A PROPOSED EXTRA INTERNATIONAL AIR TRANSPORT CORRIDOR ALONG THE WORLD'S EQUATORIAL BELT

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ABSTRACT

The combination of some recently developed technologies make possible the concept of an inexpensive, environmentally neutral form of intercontinental civil aviation. The main disadvantage of the proposed system is that it would be about 3 times slower than current methods. It is also limited to an air corridor within the world's equatorial belt.

It is considered that the concept merits consideration for the air freight market in the first instance with the ultimate intention of providing much cheaper air transport for passengers.

The concept originated from an inquiry into the possible use of underutilised flat land in airports which could conceivably also be used for growing algae. Growing algae is one of the most promising approaches we have for finding alternative liquid fuels to replace liquid fossil fuels.

The proposed airport-based 'race-course' algae ponds could also be used to cable-launch 100 tonne seaplanes to 1000 m altitude using a development of the Supacat winch used by today's gliding clubs.

At a height of 1000m, a suitably designed aircraft would be able to use extensive bands of cumulus clouds for 'cloud hopping'. Geostationary and 'polar'satellites provide real-time data of cloud cover worldwide. By equipping an aircraft with 94GHz doppler radar and a longer wave-length radar, together with instrumentation in the optical range, a pilot can select the most suitable clouds to gain height and collect water. This water is needed to produce the small quantity of supplementary 'hydrogen on demand' for the aircraft. This radar system would allow a pilot to assess and choose local clouds for spatial location of updraft, downdraft, turbulence and any precipitation.

The aircraft would need to be specially designed. For example it would use longer Fowler flaps which would also be adapted to collect water droplets from cloud at the flaps' trailing edge. The strong delta-shaped wing would be designed for a low stalling speed with increased slots to reduce separation by energising the boundary-layer at the wings upper surface. By continuous use of flaps during flight it would be able to tarry within a suitable cloud formation when necessary. Energy use efficiency is relatively unimportant.

The aircraft would only need its own propulsion occasionally. Two very small hydrogen-fueled turbofans, mounted high, would use hydrogen, generated on demand, using the system developed by Power Ball Technologies. This company has developed plastic encapsulated balls of sodium hydride which can be sliced open to produce a controlled flow of hydrogen from reaction with water. The sodium hydroxide by-product would be stored in the aircraft's wings to be recycled later to manufacture 'power balls' within the airport's precincts. The energy requirements and all other materials for this process can be provided from the algae grown.

Apart from using algae race-course ponds at conventional airports to launch, land, service and moor these aircraft, it also seems feasible to use suitably-adapted ships, in sheltered waters, such as in the Indonesian Archipelago, for the same purpose.

Despite its radical design compared with today's aviation technology, there is good reason to believe that it will be possible to develop it into a much safer aviation system than we have at present. There would be no danger of incineration of the aircraft by kerosene and at its maximum operational height of 5000 metres, passengers could survive a serious mid-air mishap. This is impossible with the present-day cruising altitude of 10000 metres and air temperatures of -40 degrees Centigrade. The seaplane version also seems to be the more attractive approach from the safety point of view.

This form of aviation would be environmentally neutral with regard to the greenhouse gas water vapour. With regard to CO2 it would even be a significant CO2 atmospheric scavenger. This is because the supplementary energy source is derived from algae and all the CO2 produced in the process would be recycled directly for absorption by the algae.

Strangely this form of proposed passenger travel is reminiscent of the 1940's flying boat service from London to the Far East. This was also equally slow but much more comfortable compared with today's economy class travel. However the technology proposed here to achieve this more pleasant form of travelling is completely different.

KEYWORDS air corridor; cumulus clouds; meteorological radar; satellite cloud cover; sustainable energy; civil aviation

1 A BIT OF HISTORY AND ITS POSSIBLE IMPORTANCE FOR THE FUTURE

About 40 – 50 years ago the Author remembers reading an article in one of the popular science journals (Was it the New Scientist?). This article advocated the exploitation of cumulus clouds for international air travel. Since this time our science and technology has advanced by 'leaps and bounds'. Also, and much less desirably, the same sense of progress applies to some of our worsening environmental problems. Is it time to reconsider the technical feasibility of 'cloud hopping' aircraft?

The concept described in this present paper arose, in a somewhat serendipitous way, from a 'routine' investigation into the possible use of much wasted space in the precincts of major airports. The long lengths of underutilised flat land at airports seem to be ideal for growing algae in 'race-course' ponds. The original intention was to use the algae harvested to produce petroleum fuel substitute. In this study(1) it was proposed to use pyrolytic oil generated from the algae harvested. Although this oil cannot be used directly for aviation purposes, the race-course pond approach has the distinct advantage of much lower capital investment requirements compared with the use of closed photobioreactors to produce a more directly-useful oil feedstock.

While investigating the possibility of cloud hopping civil aviation, the Author was unable to find a feature which showed that the concept was impractical. However there is also much greater uncertainty as to whether the Author's present suggestions are the best way to go in exploiting this future energy source. This is an energy source which is both secure and also environmentally sustainable for present-day civil aviation. As an example of this type of problem, this paper describes two quite different possible scenarios which have emerged. Only a much more detailed numerical analysis than can be given here would clarify which is the more profitable path to take. Nevertheless the concept discussed here is, at least, an all-embracing and comprehensive one. It has a distinct advantage for further exploration in that it is a fully integrated proposal.

We are facing the very pressing need to find a more sustainable form of civil aviation for the future and we need to start our investigations somewhere. It is in the light of this reasoning that this paper is submitted to the triennial conference of WCTR.

2 THE PROBLEMS FACING CIVIL AVIATION TODAY

Civil aviation accounts for about 7% of liquid fossil fuel consumed. Also at least 25% of any airline's direct costs are for fuel and this proportion can be expected to rise in the future. Aviation is a major contributor to the emission of CO_2. Its dispersal in the upper atmosphere is much more damaging than dispersal of CO_2 produced at ground level.
At the typical cruising altitude of 10 000m, the condensed water vapour from a jet airliner's engines (the "contrails") is also a very significant greenhouse gas because it persists in the upper atmosphere much longer than when emitted at sea level.. The upper atmosphere is very dry and lacking in adequate turbulent transfer which aids natural cleaning and drying. All pollutants emitted by an airliner may together have 2-5 times the greenhouse effect of CO2 alone(2) . However, the present consensus of scientific opinion, which is still somewhat uncertain, seems to indicate that water vapour in the upper atmosphere is much less persistent than CO_2.

