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Edition 1.0 2014-12

PUBLICLY AVAILABLE SPECIFICATION

PRE-STANDARD

colour inside

**Process management for avionics – Atmospheric radiation effects –
Part 6: Extreme space weather and potential impact on the avionics environment and electronics**

IEC PAS 62396-6:2014-12(en)

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ELECTROTECHNICAL
COMMISSION

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The document "Extreme Space Weather: impacts on engineered systems and infrastructure" from the Royal Academy of Engineering (United Kingdom, London) has served as a basis for the development of this publicity available specification.

The permission from the Royal Academy of Engineering (United Kingdom, London) to include the report within this PAS is gratefully acknowledged by the IEC.

IEC PAS 62396-6 has been processed by IEC technical committee 107: Process management for avionics.

The text of this PAS is based on the following document: | This PAS was approved for publication by the P-members of the committee concerned as indicated in the following document

Draft PAS	Report on voting
107/244/PAS	107/250/RVD

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PROCESS MANAGEMENT FOR AVIONICS – ATMOSPHERIC RADIATION EFFECTS –

Part 6: Extreme space weather and potential impact on the avionics environment and electronics

1 Scope

This PAS details the mechanisms and conditions that produce "extreme space weather" (ESW) and the changes within the avionics environment under such conditions. Consideration is given to the impact and risks of ESW on passengers and crew travelling on aircraft in flight and the option for in flight monitoring of the environment. Avionics electronics and systems operating during flight can be affected under such conditions and these are reviewed. By testing of complete equipment for extreme space weather tolerance, the degree of robustness to ESW can be assessed. In the PAS, flight related infrastructure (not the aircraft itself) that can be affected or disabled by an extreme space weather event is identified; such infrastructure can be in the local "space" environment or on the ground.

This PAS is identical to the "Extreme Space Weather: impacts on engineered systems and infrastructure" document from the Royal Academy of Engineering (United Kingdom, London) which is included in Annex A.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this PAS and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 62396-1:2012, *Process management for avionics – Atmospheric radiation effects – Part 1: Accommodation of atmospheric radiation effects via single event effects within avionics electronic equipment*

3 Terms, definitions and abbreviations

For the purposes of this PAS, the following terms, definitions and abbreviations apply.

3.1 Terms and definitions

For the purposes of this PAS the terms and definitions given in IEC 62396-1:2012 apply.

3.2 Abbreviations and acronyms

For the purposes of this PAS the abbreviations and acronyms given in IEC 62396-1:2012 and in Clause 15 of Annex A, as well as the following, apply.

CAA	Civil Aviation Authority
CME	Coronal mass ejections
EASA	European Aviation Safety Agency
EMC	Electromagnetic compatibility
ESD	Electrostatic discharge

ESW	Extreme space weather
FAA	Federal Aviation Administration
GEO	Geostationary orbit
GMD	Geomagnetic disturbance
GNSS	Global navigation satellite systems
GPS	Global positioning system
HF	High frequency
ICAO	International Civil Aviation Organisation
ICRP	International Commission on Radiological Protection
IEEE	Institution of Electrical and Electronic Engineers
LEO	Low earth orbit
MEO	Medium earth orbit
MTTR	Mean time to repair
NOAA	National Oceanic and Atmospheric Administration
NRA	National risk assessment
SAE	Society of Automotive Engineers
SEIEG	Space Environment Impact Expert Group
UHF	Ultra high frequency
VHF	Very high frequency

4 Technical recommendations

4.1 General

Annex A describes the effects of the extreme space weather (ESW) improving the understanding, evaluates the impacts and provides recommendations on suitable mitigation strategies.

4.2 ESW environment

4.2.1 Mechanisms responsible for ESW

An understanding of how an ESW event occurs, its impact and duration is given in Clauses 3 and 4 of Annex A.

4.2.2 Changes in avionics environment due to ESW

Consideration is given to the radiation environment at aircraft altitudes and the recommended potential radiation levels.

