk and forecast quality. We look forward to discussion of how to draw these lines as the policy process proceeds.

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