ENGINE NON-CONTAINMENT -- THE UK CAA VIEW

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SUMMARY

Present turbine engine non-containments happen too frequently for comfort, although fortunately the world-wide fatal accident level from this cause has not been excessive.

By far the majority of turbine engine induced accidents lie in non-containments, and therefore if the engine industry is to contribute to improved airworthiness, this is the problem it must tackle.

Because -

(a) the world-wide non-containment rate shows no sign of diminishing over the last decade,

(b) there seems to be no immediately obvious engineering avenues which will confidently lead to a quick reduction of incidents,

(c) the weight penalty of total containment is high,

the only valid solution for the immediate future seems to be to provide an adequate level of aircraft invulnerability.

This the CAA has attempted to achieve by introducing a requirement which it believes to be objective and capable of rational analysis. It can be applied to new designs without undue economic penalty and will enable an acceptable level of airworthiness to be achieved.

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PART 1 The Perspective

At first sight, the reader may wonder what FIG 1 has to do with the title of this paper or the purpose of this 'Workshop'. In fact it shows that for more than 200 years we have been throwing pieces of hot metal at each other! FIG 2 shows that we are still at it. We can, of course, take comfort from the fact that the present situation is unintentional and not done with 'malice aforethought', but it must still be obvious to anyone closely engaged in the aviation business that not infrequently an aircraft hazard is created by the energetic debris arising from an engine rotor disintegration. This hazard was introduced at the same time as turbine engines and may perhaps be regarded as fundamental to them, since the rotation at high speed of the sort of mass typical of modern engine spools ties up huge amounts of energy. Some idea of the destructive potential is given by the realisation that the energy of rotation of a large modern engine can now be reaching 20 million ft.lb. and that across an aircraft can be approaching the energy rejected into the brakes during an abandoned take-off. (FIG 3).

The potential for hazardous damage is therefore obvious, although it will be shown later that this particular hazard has not been responsible for large numbers of fatal accidents. Therefore while it is proper, in fact necessary, that the Industry and Authorities should look into the whole situation, it is important that perspective is maintained so that in a world where resources are not infinite, a good balance of effort will be maintained.

Let us therefore spend a few minutes putting the whole problem into some kind of perspective. FIG 4 shows an analysis of a large number of 'accidents' to public transport (ie air carrier) turbojet aircraft. It is not an exhaustive survey but it is based on world-wide accident records to a given list of aircraft over a period from 1966 to 1976 inclusive.

(An accident here is that defined in Annex 13 of ICAO Standards and Recommended Practices, ie, one in which -

(a) any person suffers death or serious injury as a result of being in or upon the aircraft or by direct contact with the aircraft or anything attached thereto,

or

(b) the aircraft receives substantial damage).

The total number of accidents in the survey is 513, and the estimated aircraft hours involved, 103 million. The total accident rate is thus running at about 5 per 10^6 aircraft hours and the fatal rate at 1.4. The accident causes may be broken down into -

299 due to operational reasons	(58%)
134 due to airworthiness reasons	(26%)
80 due to other (or undetermined) reasons	(16%)

The airworthiness accidents, which are the sort of prime interest to this Workshop, thus account for roughly a quarter of the total, at a rate of 1.3 per 10^6 aircraft hours, and which may again be broken down (FIG 5) into:-

55 due to powerplant reasons	(41% of the airworthiness accidents)
79 due to other than powerplant reasons	(59% of the airworthiness accidents)

FIG 6 then subdivides the powerplant reasons into further detail, the chief message of which, for the purpose of this paper, is that by far the majority of powerplant caused accidents are attributable to or directly involve an engine non-containment of some form. The non-containment caused accident rate is 0.4 per 10^6 aircraft hours, the rate involving fatalities being fortunately lower at 0.03, this failing to meet our current suggested airworthiness target of 1 per 10^8 aircraft hours (for a single engineering cause) by a factor of 3.

This leads to the first main point I wish to make (FIG 7) viz that -

> "any significant improvement to the overall accident scene by virtue of action in the powerplant area must best lie in the direction of diminishing the danger arising from non-containment."

PART 2 Engine Statistics

Having decided (and I am sure my 'Workshop' hosts will be gratified to hear it!) that we have a problem worth attacking, it is now necessary to dig deeper to see if we can ascertain where the problems are arising. For a number of years now, the Power Plant Department of the CAA has kept a record of all non-containment incidents it could lay its hands on. For UK produced engines, we have complete records, but of course our accuracy is less for other countries. We are however, fairly sure that the hours used for determining the statistics are accurate enough to allow fairly confident use to be made of the data.

FIG 8 shows the non-containment rate, world-wide, for the past 10 years or so. Two obvious conclusions strike one immediately from the data, ie that the rate is about 1 non-containment per 10^6 engine hours, and that the rate has been reasonably constant over the period.