Air transport is one of the fastest growing industries, expanding in some areas at about 7% annually. Yet its future is uncertain and it depends critically on achieving social and environmental acceptability. At present it enjoys a very privileged position in that all aviation fuel is untaxed. Inevitably it will have to accept future international regulation with regard to emissions. Yet civil aviation is a vital and large part of modern society. It is also extremely vulnerable to any economic downturn. It has to persuade customers to pay significant airfare costs. Its very profitable Business Class, mainly intended for company executives, also has to face serious competition from improving teleconferencing, for example.

2.1 Where We Need to Make Changes to Develop a Non-Polluting Airliner

Ideally a minimally-polluting aircraft should run on hydrogen fuel but, hitherto, this has been thought to be impossible because of weight and other considerations. Anyway, the much touted 'hydrogen economy' is a non-starter because it is uneconomical(3) to make hydrogen from fossil fuels. Perhaps, one day, cheap hydrogen will become obtainable from nuclear fusion or from special algae but both these technologies are still at a very early experimental stage(4).

CO_2 produced on take off and landing is less damaging environmentally because it is emitted in the lower atmosphere where it can be recycled more easily by natural processes. Ideally we should sequester this CO_2 but this is impossible with conventional aircraft. Also, apart from its emissions, the modern turbofan jet engine is very wasteful energywise as a means of getting the aircraft launched. Also these heavy powerful engines are only required at take-off: much smaller engines are sufficient for cruising.

Fuel economy considerations dictate that today's conventional jet aircraft must operate at 10 000m but at this height passengers cannot survive a serious mishap at an outside temperature of -40 degrees C. Would it be possible to use airspace of the lower atmosphere which is also still relatively uncongested?

Optimising a new aircraft design is a huge, slow and costly exercise well beyond normal resources. It can only be undertaken by one of the largest aircraft-manufacturing companies. Consequently the best that can be done at this early stage is to make what appears to be a sensible guess at the final design.

Let's presume that tomorrow's airliners will still be wide-bodied but at about 100 tonnes all-up weight compared with a 747 at 400 tonnes. Let them take-off using a winch launching system and have very small twin hydrogen-fueled turbofan high by-pass engines. Let these engines only be able to maintain level flight at about 80% of full power. Almost all of the in-flight energy needs can come from using the energy from cumulus clouds in the Earth's equatorial belt by a system of planned cloud hopping.

The cumulus cloud is a unique form of renewable (sustainable) energy because it is a natural form of energy concentration. Other forms of energy exploitation such as solar and wind farms are 'dispersed' and lack this most desirable attribute of energy concentration. Like coal and petroleum which are also naturally-concentrated forms of energy, the cumulus cloud is especially attractive but it also has the added advantage of being renewable.

All this suggests that the World's main future transcontinental air corridor may be East-West and vice-versa and near the Equator. These aircraft would use advanced communication systems and at least 2 different radar units. Internationally-based air flight control will need to be completely computer controlled because of the complexity facing human operators. Global positioning and other (especially weather) information, already available from geostationary and polar orbital satellites, would be necessary.

2.2 A New Launching System and Take-off

These aircraft would be unable to take off under their own power. The most attractive system for take-off seems to be the winch/cable method similar to that which is used by gliding clubs. For example, the Supacat glider winch[5] can launch up to 16 gliders/hour to a height of 400m. using a 200kW diesel engine. Of necessity the winch is heavy and needs to 'dig its feet in' or the glider can pull it backwards. . This problem would not occur with the present proposal because the winch would be a permanent fixture on a concrete base. The Supacat launching winch uses a 1 metre diameter drum for its 1000m long cable. A variation of this basic design is illustrated in fig(1).

A specification of 12 aircraft launches per hour to 1000m altitude seems reasonable. The winch would be powered by a large industrial gas turbine which could have a maximum power rating which may be as high as 15MW. This is a big unit but it is not unreasonable in size for its task compared with the big turbofans it replaces. The largest commercially available gas turbine known to the Author is a unit rated at a massive 340 MW! The gas turbine would be housed in a sound-proof building A in fig (1) in order to take advantage of this noiseless form of take-off. Because of its size and cost, it is suggested that this turbine should also be used to drive a peak load electrical generator when not launching aircraft. The turbine could run on crude i.e. unrefined pyrolytic oil from processing the algae[1]. Its exhaust would be scrubbed and the effluent returned directly to the algae pond as nutrient. The turbine supplies power to a hydraulic drive B for the winch drum. This drive is outside the turbine building. Like the Supacat, the winch drum can swivel slightly on its concrete base to accommodate the effects of strong cross-winds. The drum drive gearbox delivers a high tension pull initially to cause the aircraft to aquaplane and then changes to give the high speed/lower tension for take-off when the aircraft is 'planing' along the algae pond surface. This system would have the advantage that a malfunction, such as a broken cable C, would occur at a safe time, i.e. before the aircraft became airborne. After launching all the aircraft, which would, most likely, be an early morning event, the cable would be pulled sideways by a service vehicle on to the algae pond bank. This would allow the same pond to be used for 'landing' aircraft (most likely an evening event) and it would also allow routine inspection of the launching cable. It is suggested that a launch acceleration of up to 1 g would not be excessively exhilarating, even for elderly passengers, as everyone would be strapped in their seats as is normal at take-off.

It so happens that the proposed launching cable (C/C*) is very similar to that suggested for the tow-rope suggested in ref (6). Consequently it is not necessary to describe it here.
It will be seen in fig (1) that this system also uses a high-speed rewind cable (D/D*). This is of much lighter gauge and would be best powered by an electric motor F. A drogue parachute (E) is used to stabilise the cable during re-winding.
A set of small tow-boats on the algae pond would be used to position airliners for take-off and dock them to their overnight moorings after landing.

2.3 On Site Manufacture of Fuel

There are a number of possible alternatives for the occasional 'hydrogen on demand' fuel required for a 'cloud hopping aircraft'. A useful simplified review of the different systems worth consideration can be found in ref(7). The boron hydride fuel family may seem attractive because of their inherent safety qualities but cost and large-scale availability problems are of concern. It is suggested that the Power Ball Technologies system of producing hydrogen on demand[(8)] may be the best option. Some simple engineering design (see later discussion on emergency crash landing) can produce a fuel system which is equally safe. The Power Ball system was originally conceived for hydrogen-powered cars[(9)]. Power Ball have produced a well-developed technology which has the advantage of an independent review for technical feasibility[(8)]. The system uses 40mm diameter plastic-coated balls of sodium hydride. These are sliced open mechanically and injected into water to produce hydrogen at the rate required[(10)] . The 'fuel' can be regenerated in the airport precincts as is described in Appendix I.

