THE PRACTICAL ISSUES OF UTILISING A EUROPEAN SPACE WEATHER PROGRAMME FOR AIRLINE OPERATIONS

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ABSTRACT

The requirement for a European Space Weather Programme for civil airline operations can be argued on the basis of several factors: recently introduced EU legislation [1] for monitoring of aircrew radiation exposure, the effect on aircraft avionics, communications and Global Positioning Satellite (GPS) navigation systems. However, the biggest problems for the aviation industry itself may not be the application of the science, but rather the development, implementation and utilisation of the Space Weather services within the many operational levels of a heavily regulated, and safety conscious industry. This paper will therefore focus on some of the identified key issues, which must be addressed, with the help of the science community, if the airlines want to benefit from the availability of a European Space Weather Programme.

1. RISKS TO AVIATION INDUSTRY

1.1 Space Weather Effects

Space Weather (SW) is the collective term for conditions on the sun and in the solar wind, magnetosphere, ionosphere, and thermosphere that can influence the performance and reliability of space-borne and ground-based technological systems and can endanger human life and health [2]. Included within this definition are the effects of Galactic Cosmic Rays (GCRs) that originate from outside our solar system, but which also affect technological systems, and endanger human life and health because their flux is modulated by solar processes.

The SW phenomena that have a direct effect on airline operations are Galactic Cosmic Rays (GCRs), Solar Energetic Particles (SEPs), Coronal Mass Ejections (CMEs) and geomagnetic storms. GCRs are the prime source of the radiation environment at aircraft altitudes. SEPs are the resultant highly energetic particles (primarily protons) from solar flares, and with sufficient energy and intensity may give rise to significantly increased radiation levels throughout the atmosphere. However, such events occur relatively infrequently and primarily, but not exclusively, during solar maximum. An eruption in the Sun's corona releases large amounts of plasma, known as a CME. If this CME is Earth-directed it can interact with the magnetosphere resulting in additional high energy particle fluences in the ionosphere and producing geomagnetic storms, mainly in the auroral regions.

1.2 Risks

The extremely dynamic SW environment has many impacts and risks, to varying degrees, for airline operations. These include Single Event Effects (SEEs) on aircraft avionics from high-energy particles, in particular, SEPs. Polar Cap Absorption (PCA) events, another consequence of SEPs, is extremely disruptive to High Frequency (HF) communications, which is of vital importance for the new ultra-long-haul "over-the-pole" routes. Solar activity can cause ionospheric disturbances, which can effect GPS operations (the future for aircraft navigation), possibly eroding safety margins. GPS also has to contend with the detrimental effects the energetic solar particles have on the on-board systems. Recent research is now suggesting a greater link between SW and terrestrial weather.

However at present, the most important SW impact is the exposure of airline crews to the cosmic radiation at cruising altitudes. Recent European legislation [1] now requires that this occupational exposure must now be assessed via the use of computer predictive software, which must also then undergo frequent validation using in flight measurements. The EU Directive also recommends for the inclusion of increased doses due to solar or geomagnetic activity but this dose can only be accurately obtained by permanently flying active monitors and correlating their data with that from ground level neutron monitors (a dying breed). A collaborative UK study to monitor cosmic radiation [3, 4] onboard long-haul flights aims to tackle both the problem of validation and that of determining whether solar flare activity can cause significant enhancement to the predicted doses, using active monitors. A study [5] has estimated that during the SEP event of 1956, the radiation dose received at 40,000ft (12km) on a transatlantic flight would have exceeded the EU recommended annual dose (6mSv) and "once-declared" pregnancy limit (1mSv) by a factor of 1.67 and 10 respectively. Such events are extremely rare, perhaps occurring once every 100 years. Studies of more typical events in September and October 1989 indicate that a crew member could have received one-third of the annual dose for a similar flight.

Such is the importance of solar flare doses, the UK Cosmic Radiation Advisory Group (UK CRAG), which advises to the UK airlines and government has requested additional work in this area and for the formulation of standardised notification procedures. This work is of particular importance when doses are applied to pregnant crew under Article 10 [1].