4.3 Impact of ESW on aircraft passengers and crew

4.3.1 Impact on passengers and crew

During an ESW event, the radiation levels during a flight at altitudes and latitudes at risk may be above those normally considered acceptable for the general public; a clear understanding of the risks and mitigations will enable the industry to manage these events effectively. This is discussed in more detail in Clause 8 of Annex A.

4.3.2 In flight radiation environment monitoring

In flight radiation monitoring is recommended because it has a number of benefits providing:

a) Reliable method for determining the onset of ESW.

b) Ability to disseminate the onset information before there is major infrastructure impact and provides warning.

c) Clear measurement of the radiation exposure of passengers and crew.

d) Identification of the radiation levels at which there is impact or weaknesses in the electronic flight systems.

4.4 Impact of ESW on aircraft electronic systems

4.4.1 Effect on electronics, equipment and systems

The effects of atmospheric radiation on avionics electronics have been understood for a number of years and in 2006, IEC TS 62396-1 was published by the IEC technical committee 107 to provide guidance to the avionics industry. When this technical specification was issued it documented that a very large space weather event occurred in February 1956 and enhancements of 300 times on the radiation flux were experienced in certain locations at flight altitudes. Clause 9 of Annex A expands on the effects and mitigations for avionics electronics.

NOTE The Technical Specification IEC TS 62396-1:2006 has been cancelled and replaced by a newer edition IEC 62396-1:2012 published in the form of an International Standard.

4.4.2 ESW simulation testing of electronics equipment and systems and analysis methods

During ESW events which may result in more than a 2-decade increase in radiation flux, the flight critical equipment will be expected to continue safely in operation.

One way to validate the equipment capability in ESW is to perform complete equipment system testing in a radiation simulator at enhanced flux levels. There are a small number of facilities world wide that can be used to test complete avionics systems and determine their robustness to this type of event. On the other hand, there are qualitative and quantitative methods for demonstrating that the electronic component, the electronic equipment and the system exhibit enough design/architecture margins to mitigate the radiation effects taking into account probabilities of increased radiation effects due to ESW in the safety analysis.

4.5 Considerations of ESW design margins

As more information becomes available from past and future large solar events, it should be possible to recommend an acceptable margin for radiation tolerance of such enhancements in atmospheric radiation.

Annex A
(informative)

Extreme Space Weather: impacts on engineered systems and infrastructure from the Royal Academy of Engineering

This Annex describes the effects of the extreme space weather (ESW) improving the understanding, evaluates the impacts and provides recommendations on suitable mitigation strategies.

Contents

Foreword

An extreme space weather event, or solar superstorm, is one of a number of potentially high impact, but low probability natural hazards. In response to a growing awareness in government, extreme space weather now features as an element of the UK National Risk Assessment.

In identifying this hazard, the UK government benefitted from the country's world class scientific expertise and from a number of earlier studies conducted in the US. However, the consequential impact on the UK's engineering infrastructure - which includes the electricity grid, satellite technology and air passenger safety – has not previously been critically assessed. This report addresses that omission by bringing together a number of scientific and engineering domain experts to identify and analyse those impacts. I believe that this study, with its strong engineering focus, is the most extensive of its type to date.

It is my hope that by acting on the recommendations in this report, stakeholders will progressively mitigate the impact of the inevitable solar superstorm.

Professor Paul Cannon FREng
Chair of the study working group

1. Executive summary

Rarely occurring solar superstorms generate X-rays and solar radio bursts, accelerate solar particles to relativistic velocities and cause major perturbations to the solar wind. These environmental changes can cause detrimental effects to the electricity grid, satellites, avionics, air passengers, signals from satellite navigation systems, mobile telephones and more. They have consequently been identified as a risk to the world economy and society. The purpose of this report is to assess their impact on a variety of engineered systems and to identify ways to prepare for these low-probability but randomly occurring events. The report has an emphasis on the UK, but many of the conclusions also apply to other countries.