2.4 Design of the Aircraft and its Method of Flight

Electrical power supplies for the aircraft are best supplied by a fan-driven wind generator located in the tail. However, it is likely that safety requirements in a final design would dictate the use of twin generators located in the base of the tail-plane. In either case the generator(s) would contribute to the aircraft's aerodynamic stability and be efficient and sufficient for all the aircraft's needs.

These aircraft would use their wing flaps continuously throughout their journey. Today's airliners make most use of flaps only on take-off and landing. Although these proposed aircraft may be considered to be gliders, the similarity with existing gliders is limited to the launch/take-off system. The low Reynolds Number[(12)] high lift/drag ratio wings of conventional gliders have no application. A structurally-strong wing similar to that in a conventional airliner is needed . A delta-shaped wing is recommended. However it would use somewhat longer Fowler flaps which would also incorporate a moveable retractable trailing rim conveniently located on the trailing edge of the Fowler flaps to catch water when moving through cloud. Fig.(2) illustrates the system. Aeronautical engineers will recognise this as a special form of the so called 'tabbed' Fowler flap.

It is considered that a high lift/drag ratio wing is less important than a wing with a low stalling speed at high lift. This arises because the energy for flight is mainly free environmentally-available energy. Energy use efficiency is a less important criterion in this application. The ability of the aircraft to tarry and gain height or water in a suitable cloud formation is considered more important. Hence the use of a wing with the ability to maintain a low stalling speed. This is best achieved by using enlarged closeable slots to energise the boundary layer of the upper wing surface to prevent separation.. Today's airliners have a glide ratio (this is the horizontal distance flown divided by the distance of free-fall and equates to the lift/drag ratio) in the range16-18. The low stalling speed requirements also suggest the use of Krueger flaps at the wing's leading edge.

The preferred system of de-icing is with inflatable pneumatic boots at the wing leading edge but other systems, which are still in the early development stage(13) may have application. Routine thermal de-icing is too energy-consuming but supplementary emergency systems can be incorporated either using the engine heat or diversion of full electrical power to aerodynamic surfaces.

Two recent technological advances are extremely important and contribute to making cloud-hopping aircraft feasible.

Firstly, as far back as the 1990's(14) we had sufficient geostationary satellite capacity to give 4km wide resolution of all the equatorial cloud cover on the Earth These together with present day polar orbit satellites give much more detailed information on worldwide cloud cover. This information can be considered to be in real time for practical purposes.. All these data can now be fed into a centralised land-based computer system and an aircraft can access this information by radio for assessing cloud cover in the aircraft's vicinity. Apart from information in the visible spectrum, the infra-red data also estimates cloud height from the temperature of the top of the cloud. An estimate of the size and height of the cloud is necessary for 'in-flight' planning. Data for further away can also be assessed for 'in-flight' flight planning. Global positioning by polar satellite is also available worldwide so that the aircraft computer system, which has limited capacity, can process the data of immediate local interest and, alternatively, additional data for flight planning as is required.

Secondly we now have reliable and compact Doppler radar systems for collecting detailed information on cloud formations(13). Of particular interest is the combination(14-16) of 3mm wave length (94GHz) Doppler radar with 915 MHz 'wind profiler' radar. A 915 MHz radar would be far too large for the aircraft envisaged. A similar dual-frequency (see Appendix II) system (say 94GHz/20GHz) can enable a pilot to have a clear picture of any cloud formation in the aircraft's vicinity. For daytime flying optical wave length instrumentation supplements this information. This real-time information, which is continuously available, includes data on updraft and downdraft atmosphere velocity in the cloud, its turbulence characteristics and any precipitation. The data as presented in the paper by Kollias et.al.(15) are not in a form suitable for an aircraft pilot but it is reasonably straightforward to devise algorithms and software to present these data in a form suited to the cockpit consoles in front of a pilot/navigator in charge of an aircraft.

Fig (3) illustrates a typical expected sequence of pilot control. On the left side of fig(3) the pilot/navigator uses a fairly weak cumulus cloud to gain height and collect water by spiralling . At B (not shown) he avoids a cloud which his radar system shows to have excessive turbulence but enters another cloud system at C . His radar indicates a typical downdraft of 2m/s at the cloud's edge so he enters the cloud system inner edge as quickly as possible to acquire a typical updraft of 8 m/s around the periphery of the cloud system which carries him to a maximum height of 5000 m which is the operational ceiling of the aircraft. He then leaves the cloud and adjusts the aircraft flaps to glide towards the next convenient cloud formation. Typical satellite input data received into the aircraft's computer are shown in figs (4-5)

Landing on an algae pond or other sheltered water, although with limited engine power, would benefit from the low stalling speed design of the wing. The fuel is safe, in the event of a crash in that, unlike kerosene, it cannot catch fire. However, it is desirable that the highly caustic NaOH stored in the wings, is not allowed to spill, Consideration may be given to using emergency explosive bolts to detach the aircraft's wings just prior to a crash. A suitable triple-gated safety system would be for the pilot to first authorise the sequence giving control to a low level altimeter which opens a further gate when altitude is less than 10 m. This final gate allows a sensitive decelerometer to fire the bolts at the first impact deceleration on touch -down.

2-5 Air Traffic Control and Integration with the Existing System

It is envisaged that Air Traffic Control (ATC) should be an international system and entirely computer controlled. It would be far too complex for direct human involvment. In addition to global position data, geostationary and polar satellites transmit meteorological data on cloud cover continuously to 'nodal' ground stations along the Equator. The nodal stations overlap and check each others peripheral data. This integrated air flight control (more aptly described as air-flight guidance) would be a STAR (self testing and repair) system to ensure 100% reliability. This information from relevant nodes is received by the pilot/navigator who plans his route. The information on this route is relayed back automatically to the Air Traffic Control System which thus knows the status of every aircraft within the system. Proximity of nearby aircraft would be advised automatically from the ATC system but there seems to be no reason why this information should not also be available from the radar system in the aircraft.

As is illustrated in Appendix III it appears that the presently existing satellite data acquisition system is sufficient for the equatorial air transport corridor proposed. The only extra requirement is the nodal data relay stations which have the prime task of filtering out unwanted data and ensuring accuracy of the useful data.

Apart from using the same airports (and the airspace around them below 5000 m) there would be no need to integrate the proposed system with existing air traffic control for conventional present-day airliners. One advantage of cloud-hopping aviation is that take-off and landing activity is likely to be compressed into early morning and evening time slots.