2. PRACTICAL ISSUES

For the airline industry, the ideal source for such a diverse range of required data would be a Space Weather Information System and ultimately for the future, one with a forecasting capability. Development of such a service will require a great deal of collaboration between the science "providers" and the industry "users". Aviation is one of the most heavily regulated industries, both nationally and internationally, in terms of safety, security and operational procedures. Therefore, the use of SW information in a similar manner to terrestrial weather should be co-ordinated and agreed by the many world-wide aviation governing bodies, i.e., from International Civil Aviation Organisation (ICAO) and International Air Transport Association (IATA) to national Air Traffic Control (ATC) and aviation regulatory authority's.

2.1 Disseminating SW Information

Assuming that the SW science community can produce the necessary models for nowcasting, warning and forecasting for the airline industry, then the next step would be to ensure timely and complete dissemination of the information. A sensible solution would be to "piggy-back" space weather onto the present world-wide distribution of terrestrial weather. Besides the possible cost-savings that this could bring, it could also simplify the inclusion of SW information and utilisation procedures into current regulations.

ICAO lays down the present meteorological services that are required for international aviation. The services are split into two categories, those provided under the auspices of the World Area Forecast System (WAFS), and those provided by individual states. Forecasts for airports fall into the latter. Larger scale products fall into the former, and it is reasonable to assume that any SW warnings would fall into this category. WAFS consists of two World Area Forecast Centres (WAFCs): one in the UK, the other in the USA. ICAO, who must also consult with bodies such as IATA and the International Federation of Air Line Pilots Association (IFALPA), approves the services provided by a WAFC. The services provided by the UK Meteorological Office (the UK WAFC) are funded by the UK's Civil Aviation Authority (CAA), who get their money from en-route charges paid by the airlines. In some cases the UK Met Office provide WAFC services directly to airlines, but it also provides them to commercial vendors (i.e., Air Data, Fico, Jeppeson, Phoenix).

Distribution of weather information around the world for this multi-tier structure is carried out in several ways and summarised in Table 1.

The Internet is another obvious distribution medium, which although it is already utilised by many vendors of terrestrial and SW products, it is not yet approved by ICAO for mission critical information. Improvements in security, transmission rates and reliability may see a change in ICAO's stance in the near future. Aircraft manufacturers are beginning to provide aircraft Internet connectibility for passengers, and many airlines are now turning towards the "paper-less" cockpit by providing laptops for all their crews' operational and administrative duties.

At present, the UK Met Office is neither involved in SW research, nor distributing any information and any involvement will require the development of a strong business case. However, if regulatory approval (ICAO, IATA or CAA) were obtained to "piggy-back" SW onto the terrestrial weather system, this would ensure that the Met Offices' expertise could be used for the collaborative research necessary to develop the applications.

2.2 Operational Impacts

The world's ATC agencies (e.g., EuroControl in Brussels, National Air Traffic Services (NATS) in the UK and the Federal Aviation Administration (FAA) in the USA) play an integral role in the dissemination of terrestrial weather data so that they, and the flight crews, have the latest information to ensure safe operations. It would therefore, be logical for all such agencies to be included in the distribution of SW information. They could then assist with information flow, but more importantly it would ensure that they

Table 1. Terrestrial weather distribution systems currently deployed, with examples of utilisation of the facility.

Distribution Systems	Utilisation
Global Telecommunications System (GTS)	Between National Weather Services (i.e., UK Met Office to US NWS)
Aeronautical Fixed Telecommunications Network (AFTN)	Between national aviation authorities (e.g. CAA to FAA)
UK WAFC – Satellite Dissemination (SaDis) USA WAFC – International Satellite Communications System (ISCS)	Direct to airlines and 3rd Party vendors
SATCOM & HF Radio	Direct to aircraft

(Note: SaDis is a single satellite over the Indian Ocean covering UK/Europe, Africa, Asia and Australasia, and backed up with ftp and landlines. The American ISCS has 2 satellites deployed over the Pacific Ocean to complete the coverage.)

could safely control the separation between aircraft in their airspace, which may decide to alter their flight profile based on received SW warnings.