Explosive eruptions of energy from the Sun that cause minor solar storms on Earth are relatively common events. In contrast, extremely large events (superstorms) occur very occasionally – perhaps once every century or two. Most superstorms miss the Earth, travelling harmlessly into space. Of those that do travel towards the Earth, only half interact with the Earth's environment and cause damage.

Since the start of the space age, there has been no true solar superstorm and consequently our understanding is limited. There have, however, been a number of near misses and these have caused major technological damage, for example the 1989 collapse of part of the Canadian electricity grid. A superstorm which occurred in 1859, now referred to as the 'Carrington event' is the largest for which we have measurements; and even in this case the measurements are limited to perturbations of the geomagnetic field. An event in 1956 is the highest recorded for atmospheric radiation with August 1972, October 1989 and October 2003 the highest recorded radiation events measured on spacecraft.

How often superstorms occur and whether the above are representative of the long term risk is not known and is the subject of important current research. The general consensus is that a solar superstorm is inevitable, a matter not of 'if' but 'when?'. One contemporary view is that a Carrington-level event will occur within a period of 250 years with a confidence of ~95% and within a period of 50 years with a confidence of ~50%, but these figures should be interpreted with considerable care.

Mitigation of solar superstorms necessitates a number of technology-specific approaches which boil down to engineering out as much risk as is reasonably possible, and then adopting operational strategies to deal with the residual risk. In order to achieve the latter, space and terrestrial sensors are required to monitor the storm progress from its early stages as enhanced activity on the Sun through to its impact on Earth. Forecasting a solar storm is a challenge, and contemporary techniques are unlikely to deliver actionable advice, but there are growing efforts to improve those techniques and test them against appropriate metrics. Irrespective of forecasting ability, space and terrestrial sensors of the Sun and the near space environment provide critical space situational awareness, an ability to undertake post-event analysis, and the infrastructure to improve our understanding of this environment.

The report explores a number of technologies and we find that the UK is indeed vulnerable to a solar superstorm, but we also find that a number of industries have already mitigated the impact of such events. In a 'perfect storm' a number of technologies will be simultaneously affected which will substantially exacerbate the risk. Mitigating and maintaining an awareness of the individual and linked risks over the long term is a challenge for government, for asset owners and for managers.

Space weather: impacts on engineered systems – a summary is a shortened version of this report suitable for policy makers and the media – see **www.raeng.org.uk/spaceweathersummary**.

Key points:

Solar superstorm environment

The recurrence statistics of an event with similar magnitude and impact to a Carrington event are poor, but improving. Various studies indicate that a recurrence period of 1-in-100 to 200 years is reasonable and this report makes assessments of the engineering impact based on an event of this magnitude and return time. If further studies provide demonstrable proof that larger events do occur – perhaps on longer timescales - then a radical reassessment of the engineering impact will be needed. The headline figure of 100 years should not be a reason to ignore such risks.

Electricity grid

The reasonable worst case scenario would have a significant impact on the national electricity grid. Modelling indicates around six super grid transformers in England and Wales and a further seven grid transformers in Scotland could be damaged through geomagnetic disturbances and taken out of service. The time to repair would be between weeks and months. In addition, current estimates indicate a potential for some local electricity interruptions of a few hours. Because most nodes have more than one transformer available, not all these failures would lead to a disconnection event. However, National Grid's analysis is that around two nodes in Great Britain could experience disconnection.

Satellites

Some satellites may be exposed to environments in excess of typical specification levels, so increasing microelectronic upset rates and creating electrostatic charging hazards. Because of the multiplicity of satellite designs in use today there is considerable uncertainty in the overall behaviour of the fleet but experience from more modest storms indicates that a degree of disruption to satellite services must be anticipated. Fortunately the conservative nature of spacecraft designs and their diversity is expected to limit the scale of the problem. Our best engineering judgement, based on the 2003 storm, is that up to 10% of satellites could experience temporary outages lasting hours to days as a result of the extreme event, but it is unlikely that these outages will be spread evenly across the fleet since some satellite designs and constellations would inevitably prove more vulnerable than others. In addition, the significant cumulative radiation doses would be expected to cause rapid ageing of many satellites. Very old satellites might be expected to start to fail in the immediate aftermath of the storm while new satellites would be expected to survive the event but with higher risk thereafter from incidence of further (more common) storm events. Consequently, after an extreme storm, all satellite owners and operators will need to carefully evaluate the need for replacement satellites to be launched earlier than planned in order to mitigate the risk of premature failures.