2.6 Another Way (one of several!) Using Merchant ships as an Alternative to Land-based Airports

So far in this paper, consideration of the scheme has been restricted to launching the aircraft from land-based airports. A less expensive possibility is to adapt or retrofit ships so that the ship's engine can also be used to winch-launch these aircraft. At the time of launching an aircraft, the full power of the ship's engine can be used for launching. The ship would be stationary and it wouldn't even need to anchor during this operation.
However, most available shipping would be underpowered for launching 100 tonne aircraft if the previous specifications are adhered to. This suggests that an alternative 30 tonne air freighter may be a more attractive design. Moreover recent advances in military technology with unmanned aircraft suggests that pilotless air freighters launched and serviced by merchant ships may be a much preferred initial development. It is surpising how much technical information concerning the Predator pilotless (more accurately described as unmanned/unoccupied as the aircraft is piloted remotely) aircraft is now effectively declassified and within the public sector. This technology can be adapted for civilian use.

3 SUGGESTED ROADMAP FOR DEVELOPMENT OF THE CONCEPT.

Stage 1: Preliminary detailed analysis.

In the light of the discourse above it is obvious that a far more detailed theoretical analysis of this proposal is required before embarking on any experimental development work. Estimates of costs, returns, choice of radars, telecommunication specifications etc. are needed. In particular which is the best system to develop? Could it be algae ponds at existing airports or smaller ship-launched pilotless aircraft or could it be some other system?. Significant reviews of the different areas of technology are still needed as is the need to establish a team of specialists who can communicate with each other and work together effectively.

Stage 2: Experimental Work

If, as seems likely to be the case, the ship-launched pilotless-freighter based on 'Predator' technology seems to be the more attractive commercial proposition, then this would also be a very convenient way to embark on development in this area. In order to gain experience, pilotless prototype aircraft would need to be flown by a human test pilot sitting in the aircraft so that a wider range of experiments can be carried out. These prototype aircraft also need to be equipped with dual-fuel gas turbines running on hydrogen or kerosene. Gas turbines with hydrogen content in the range 9-61% work well but experience is needed in using them in this application.

Stage 3: Establishing a Profitable Air Freight Network

Stage 4: Adapting the Air Freight System for Passenger Travel

Despite the fact that passenger tickets would be much cheaper using cloud hopping aviation, naturally the travelling public would not accept this form of transport until it had achieved a good and longstanding safety record in the air-freight arena

4 SERVING THE VARIOUS ECONOMIES OF THE WORLD

By today's standards, one major and obvious criticism of an equatorial air corridor is that it cannot serve directly the existing major economies of Europe and North America. However the emergent super economies of India and China are better placed. Certainly the equatorial air corridor would benefit commercial development in central Africa and South America. However, to be really valuable in a future world economy, this air corridor is seen as part of an integrated transport system. The likely direct involvement of merchant shipping has already been mentioned. Perhaps North America and Europe could be served with a connecting high speed rail network because this is a very energy-efficient form of transport particularly in the large scale system envisaged? The Equator is potentially a good source of renewable energy. Perhaps much of the energy for this rail system could be algae-based for North America and powered by Saharan solar energy for Europe?

5 THE FUTURE CONTRIBUTION WHICH COULD BE PLAYED BY CIVIL AVIATION IN SEQUESTERING CO_2.

About 30 million tonnes of air freight are carried annually. If much of this could be carried in a CO_2 sequestering system as described here, this would help the aviation industry to acquire much credibility in environmental management. It would relieve some of the pressure of criticism relating to conventional airliners. Ultimately the goal is to find a form of passenger travel which is much cheaper and also with a lower polluting footprint.

6 AN OVERALL VIEW OF THE ULTIMATE OBJECTIVE

Few of us can remember when air travel was 3 times slower and much more leisurely than it is today. The Author recalls in the late 1940's travelling on the flying boats from U.K. to Mumbai for school holidays . Apart from the turbulence flying just a few metres above the Libyan Desert, it was pleasant and luxurious compared with the cramped conditions of today's economy class travel. We also had a bed to sleep in at night.

Environmentally and technically the old flying boats have nothing to offer but the new system proposed here is environmentally neutral when cruising, taking in just as much water vapour as it emits. During take-off it can even be considered to scavenge CO2 from the atmosphere by absorption into algae because algae is its only man-made energy source which is used. NOx emissions are also easily controlled because surplus collected water can be injected into the gas turbines when they are used.

Perhaps the most important consideration of all is that this proposal is potentially a very cheap form of air transport with minimal fuel costs. The reasons for the downfall of Concorde versus the success of the 747 is a part of our aviation history which is worth bearing in mind when we look towards future development.

As a means of emphasising the apparent importance of this new technology it seems appropriate to quote some recent words of President Barack Obama stated on November 26th 2009:-

"It is a moral imperative that we do something about (climate change) so that we can leave to our children and grandchildren a liveable planet"

<u>APPENDIX I :</u> 'FUEL ON DEMAND' RECYCLING/MANUFACTURE IN AIRPORT PRECINCTS

The hydrogen on demand in the aircraft is produced by the well-known reaction :-

$NaH + H_2O = NaOH + H_2$

The sodium hydroxide by-product[10] would be stored in the aircraft wings to be recycled later to make more NaH after the aircraft has landed. It is envisaged that the regeneration of fuel would take place adjacent to the algae ponds within the airport precincts.. The energy requirements for the process would come from algae-generated pyrolytic oil[1] but a portion of the algae harvested would be digested anaerobically to produce methane which is needed for fuel regeneration. The process can be summarised by the equations:-

$NaOH + CH_4 = Na + CO + 2.5\ H_2$ and

$2NaOH + CH_4 + O_2 = 2NaH + CO + 2H_2O$

but there are several stages to the regeneration process[8] which is more complicated than these equations indicate.

It appears, however[8] that there is no reason why the manufacture of the 'powerballs' cannot take place adjacent to the algae ponds in the airport precincts.. In this way effluents (mainly CO2) can be recycled easily as nutrient for algae production. Because these algae ponds would be near the Equator, the growth rate of the algae is not subject to seasonal change. This is a most important convenience in the design of an industrial facility.

Most of the water required to generate hydrogen in flight would be acquired from the surrounding atmosphere (the wing structure to achieve this is illustrated in fig (2)). Examination of fig. (1) in ref (11) shows that this is feasible. Fig (1) in this document [(11)] shows that the typical atmospheric mixing ratio (mass of water vapour/mass of air) varies between 10^{-3} kg/kg at an altitude of 5000m to a value of about 10^{-2} kg/kg at an altitude of 1000 m. These altitudes are the operational cruising limits of this type of aircraft. In this way only a small reserve tank of water would be needed in the aircraft wings

APPENDIX II : THE AIRCRAFT'S DUAL FREQUENCY RADAR SYSTEM
The purpose of the dual frequency radar is to have differential radar penetration into the cloud and also to be able to assess the characteristics within the cloud. These required characteristics are peripheral updraft, downdraft, turbulence and state of water droplets. The proposed system resembles, in some respects, existing weather measuring radars.