FIG 9 shows the same data broken down into incidents arising from compressors (including fans) as against those arising from turbines. The curves show that there is little to choose between the two, though perhaps in view of the larger number of compressor stages compared with turbines, it could be said that individually turbine rotors are more prone to failure than compressor rotors.

Non-containments involving only blades represent to some extent a failure to meet existing international engine requirements which all demand blade containment. However, the tests conducted are only required to demonstrate containment of one blade, and obviously many real failures involve more than this. Additionally, some non-containments of blades are produced by the blade being punched through the casing rather than breaking through ballistically, and these types are of a less dangerous nature, since the emergent energy is low. As might be expected, and as is borne out in practice, non-containments involving a failure of some part of the disc are generally more dangerous than those involving blades. FIG 10 shows the rate of such failures and FIG 11 the same data divided again as between compressors (with fans) and turbines. The conclusions to be drawn are that about half of non-containments involve a failure of some part of the disc, again that the compressor/turbine rates are not dissimilar, and again that there is no great sign of improvement over the years.

There are two other data that might be useful. FIG 12 shows non-containments grouped by 'phase of flight'. The criterion of prior to or post V_1 is not always determinable from incident reports, but the volume of statistics is probably enough to swamp minor errors. The data may be interpreted in a crude way as showing incidents divided into four roughly equal flight phases, viz prior to V_1, V_1 to power reduction, climb, remainder of flight. Paragraph (f) below gives the data more accurately but in a way less easy to remember. FIG 13 attempts to show the underlying causes. Here we are on much more difficult ground, since causes are treated very subjectively. For example, it may be easy to see that a failure had its origin in combustion chamber distortion, but whether the cause of that was due to poor operation, faulty material, errors of overhaul, fundamental design, etc, is often not clear and can depend on who is making the judgement! It is, of course, almost always the fault of someone else! However, the Figure is attached for what it is worth, and primarily because of one main conclusion which can be drawn from it - that is that there is no obvious single item which if tackled successfully would in itself produce a dramatic improvement in the non-containment scene - a point to which we shall return later.

All the above data was recently presented to a UK committee comprising the UK engine and aircraft industries as well as the CAA, and I append below the conclusions of that committee in summary form. (In case you think I am passing the buck, I should perhaps say I was a member of the committee).

(a) The average (world-wide) non-containment rate from all causes is 1 per million engine hours. This figure has been fairly constant for 10 years.

Note Roughly one-quarter of these non-containments have caused aircraft damage outside the confines of the nacelle. The 'significant' non-containment rate may therefore be regarded as about 1 per million aircraft hours. It might be noted, by referring back to FIG 6, that about half the 'significant' non-containments are serious enough to be classified as reportable accidents.

(b) Of all non-containments, about half involve a disc failure of some degree. The non-containment rate for disc failure is, therefore, 1 per 2 million engine hours. As might be expected, discs contribute more 'significant' non-containments than blades, in fact twice as many.

(c) Of all non-containments about one-eighth have resulted in the release of debris approaching or equal to a third of a disc. The major fragment rate is, therefore, about 1 in 8 million engine hours (say 1 per 2 million aircraft hours).

(d) Compressors and turbines make about equal contributions to non-containments. Fans provide perhaps 10% of the total (based on less experience obviously).

(e) Although depending on a somewhat subjective judgement, it appears that about half the disc failures are of a secondary nature.

Of the primary failures, nearly half are attributable to HCF (High Cycle Fatigue). No other single cause stands out on either the primary or secondary failures.

(f) As to phase of flight, the following is broadly true (although with the advent of engines whose rpm increase with altitude to the extent that cruise rpm may exceed that of take-off, this breakdown may be modified).

Phase:	T O before V_1	V_1 to power reduction	Climb	Remainder
% :	35	20	22	23

(g) No single predominant cause can be identified the cure of which would give a dramatic decrease in non-containment incidents. However HCF accounts for a high proportion and should therefore be given special consideration.

PART 3 Possible Solutions

In considering what might be done to minimise potential accidents due to non-containment, there are three immediately apparent solutions (FIG 14) -

(i) We may work on the root causes of the failures and attempt to eliminate them.

(ii) We may assume that the failures will continue to occur at a rate higher than is tolerable, and attempt to contain all the debris within a strengthened engine casing.

(iii) We may accept that uncontained debris will continue to be generated and make the aircraft design acceptably invulnerable to the debris by such means as deflection, the judicious siting of critical parts and structure, suitable duplication where appropriate, armouring, etc.

