



Example of risk analysis for an aircraft subject to performance errors

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EXAMPLE OF RISK ANALYSIS FOR AN AIRCRAFT SUBJECT
TO PERFORMANCE ERRORS

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1. NOTATION AND UNITS

Notation

		Unit
H_p	pressure height	ft
T_a	ambient temperature	C
W	aircraft weight	kgf
ρ	density	kg/m ³
σ	relative density, ρ/ρ_0	–

Subscript

0	denotes value at sea level in ISA
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1.1 Acronyms and Definitions

AFM	Aircraft Flight Manual	
EAS	equivalent airspeed	knot
IAS	indicated airspeed	knot
ISA	International Standard Atmosphere (datum of 15 °C)	
MCP	maximum continuous power	
MTOP	maximum take off power	
OAT	outside air temperature	C
SL	sea level	
TAS	true airspeed	knot
TOSS	take off safety speed (the speed an aircraft reaches shortly after lift-off)	knot
TOP	take off power	
WAT	weight-altitude-temperature	

2. RISK QUESTION

A small aircraft being operated in a hostile environment is subject to performance errors because the ambient conditions are not known accurately: for example the temperature indication may over-read when the aircraft is stationary on the ground. Is this likely to endanger the aircraft seriously? Also, what are the parameters that most affect the aircraft performance, and what simple analysis can be done to show where the risks might lie?

3. INTRODUCTION

This Data Item should be read in conjunction with the introductory Data Item on the treatment of risk, ESDU 08003 (Reference 1) and examples of risk analysis, ESDU 08004 and 08005 (References 2 and 3).

It is easily established that a number of factors will affect aircraft performance and these will clearly be seen inside the Aircraft Flight Manual (AFM) or other equivalent performance document. When operating normally the flight crew or company dispatchers will have access to all the information necessary for them to load the aircraft correctly and within limits, and to establish the performance information with regard to take-off, thereby enabling the aircraft to make a safe flight. However, circumstances can be envisaged where an aircraft has to be operated, for example in a war zone, where a pick-up has to be made in a remote and dangerous area when the operator will not have access to airport data. Such data may be ambient temperature and may include an uncertainty about the weight of the load to be carried by the aircraft. In more extreme circumstances the operator may be uncertain about the length of available runway, where runway damage or other circumstance has restricted the length, and as a result may not have the safety benefit of engine failure accountability within the distance actually available.

Given the above circumstances, what are the relative risks? Given a controlled analysis can the risks be understood and mitigated?

The above suggested “in-theatre risk” is only one case where a fuller understanding of the relationships between parameters critical to the performance of the aircraft is helpful. Other examples can be suggested, for example determining the accuracy of measurement for each parameter of a test aircraft instrumentation system – a “sensitivity analysis”, or an airline seeking a better understanding of where economies accruing from aircraft performance can be made.

By making use of published performance information the sensitivity of an aircraft to variations in those data can be established, which in turn provides a measure of the variations in risk.

In discussing this subject it should be made very clear that normal operations of any aircraft must be conducted in accordance with the AFM. The exercise demonstrated within this worked example is to show relationships within the AFM data that enable relative risks to be expressed and is not intended to suggest alternative un-approved modes of operation.

4. DATA

This example makes use of a set of published performance data in the form of “Performance Charts” applicable to a small twin turboprop, which is civil certified, but which is also used for military purposes. It has been certified to older airworthiness standards at weights up to 6120 kg without consideration of engine failure accountability, in other words the data assume no engine failure until after the aircraft has reached a take-off safety speed. Information is also available at weights up to 6120 kg including full engine failure accountability on take-off: in other words safety, will normally not be compromised by an engine

failure at any point in the take-off. As explained, this example makes use of performance charts, but the following workings apply equally well to data presented in tabulated form.

Regarding the regulations governing aircraft performance it should be noted that there are a number of hidden inherent assumptions. For example, no consideration of double failures is included, it is assumed that the regulations governing equipment reliability ensure that the probability of a double failure is sufficiently low that it need not be considered. Further, the use of climb data following an engine failure for some scheduled performance is because this has been shown to be a worst case. For example, a failure to retract the landing-gear will not be likely to occur at the same time as an engine failure. If the gear does fail to retract, the rate of climb with all engines operative will not be worse than with one engine inoperative and with the landing gear up.

5. CLIMB CAPABILITY

The climb capability of the aircraft will affect its ability to clear obstacles. This worked example does not consider specific take-off obstacle avoidance at a particular departure airport, but looks at the general climb capability as a means to avoid obstacles.

It would be possible to do a comparison by looking at the various pieces of published information, where different take-off weights are permitted depending on the regulation basis or the selected flap setting. Assuming that the power available is the same, these variations will, to some degree, indicate the respective risks, where it can be assumed that a heavier aircraft or one with a lower rate of climb is more at risk. However, inherent in this assessment is the regulatory basis: in other words that which is permitted by the regulation. It may be that different regulatory minimum climb gradients give an inaccurate sense to the results, because the regulation included an arbitrary bias that was unjustified or inaccurate.