For a particular situation the Rayleigh backward (reflected) scattering (t) of radiation given by a single water droplet is given by

$t= Ad^6L^{-4}$
where A is a constant for a particular situation, d is the scattering cloud particle diameter and L is the wave length of the radar beam given by Lf=c where f is the radar frequency in Hz and c the velocity of light. In this non-coherent situation the reflected signal is additive for all particles illuminated in the radar beam. Because the reflected radar signal is so strongly proportionately dependent on cloud droplet size d to the sixth power and so strongly dependent on the radar frequency to the fourth power much information about the cloud dynamics can be inferred from reflected relative radar signal amplitudes. A Doppler radar also allows velocities within the cloud to be measured by beam scanning and the measured accuracy improves as the cloud is approached.

In passing it is worth commenting that today's research climatologists would have welcomed the wealth of useful data from commercial cloud-hopping aircraft. There are plans to use similar radar systems in satellites. This is prohibitively expensive compared with the data which would have been a valuable by-product from a cloud-hopping aviation system.

Modern high frequency radar equipment is compact, lightweight and has sophisticated data processing systems and can also use polarised beams. Optical vision is also, in principle, a third radar system with zero cloud penetration.

APPENDIX III CURRENTLY AVAILABLE SATELLITE DATA
Fig (4) shows typical cumulus cloud cover data along the Equator obtained from satellites. Two very large cyclones can also be seen.. A pilot would avoid these by flying to the North of the equatorial Hadley cells where the cloud cover is benign but still adequate. In the other six months of the year, similar bad weather detours would be to the South.

Fig (5) shows more detailed imagery which would be used. In this picture flying across the Amazon at latitude 1.79 degrees South and longitude 53.47 degrees, this 214 x 143 km photograph shows how the pilot would cross the lower reaches of the Amazon in the centre of the picture where there is more cloud. The scientific explanation of the unusual features in this image is that cumulus clouds were being generated mainly from forest transpiration and not from the relatively cold Amazon River.

Satellites estimate the height of cumulus clouds by measuring the infra red temperature at the top of the cloud. More accurate confirmation of the height of the cloud would be obtained by the aircraft's instrumentation.

Figs(6-7) show satellite imagery which would be excluded from data transmission to the 'nodal' ground stations proposed. Fig (6) shows coastal fog near Namibia, which is well outside the equatorial belt and where any form of rainfall is a rarity. Fig (7) shows orographic cumulus clouds over Trinidad which also lies well outside the Equatorial air corridor These data would be simply ignored by the 'nodal' relay data transmitters. The important conclusion is that the existing data acquisition system from satellites appears to be sufficient for the purposes of the equatorial air corridor and the only extra requirement is for the 'nodal' data repeating stations. These repeating stations could be quite small and often unmanned.

DIAGRAMS

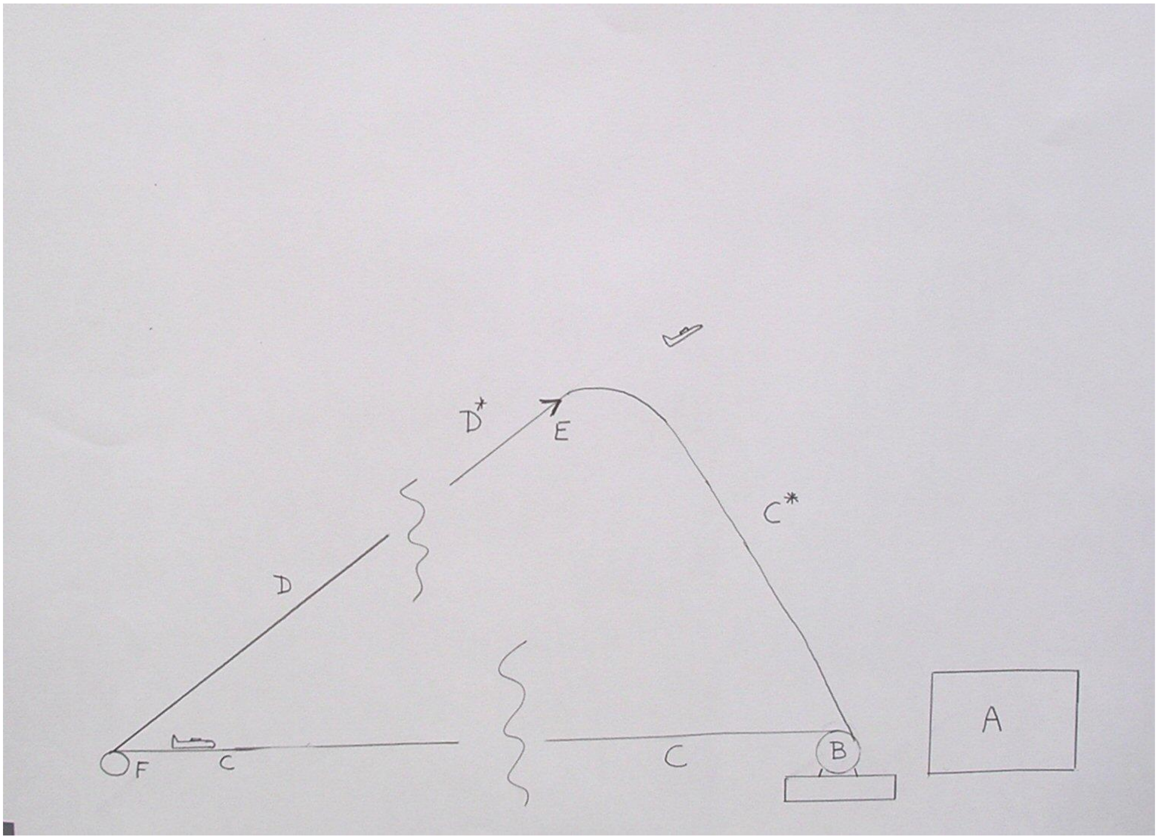

Fig (1) Winch launching of aircraft from an algae 'race-course' pond (schematic/not to scale). The 15 MW gas turbine in sound-proof building A powers an external hydraulic drive B which can swivel slightly on its concrete base. The turbine exhaust is scrubbed with pond water to return CO_2 to the pond after generating steam in a form of IGCC power cycle. The drum B launches the aircraft with cable C. At height 1000m the cable C* is detached and rewound by cable D/D* using motor F. Drogue D* stabilises the cable rewind.