It is likely that any significant SW events would effect specific geographic areas. It may therefore be sensible to adopt different response procedures depending on the type of airspace management in each area. Creating these response procedures could primarily be carried out by the National ATC agencies Planning and Implementation Management Groups, which are integrated with ICAO.

The NATS Scottish and Oceanic Area Control Centre (ScOACC) based at Prestwick in Scotland provides an air traffic control service to aircraft in the eastern part of the North Atlantic from the south of Iceland to north of the Azores. Radar only has a range of some 200 miles, so aircraft over the Atlantic are controlled by using position reports and estimates passed to the controllers by the pilots using HF communications or more recently by an automatic satellite data message. During the aircraft's passage, the ground controllers will assess requests (received only via HF) for any changes to level, speed or route, and will co-ordinate with adjacent Oceanic Control Centres before authorising any such change.

Due to passenger demands, time zone differences and airport noise restrictions, much of the North Atlantic traffic is concentrated at particular times: westbound in the late morning/afternoon, and eastbound during the night/early morning. Because of this concentration and the limited height band for economical jet operation, the airspace is comparatively congested. Fig. 1 shows the system of organised North Atlantic Tracks (NATs), which change daily due to the prevailing terrestrial weather conditions. This illustration also shows the aircraft separation minima used on these tracks between 31,000 and 39,000 feet known as Reduced Vertical Separation Minima (RVSM).

As an example of the operational impact that a SW event (i.e., a solar flare) could have on this particular ATC environment, statistics for August 2001 and a "snapshot" for 19 November 2001 are provided below (provided by ScOACC).

<u>North Atlantic Tracks – Maximum figures for Aug 01</u>

No. of aircraft/hour	- 110
No. of aircraft/day	- 1100
No. of aircraft > 41,000ft (13km)	- 5-7% of Traffic
No. of aircraft < 28,000ft (8.5km)	- 2% of Traffic

<u>Snapshot 19 Nov 01 13:47:44 (Now to +3hrs)</u>

No. of aircraft at or above 36,000ft (11km)	- 67
Aircraft on random or crossing track routing	~50%

In the event of a Solar Radiation Nowcast advising descent below 36,000ft being issued to some, or all of these aircraft, maintaining safe separation minima between aircraft could prove extremely difficult, especially if non-standardised procedures are used. It is likely that the airspace capacity would be reduced to approximately 40 aircraft/hour with large delays effecting all aircraft on the ground. This scenario becomes all the more complex when terrestrial weather and increased fuel consumption is superimposed on the decision process. Therefore a variety of carefully planned, and ATC controlled procedures should be designed to react to a rising scale of SW severity.

For westbound traffic, the entry into NATs is a major choke point due to the relatively short distance between most of the major European Airports and the start of the Atlantic routing. The ScOACC believes it would require a minimum of 2 hours warning to safely implement the flow management necessary to allow all aircraft to reduce their altitude. As the depth of RVSM may soon increase to 28,000 and 43,000 feet, and with increasing numbers of business jet traffic above 43,000 feet, then the requirement for meticulous procedure modelling becomes all the more compelling.

2.3 Commercial Impacts

Utilising SW information either means flying lower and/or delaying flights on the ground to avoid the effects from SEP events. The commercial considerations for such actions are the increased fuel

