



Example of risk analysis applied to en-route flight path for large jet transport aircraft

Endorsed by
The Royal Aeronautical Society

ESDU DATA ITEMS

Data Items provide validated information in engineering design and analysis for use by, or under the supervision of, professionally qualified engineers. The data are founded on an evaluation of all the relevant information, both published and unpublished, and are invariably supported by original work of ESDU staff engineers or consultants. The whole process is subject to independent review for which crucial support is provided by industrial companies, government research laboratories, universities and others from around the world through the participation of some of their leading experts on ESDU Technical Committees. This process ensures that the results of much valuable work (theoretical, experimental and operational), which may not be widely available or in a readily usable form, can be communicated concisely and accurately to the engineering community.

We are constantly striving to develop new work and review data already issued. Any comments arising out of your use of our data, or any suggestions for new topics or information that might lead to improvements, will help us to provide a better service.

THE PREPARATION OF THIS DATA ITEM

The work on this particular Data Item was monitored and guided by the Performance Committee. This Committee first met in 1946 and now has the following membership:

Chairman	
Mr G.J.R. Skillen	— Independent, UK
Vice-Chairman	
Mr K.J. Balkwill	— Independent, UK
Members	
Mr P.V. Aidala *	— Northrop Grumman ESID, Bethpage, New York, USA
Dr J.D. Avery	— MoD Boscombe Down, UK
Mr T.G.R. Bos *	— Dutch Airline Pilots Association, The Netherlands
Mr M. Broad	— Independent, UK
Dr G. van Es	— National Aerospace Laboratory NLR, The Netherlands
Mr N.J. Herniman	— Airbus Industrie, Toulouse, France
Mr M. Holcomb *	— Eclipse Aviation Corporation, Albuquerque, New Mexico, USA
Mr R.G. Humpston	— Rolls-Royce plc, Aero Division, Derby, UK
Mr D. Law	— Civil Aviation Authority, Safety Regulation Group, Gatwick
Mr D.J. Mitchell	— Independent, UK
Mr R.J. Orlowski *	— Boeing Commercial Airplane Company, Seattle, Washington, USA
Dr P. Render	— University of Loughborough, UK
Dr A. Smith	— Air Systems Test & Evaluation, QinetiQ, MOD Boscombe Down, UK
Mr G.E. Smith	— Independent, UK
Mr R. Storey	— BAE SYSTEMS, Brough, UK
Mr J. Tempest	— de Havilland Support Ltd, UK
Mr S. Tsach *	— Israel Aircraft Industries, Jerusalem, Israel
Mr C.J. Turner *	— Boeing Commercial Airplane Company, Seattle, Washington, USA

* Corresponding Member

The technical work involved in the assesment of the available information and the construction and subsequent development of the Data Item was carried out under contract to ESDU by

Mr G.J.R. Skillen — Consultant to ESDU

Particular assistance was received from Mr K.J.Balkwill. The person with overall responsibility for the work in this subject area is C.J. Loughton, Head of Performance, Mechanical Motion and System Dynamics Groups.

EXAMPLE OF RISK ANALYSIS APPLIED TO EN-ROUTE FLIGHT PATH FOR LARGE JET TRANSPORT AIRCRAFT

CONTENTS

	Page
1. NOTATION AND UNITS	1
1.1 Definitions	2
2. INTRODUCTION	2
3. QUESTION TO WHICH AN ANSWER IS SOUGHT	3
4. REVIEW OF BACKGROUND TO PERFORMANCE MARGINS	3
4.1 Regulatory Basis	3
4.2 Assumptions Made in Final Report	4
4.3 Discussion of Regulatory Basis	4
5. TECHNICAL REVIEW OF FACTORS	5
5.1 Methods of Final Report	5
5.2 New Information	5
5.3 Grouping of Fleets	6
5.4 The Deduction Basis for Incident Probability	7
5.5 Critical Flight Time	8
5.6 Deductions from Probability Equation (Consistent Single Engine Failure for Multi-engined Aircraft)	8
5.7 Single Engine Failure for all Groups of Multi-engined Aircraft	9
6. DISCUSSION OF AIRCRAFT GROUPINGS	9
6.1 Application of Findings – Cautionary Note	10
7. CONCLUSIONS	11
8. JUDGEMENT AND PROPOSALS	11
9. REFERENCES	12
FIGURES 1 to 6	13 to 15