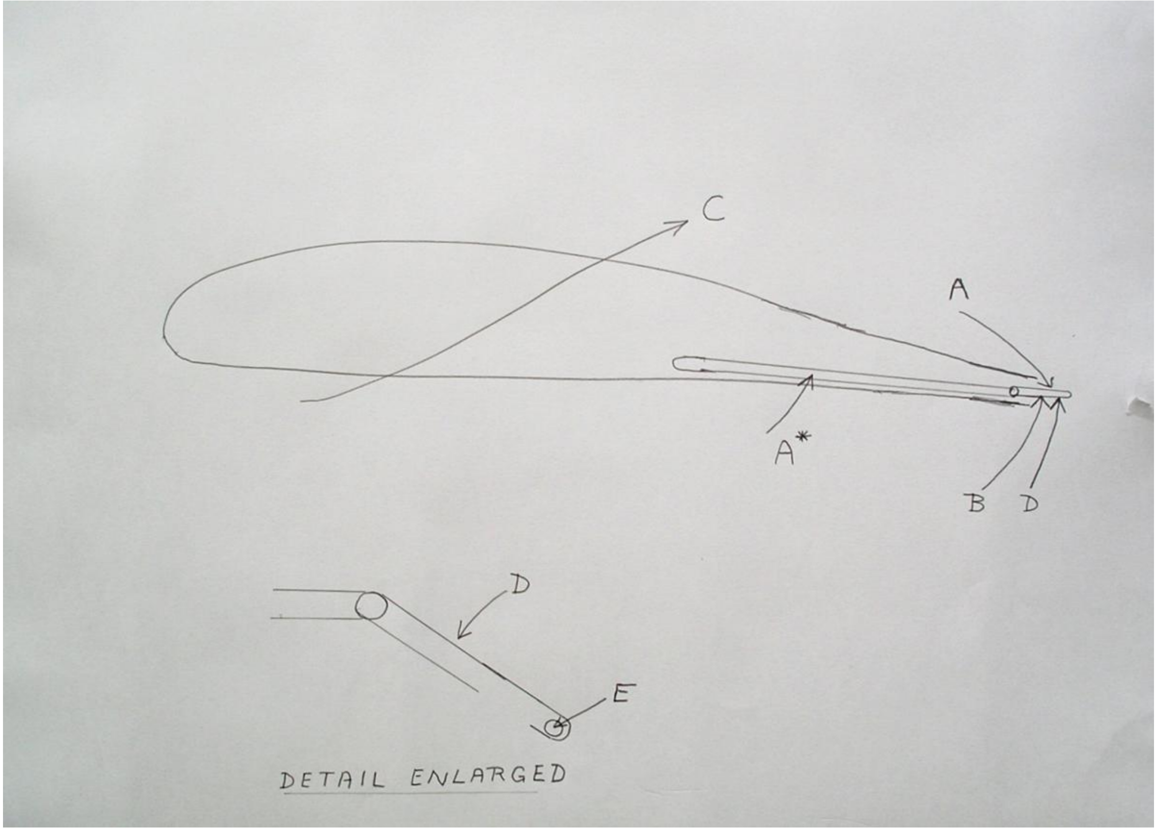

Fig (2) Collection of Water for hydrogen-fueled turbofans.
C is air bleed to reduce stalling speed; A/A* is the Fowler flap; D is the Fowler flap extension to collect water at E; B is Fowler flap extension in glide position.

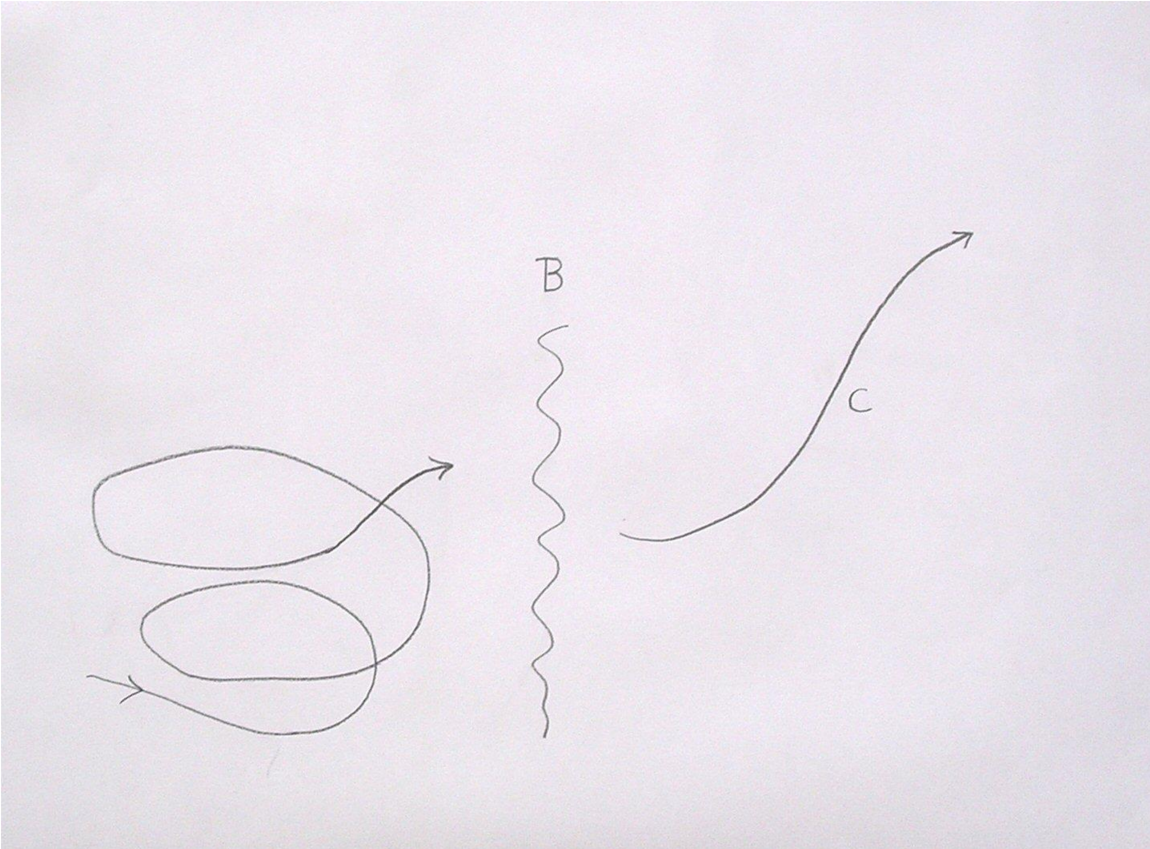

Fig (3) Example of Pilot Control using cumulus clouds to gain height and water. Having received satellite data such as shown in fig (5), the pilot/navigator enters a small cloud on the left to gain height and water but rejects a cloud at B (not shown) to enter a smaller cloud at C to achieve an operational ceiling at 5000m.