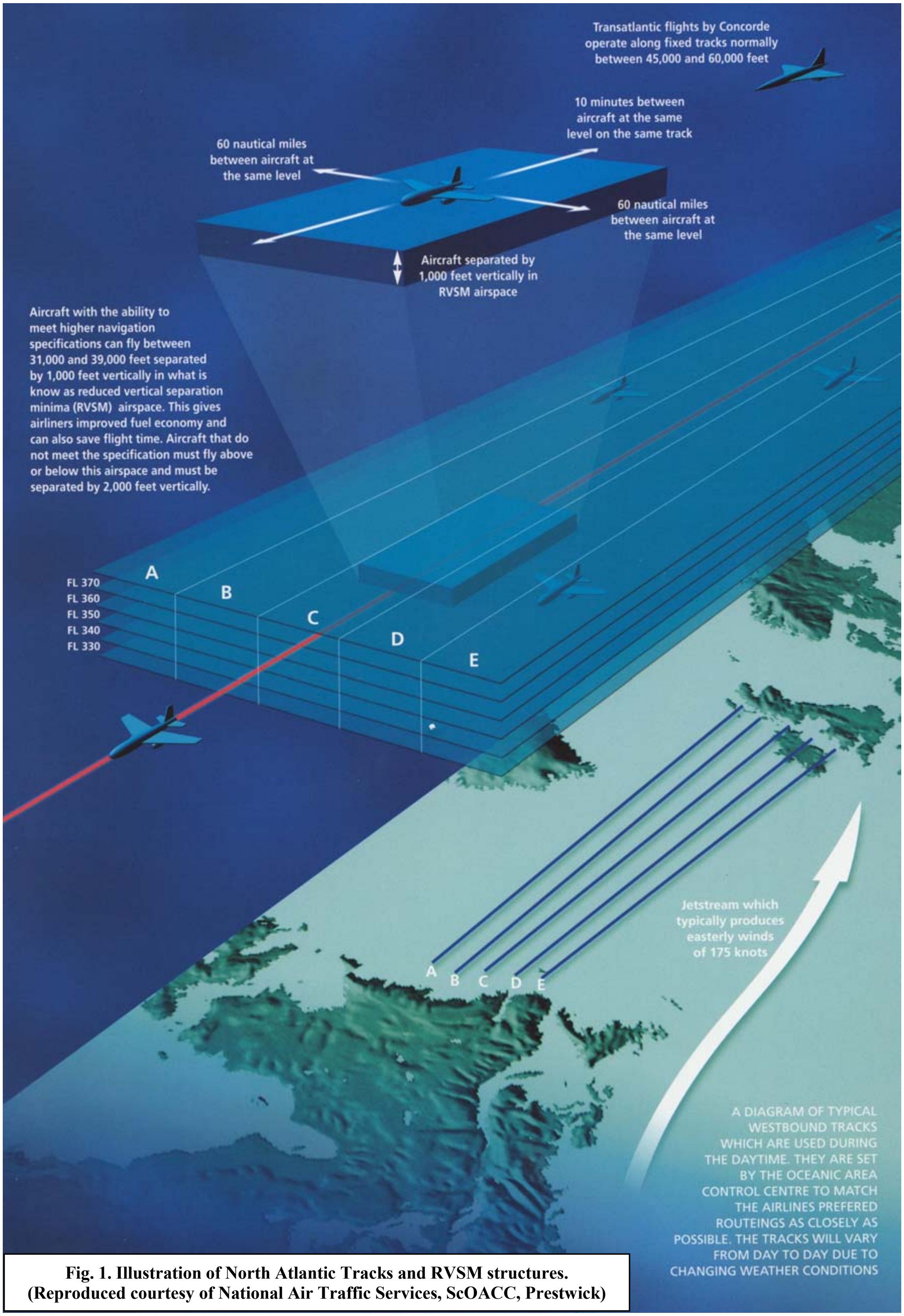

Fig. 1. Illustration of North Atlantic Tracks and RVSM structures.
(Reproduced courtesy of National Air Traffic Services, ScOACC, Prestwick)

burn at lower, less economical altitudes with the possibility of a diversion to refuel. A refuel stop incurs landing, handling and fuel charges. Any significant delay on the ground during the diversion may then lead to a minimum 12-hour stopover due to crew duty hour limitations, which would then incur further charges (i.e., hotel accommodation for passengers and crew) as well as severe disruption to the flying programme. Another consideration of flight at lower altitudes is possible increased costs due to operating the engines outside of their optimum parameters.

Conversely, there are important considerations if available SW information is ignored. Albeit extremely unlikely, annual dose limits may be reached or even exceeded on a single flight. This would mean either the crew member is re-categorised as a Category A [1] radiation worker (doses >6mSv/year) but continues to fly, or does not fly for a period of time but risks going out of currency and requiring further training. Consideration may need to be given for additional crew numbers to be factored into establishment figures. For a primarily female workforce, these considerations are very important when Article 10 pregnancy limitations are applied.