Consequently it is best, initially, *not* to consider WAT (Weight-Altitude-Temperature) curves in making an assessment, but to work from basic rate of climb data, which reflects the capability of the aircraft, as measured.

5.1 Performance Chart Reading

Before examining the Performance Charts contained in this worked example it is worth explaining briefly how aircraft performance charts are constructed and presented. The principles are broadly similar for all charts, but this description refers specifically to a climb-gradient chart, similar to the chart shown as Figure 1.

The climb-gradient chart in question relates to take-off with flaps at 18° and for maximum power with one engine inoperative. The chart is normally read from left to right, following the direction of the arrowed dotted line overlaid on the chart. The chart consists of two groups of information, interlinked by a y-axis, or ordinate, scale of climb gradient expressed as a percentage.

The first group of information on the left-hand side of the chart consists of a matrix or carpet of values of pressure altitude, varying from sea level to 10000 ft, against temperature, varying from ISA – 20 °C to ISA + 30 °C. This carpet of values is set against an x-axis, or abscissa, of ambient temperature in °C and is constructed at a datum value of weight, in this case at a value of 5250 kg.

The second group of information on the right-hand side of the chart consists of a set of sloping individual curves, each varying with aircraft weight about the mean reference, or datum, value of 5250 kg. These curves allow an adjustment to the climb gradient due to an adjustment in the weight to another, desired,

higher or lower weight. Given input values of temperature, altitude and weight, a climb gradient can be found.

The dotted lines drawn on the chart are generalised example lines showing how the charts should be used, with the arrows indicating the direction to read the chart. When using the weight grid one must always enter the chart from the left and go directly to the datum or reference line and then read, down and right or up and left, to intercept the vertical line of the input value of adjusted weight.

With care, the charts can be used in reverse where, for example, with a required value of gradient a maximum value of weight can be established, the altitude and temperature being given. If in doubt in this situation, an iterative process using the chart only as directed from left to right is recommended.

The term 'gradient', as used in this Data Item, refers to the change in height of the aircraft divided by the horizontal distance that it travels in the period of time under consideration (expressed as a percentage value). An incremental gradient or change in gradient is expressed in absolute terms.

5.2 Single-engined Climb Capability

Two pieces of gradient information are available, take-off climb gradient at the take-off flap setting (18°), see Figure 1 and en-route climb gradient, flaps retracted, see Figure 2. Taking Figure 1, the vertical axis is a measure of the absolute climb gradient. In the processes described below only absolute values of gradient, expressed as a percentage, are used and it should be noted that where percentage is used it refers only to an absolute measured value and not the relationship in percentage terms of one reading to another.

To establish the effect of temperature on climb gradient two points can be chosen on a line of constant altitude on the left hand grid, for example 6000 ft at ISA $^\circ\text{C}$ and 6000 ft at ISA + 30°C . At the datum weight of 5250 kg these give climb gradients of 3.0% and 0.2% respectively, so for a change or error in temperature of 10°C the change in gradient will be 0.9%, as noted in Table 5.1. This establishes a 'rate of exchange' between temperature and gradient for the conditions chosen, namely 6000 ft and 5250 kg. This can be repeated for other altitudes and weights or an assumption can be made that as the slopes of the lines on the grid in Figure 1 do not vary very much the figure of 0.9% can be used as a typical value.

Repeating the above process, but using two starting points on a line of constant temperature will then give the effect on climb gradient of a change in altitude. Taking 2 000 ft, ISA + 10°C and 10 000 ft at ISA + 10°C , gives climb gradients at a datum weight of 5250 kg of 3.7% and 0.5% respectively, so that it can be seen that a change in altitude of 1000 ft for datum conditions of temperature of ISA + 10°C and a weight of 5250 kg gives a change in gradient of 0.4%, also noted in Table 5.1.

The effect of a change in weight on climb gradient can be established using the right-hand weight grid in a similar manner. With use of an arbitrary datum condition of temperature of ISA + 10°C and an altitude of 6000 ft, which on the Performance Chart relates to the fourth from bottom weight line on the right hand grid, it can be seen that at weights of 6000 kg and 4500 kg the gradients will be 0.3% and 4.2% respectively, so that it can be determined that the effect of a 500 kg weight change will be 1.3%, as noted in Table 5.1. Note that the example lines of Figure 1 show this reading for the 6000 kg point and those for Figure 2 for the 4500 kg point.

What is being done in the above process is to reduce the variables affecting performance, altitude, temperature and aircraft weight to equivalent values of one parameter, namely gradient, such that the effect of errors or changes in altitude, temperature and weight can be compared using a common, equivalent basis.

In this way Figures 1 and 2 can be examined and average 'exchange rates' in terms of climb gradient can be established for all the parameters shown, temperature, altitude and weight and, by using either Figure 1