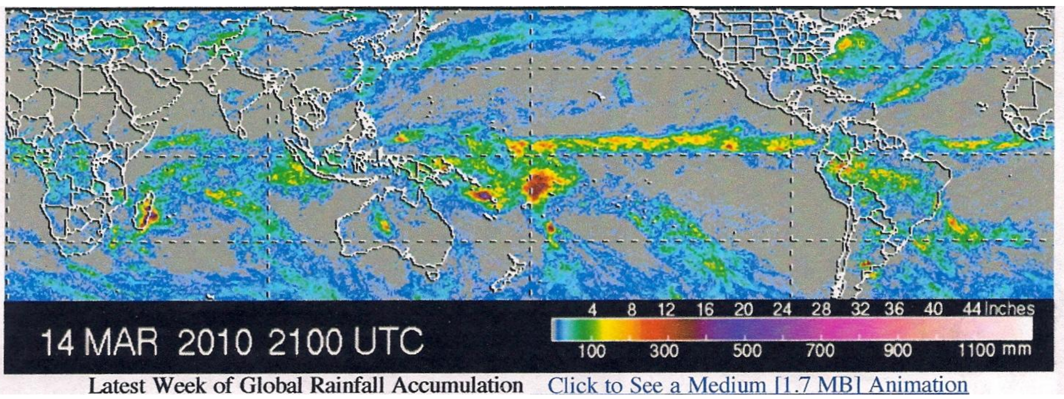

Fig (4) Equatorial Cloud Cover showing the width of the Hadley cells

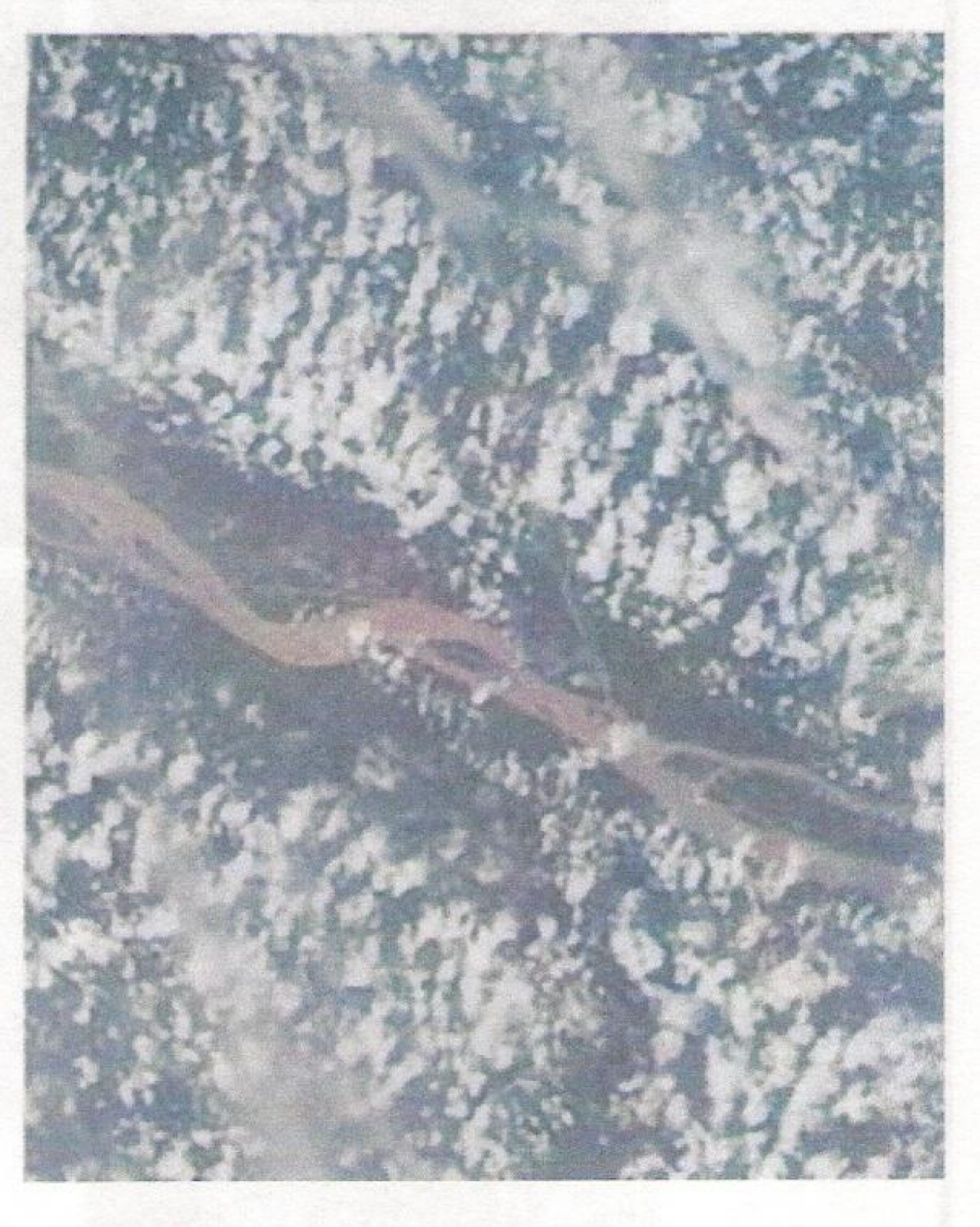

Fig (5) Example of Cloud Cover Details Used from Nodal Repeating Stations

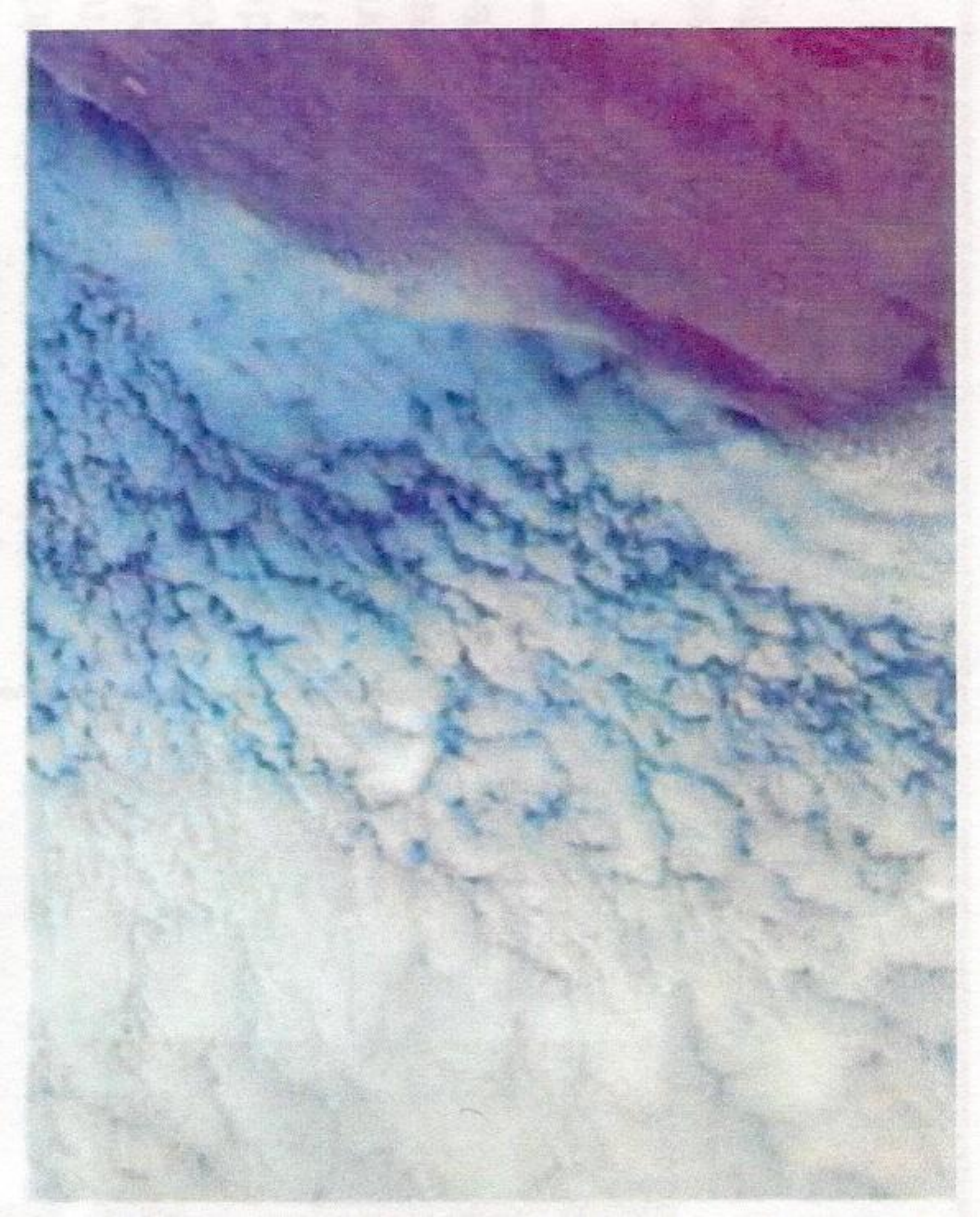

Fig (6) Example of Data rejected by Nodal Repeater Stations

Fig (7) Example of Data rejected by Nodal Repeater Stations

Acknowledgments

Figs (4-7) are available courtesy of NASA's Goddard Space Flight Centre.(TRMM- Tropical Rainfall Measuring Mission.)

Normally these and many other relevant and huge datasets are available free of charge for research purposes.

References and Footnotes

(All references cited are necessarily specific to this paper and available 'on-line' and found easily by a Google search except for those marked with an asterisk (*)). All hyperlinks were last retrieved on 6th May 2010. Readers are also likely to need to refer to a wide variety of standard texts concerning Doppler radar; electromagnetic scattering; gas turbines; aerodynamics; polar satellite technology; cloud physics; information technology etc. in addition to more mundane matters in general engineering and science. It is not considered necessary to quote these references.)

1) . Boothroyd. R. G 'Exploiting Algae as a Biofuel Feedstock and for Reduction in CO2 Emission', January 5, 2007, http://www.oilgae.com/ref/sub/sub1.html

2) IPPC (International Panel on Climate Change)April 1999 report 'Aviation and the Global Atmosphere, Chapter 9, Aircraft Emissions: Current Inventories and Future Scenarios (see also chapters 1 & 3 (Aviation produced Aerosols and Cloudiness)). (http://www.ippc.ch/pdf/special-reports/spm/av-en.pdf)

3) See, for example, Ulf Bossel's announcement at Lucerne Fuel Cell Forum , 2-6 July, 2007, Lucerne, Switzerland. (www.efcf.com/reports)

4) Ghirardi, M.L., Huang, Z., Forestier, M.,Smoluski, S., Poswitz, M. and Seibert, M., Development of an Efficient Algal H2-Production System. Proc 2000 Hydrogen Program review (NREL/CP 570-28890)

5) . The Supacat Winch The best pictures are available at http://www.norfolkglidingclub.com/NewWinchDetailed.aspx