Other factors are the cost of avionics maintenance due to SEEs and the potential increases to insurance premiums if SW information is available but not used. Many airline industry brokers are the same large companies that deal with the satellite and space industries and are therefore, already well educated to the potential risks from SW.

2.4 Education

Within the airline industry there is a poor level of awareness and understanding of SW science and of its possible impacts. This in part stems from a poor educational "outreach" programme, but also that the impacts have never been sufficiently proven to warrant the cost of further research or risk assessment.

These failings need to be addressed immediately if the industry is to assist with additional research. Even though the present risks may be considered commercially low, the educational programme must be improved to make all areas of the industry aware that technological advances in future aircraft, and the likely use of higher altitudes, will significantly enhance the risks.

3. INDUSTRY STUDIES

Several studies of cosmic radiation at aircraft altitudes are believed to be underway in Europe and North America. These include measurements using Tissue Equivalent Proportional Counters (TEPCs), which are designed to mimic human tissue providing a measure of the dose equivalent to a few micro-metres of tissue.

Within the EC there is a working group, EURODOS, which has been given responsibility for collating all cosmic radiation study data sets in an attempt to define best practice dosimetry procedures. DOSMAX [6] is an EU funded cosmic radiation research group, which is also trying to investigate the effects of SW on the radiation exposure.

In the USA, a SW airline workshop is being formed to bring together the expertise of the Space Environment Center (SEC), part of the National Oceanic and Aerospace Administration (NOAA), with representatives from the US airline industry. These include the FAA's Aerospace Weather Standards Division and its Civil Aerospace Medical Institute (CAMI). The US National Weather Service (NWS) is also represented. However, actual airline involvement is still limited. CAMI has for many years carried out research on cosmic radiation and is the provider of the freely available computer software code, CARI, used by many airlines to predict exposure from air travel.

4. CONCLUSIONS

The requirements for a SW service for the airline industry is based on several factors, most notably that of assessing the exposure to cosmic radiation and any variations caused by SEP events. SW effects on aircraft avionics, communication and navigation systems are also considered to be significant. Future developments in aircraft design and the likely increases in operating altitudes will make the impacts more noticeable.

The dissemination of SW information around the globe and to all aircraft could be achieved using present terrestrial weather systems and technology. However, due to the complexity of the airspace environment, utilising such information could have a severe impact on safe operations.

A lack of industry R&D funds is primarily due to poor awareness and understanding of SW effects. The present educational outreach is insufficient to convince the industry of the present, but more importantly, the future risks to operations.

5. RECOMMENDATIONS

The development of a European Space Weather programme for use by the airline industry must first produce a significantly enhanced Educational "Outreach" programme to improve the awareness and understanding of the Space Weather environment and it's many impacts. This programme must reach all levels of this heavily regulated and safety conscious industry: from airlines to ATC agencies to ICAO and IATA.

In parallel with the Outreach programme, the "Business Case" for a SW service should be enhanced with more accurate risk assessment models. Then in collaboration with the science community, the industry should be able to carry out thorough cost/benefit analysis for all SW impacts.

To help assess the risk and develop accurate solar flare dose models the airlines, the manufacturers (i.e., Airbus, Boeing, Gulfstream, etc) and the higher flying corporate business jets should be encouraged to fly more active monitors like the TEPC. Permanent installations integrated with aircraft power, GPS and communication systems, installed at the factory, could ensure almost world-wide, full-time coverage. At the same time the science community should ensure that the number of ground level neutron monitor data sets does not reduce further.

A European Airline SW Working Group with suitable representation from all sectors (i.e., ESTEC, airlines, NATS, EuroControl, UK Met Office, Civil Aviation Authorities and manufacturers) should be considered, with sub-groups responsible for different areas. It would be sensible for such a group to discuss and co-ordinate ideas with the equivalent US airline SW Working Group.

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