Aircraft passenger and crew safety

Passengers and crew airborne at the time of an extreme event would be exposed to an additional dose of radiation estimated to be up to 20 mSv, which is significantly in excess of the 1 mSv annual limit for members of the public from a planned exposure and about three times as high as the dose received from a CT scan of the chest. Such levels imply an increased cancer risk of 1 in 1,000 for each person exposed, although this must be considered in the context of the lifetime risk of cancer, which is about 30%. No practical method of forecast is likely in the short term since the high energy particles of greatest concern arrive at close to the speed of light. Mitigation and post event analysis is needed through better onboard aircraft monitoring. An event of this type would generate considerable public concern.

Ground and avionic device technology

Solar energetic particles indirectly generate charge in semiconductor materials, causing electronic equipment to malfunction. Very little documentary evidence could be obtained regarding the impact of solar energetic particles on ground infrastructure and it is consequently difficult to extrapolate to a solar superstorm. More documentary evidence of normal and storm time impacts is available in respect to avionics - no doubt because the operating environment has a higher flux of high-energy particles. Our estimate is that during a solar superstorm the avionic risk will be ~1,200 times higher than the quiescent background risk level and this could increase pilot workload. We note that avionics are designed to mitigate functional failure of components, equipment and systems and consequently they are also partially robust to solar energetic particles.

Global navigation satellite systems (GNSS)

Assuming that the satellites – or enough of them – survived the impact of high energy particles, we anticipate that a solar superstorm might render GNSS partially or completely inoperable for between one and three days. The outage period will be dependent on the service requirements. For critical timing infrastructure it is important that holdover oscillators be deployed capable of maintaining the requisite performance for these periods. UK networked communications appear to meet this requirement. There will be certain specialist applications where the loss or reduction in GNSS services would be likely to cause operational problems; these include aircraft and shipping. Today, the aircraft navigation system is mostly backed up by terrestrial navigation aids; it is important that alternative navigation options remain available in the future.

Cellular and emergency communications

This study has concluded that the UK's commercial cellular communications networks are much more resilient to the effects of a solar superstorm than those deployed in a number of other countries (including the US) since they are not reliant on GNSS timing. In contrast, the UK implementation of the Terrestrial European Trunked Radio Access (TETRA) emergency communications network is dependent on GNSS. Consequently, mitigation strategies, which already appear to be in place, are necessary.

High frequency (HF) communications

HF communications is likely to be rendered inoperable for several days during a solar superstorm. HF communications is used much less than it used to be; however, it does provide the primary long distance communications bearer for long distance aircraft (not all aircraft have satellite communications and this technology may also fail during an extreme event). For those aircraft in the air at the start of the event, there are already well-defined procedures to follow in the event of a loss of communications. However, in the event of a persistent loss of communications over a wide area, it may be necessary to prevent flights from taking off. In this extreme case, there does not appear to be a defined mechanism for closing or reopening airspace once communications have recovered.

Mobile satellite communications

During an extreme space weather event, L-band (~1.5GHz) satellite communications might be unavailable, or provide a poor quality of service, for between one and three days owing to scintillation. The overall vulnerability of L-band satellite communications to superstorm scintillation will be specific to the satellite system. For aviation users the operational impact on satellite communications will be similar to HF.

Terrestrial broadcasting

Terrestrial broadcasting would be vulnerable to secondary effects, such as loss of power and GNSS timing.

> *OUR ESTIMATE IS THAT DURING A SOLAR SUPERSTORM THE AVIONIC RISK WILL BE ~1,200 TIMES HIGHER THAN THE QUIESCENT BACKGROUND RISK LEVEL AND THIS COULD INCREASE PILOT WORKLOAD.*