It also seems feasible to launch these aircraft piggy-back on a specially designed launch vehicle. This method seems to be very inferior to the system proposed. Such a system would be just as noisy as the present take-off method and it would be much more expensive compared with the winch system. The CO2 emitted would be less harmful as it is all emitted below 1000m but it cannot be eliminated completely as is the case with the winch launch method

6) Boothroyd, R. G., 'Research/Development Suggestions Related towards Sustainable Merchant Shipping' p8/section 2.5. This Conference

* 7) Adam, D., Power on Tap, *New Scientist*, 29 July , 2006, p35

8) Di Pietro, J. P. and Skolnik, E.G., "Analysis of the Sodium Hydride-based hydrogen storage system" Prepared for US Dept of Energy Office of Power Technologies. October 29, 1999, pp 861-888. www.eere.energy.gov/hydrogenfuelcells/pdfs/28890

9) Daimler-Chrysler designed an excellent hydrogen-powered car called the Natrium . The project was abandoned on the grounds of perceived problems in providing a fuel supply network, Additionally there still remains the problem of finding a cheaper method of producing hydrogen.

10) An unusual feature of this aircraft is that its all-up weight increases slightly during its flight as fuel is consumed. Design-wise this is not an issue of much consequence. This is one of the less important reasons for selecting a seaplane design. Conventional airliners must be much lighter when they land. This is because undercarriage stresses are much larger due to impact when landing compared with the more gentle undercarriage stresses on take off. This explains why jet fuel often has to be dumped in emergencies.

11) Water Vapour in the Climate System (Special Report dated December 1995 published by the American Geophysical Union) Also available as ISBN 0-87590-865-9. (http://www.eso.org/gen-fac/pubs/astclim/espas/pwr/mockler.html)

*12) Liebeck, R.H. Design of Subsonic Airfoils for High Lift , *Jnl Aircraft*, **15**(9) Sept 1978. 547

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