EXAMPLE OF RISK ANALYSIS APPLIED TO EN-ROUTE FLIGHT PATH FOR LARGE JET TRANSPORT AIRCRAFT

1. NOTATION AND UNITS

		Units
EPR	engine pressure ratio, a thrust setting parameter	–
$\text{MIN}\left[\quad \right]$	minimum of terms in $[\quad]$	–
N	number of engines on aircraft	–
N_1	engine first stage compressor rotational speed, used as a thrust setting parameter, expressed as a percentage	–
n	number of engines failing on aircraft	–
$O[\quad]$	observed value of $[\quad]$	–
$\text{Pr}[I]$	probability of an incident	–
$\text{Pr}[n]$	probability of an incident with n engines failed	–
$\text{Pr}[N, n]$	probability of failure of exactly n engines for aircraft with N engines	–
$\text{Pr}\left[O[\gamma_n] > \gamma_n\right]_N$	probability that $O[\gamma_n] > \gamma_n$ for aircraft with N engines	–
$\text{Pr}\left[\chi^2\right]$	probability of occurrence of χ^2	–
t_0	planned flight time	hr
$(t_0)_{crit}$	critical flight time	hr
t_1	flight time to diversion airfield	hr
z	percentage point in Normal distribution	–
γ_n	difference between net and gross climb gradients with n engines failed, expressed as a percentage	–
$\Delta[\gamma_n]$	difference between expected (mean) and measured climb gradients with n engines failed, expressed as a percentage	–
ρ	probability of failure of any engine	per hr
$\sigma[\quad]$	standard deviation of value of quantity in $[\quad]$	–
χ^2	“Chi-squared” test statistic (see Reference 1)	–

1.1 Definitions

Incident Probability	<i>The probability on a given flight of the performance of an aircraft falling below a defined datum performance (see page III 12 of Reference 6). Note that an incident does not necessarily lead to an accident as further factors may be involved.</i>
Design Incident Probability	The incident probability assumed by design or Regulation.
Datum Performance	<i>The performance of an imaginary aircraft that would just fly on a surface, where obstacles below that surface would mean that an accident was highly probable (see page III 12 of Reference 6).</i>
Gross Performance	<i>The Gross Performance is such that the performance of an aeroplane, measured at any time, is at least as likely to exceed the Gross Performance as not (see Reference 3).</i>
Net Performance	<i>The Gross Performance modified in the manner prescribed in the relevant Regulation to make appropriate allowance for those variations from the Gross Performance which are not dealt with in Operational Regulations (see Reference 3).</i>
NTSB	<u>N</u> ational <u>T</u> ransportation <u>S</u> afety <u>B</u> oard, the U.S. Federal accident investigation organisation.
ETOPS	<u>E</u> xtended <u>T</u> win <u>O</u> perations, the operation of twin-engined aircraft over very long distances under additional safety regulations.
Critical Flight Time	A flight of duration such that the probability of failure of a second engine is equal to the specified incident probability (see page III 84 of Reference 6).
IFSD	<u>I</u> n- <u>F</u> light <u>S</u> hut <u>D</u> own rate, the frequency in a defined period for a defined fleet of aircraft or model of engine shut-downs. This figure will include precautionary shut-downs for any reason as well as engine failures.

2. INTRODUCTION

This worked example follows the process where a question is asked that requires judgement to be used to assess the risk associated with a potential change, in this case, in a long-established regulation. The data used within the example are valid and have not been 'invented' to illustrate a theoretical method, and hence the findings are considered valid. Every effort has been made to illustrate the thought process and judgements reached within the example, which are illustrative of one method, but are not necessarily either the only or the best method. Further information or a better analysis of existing information could result in a more refined solution.

An introduction to the treatment of risk within commercial air transport is provided by Reference 2.

3. QUESTION TO WHICH AN ANSWER IS SOUGHT

Certification Standards (CSs) (formerly known as Joint Airworthiness Regulations, JARs), state for large transport aeroplanes, the following performance requirement.

CS25.123 En-route flight paths

CS25.123(b) The one-engine-inoperative net flight path data must represent the actual climb performance diminished by a gradient of climb of 1.1% for two-engined aeroplanes, 1.4% for three-engined aeroplanes, and 1.6% for four-engined aeroplanes.

Is this margin necessary, or correctly sized, for an acceptable level of safety and should there be a distinction between aircraft with different numbers of engines?

This same question, if stated in terms of risk, can be expressed as follows.

If the en-route performance margin were to be removed, would the risk to fare-paying passengers be increased to a point where it would be considered unacceptable? If it were diminished or the differences between aircraft with 2, 3 or 4 engines removed, would the risk to fare-paying passengers become unacceptable?

4. REVIEW OF BACKGROUND TO PERFORMANCE MARGINS

4.1 Regulatory Basis

The over-arching principle governing regulatory aircraft performance is the definition and certification of gross performance followed by the application of a margin. The margin essentially adds safety and is usually applied by operational regulation, to give net performance, which is then used by the aircraft operator. In this example the regulatory margin is stated in the Certification Standard, CS25 (Reference 4).

It can be shown that this standard is similar to the U.S. Regulation, FAR25 (Reference 5), and that they both have their roots in ICAO documentation going back at least to the Final Report of the Standing Committee on Performance, issued in 1953 (Reference 6).

That Final Report determined en-route net to gross margins for two arbitrary design incident probabilities and for a given level of engine reliability. The exact mathematical workings and the link between these margins and those adopted later in the Regulations are not clear, but they appear to be broadly related.

The Final Report (Reference 6) assumed an engine failure rate of 350×10^{-6} per flight hour for piston-engined and turbo-jet powered aircraft, whilst today an ETOPS-accepted aircraft will have an in-flight shut-down (IFSD) rate of better than 20×10^{-6} per flight hour.

Further, an examination of the aircraft accident record for the last 20 years, for example as given by NTSB, Boeing or Airclaims, shows that no accident had, as a major contributory element, a shortfall in performance following engine failure in the en-route phase of flight.