The first solution, being basic, seems right and attractive but as will be shown later, a reduction in present non-containment rates of at least an order of magnitude is necessary for this solution to be viable. Unfortunately, as FIG 13 indicates, something like a third to a half of all disc failures are from causes to which the disc failure is secondary, and we felt it would unrealistic to believe that any overwhelming improvement could be made to such a large number of unrelated prime causes. Even taking those cases where the disc failure is itself primary, there are still six or seven fundamentally different causes, none of which carries any obvious promise of easy solution and cure. Perhaps the relatively low number of basic LCF failures is interesting since this is a subject to which, after a few early failures, a great deal of attention has been paid, obviously to good effect. However, HCF, which now probably accounts for more failures than LCF, is much more difficult to cater for, since it tends to arise in much less predictable ways. I hope some other papers at this Workshop will be devoted to that subject.

It was therefore reluctantly concluded in the CAA that there could be little confidence in the engine industry's ability to produce engines which within the foreseeable future (by which we mean the next ten years) would achieve significantly reduced levels of non-containment incidents, and nowhere near the order of magnitude reduction we would need. I say reluctantly in the sense that regarding myself as a member of the engine fraternity, I am disappointed that we cannot guarantee to deliver engines free from this endemic disease. However, we must be honest enough not to try to avoid the truth and to admit, even with red faces, our inability to be certain of doing much better in the immediate future. (And I hope nothing here said will in any way diminish the desire and intent of this Workshop to prove me completely wrong).

Moving to the second solution, this is also an attractive one to an Airworthiness Authority since if we cannot stop the debris being generated, it would be almost as good to keep it inside the engine. It also has merit in lessening the danger arising from such unavoidable incidents as large bird ingestion where the benefit of total containment is obvious. Unfortunately, after numerous discussions with both the engine and aircraft industries, we were left with little hope, in the present state of the art, of effecting containment without swingeing increases in engine weight, except possibly on quite small engines or APU's. Estimates of 1 pound per 10,000 ft.lb. of energy to be absorbed or 2/3 pound per pound of bladed disc weight have been variously calculated, the final results implying an increase of bare engine weight of anything up to 50%. Of course containment does not have to be total, and it is interesting to look into partial containment, for example of the smaller debris, together with possible deflection. NAPTC may be able to suggest ways of reducing these figures, and I will be interested to hear of their recent work, but of course if the consideration of the larger pieces dictates the design, containment of the smaller ones may be less attractive.

However, the conclusion we reached, in association with our manufacturers was that the most reliable, practicable and cost-effective solution is the third, ie to make the aircraft relatively invulnerable to any likely debris which may affect it. (Though this decision was one which we felt we had to take in the time scale we were considering, it would be quite premature to abandon all hope of someday achieving solutions one or two, and such efforts as are being made by this Workshop are to be encouraged to keep this difficult task in active play).

PART 4 The UK Requirements

The CAA, having reached the conclusion that the only practicable requirement for the immediate future was to achieve a reasonable degree of aircraft invulnerability then gave thought to the form which the requirement should take. Phrases like "Shall minimise the risk" are very easy to put into requirements and are attractive in that they can be agreed with industry without too much argument since the broad principles involved are so obviously sensible. Unfortunately, when the crunch comes, it soon becomes apparent that there is a considerable conflict of opinion as to where minimising should stop!

The aim of the requirement in its simplest form is clear, viz, that unless an engine will contain any likely debris that it might generate, the chance of catastrophe occurring to an aeroplane from being struck by such debris should be something less than 10^{-8}/aircraft hour. While this provides a good aim, it was much more difficult for the aircraft industry to see a way of being able to demonstrate compliance in a convincing way, since of the two components contributing to the risk, ie 1) the probability of debris being generated and 2) the probability of the debris causing catastrophic damage, the former and more critical component was completely outside the competence of the aircraft constructor to assess. It was therefore decided to write the requirement such that only the latter term would be quoted, the former being assessed by the CAA and appearing only implicitly in the requirement.

I have already shown that a figure for debris generation of 1 per 10^6 engine hours was well founded as an average, and not subject to a particularly wide variation over a range of current engines. Knowing that about a quarter of the incidents caused 'significant' aircraft damage, ie damage outside the nacelle, the 'significant' rate may be expressed as being in the order of 1 per 10^6 aircraft hours. Starting from this precept therefore, the aircraft constructor needed to provide an additional factor of about 1 per 100 against a 'significant' engine non-containment ending in catastrophe.

Thus the aircraft constructor would be left with an assessment to make which was well within engineering judgement. The only further point remaining to him was to have a definition of the sort of non-containment debris that he had to consider, ie a freedom from catastrophe of 1 in 100 against what? We again decided that this judgement was also outside the area of knowledge of aircraft designers and in fact we doubt if even the engine designers can do much in the way of valid prediction since their avowed intent is to produce engines which never fail in this way.

We therefore decided that past experience was the only valid guide available to us, and although the requirement should be written in a way flexible enough to allow any peculiarities of an engine to be taken into account, the failures to be considered would be based on past history.

Thus the task was to provide a failure 'model' with which the aircraft constructor could assess his design against the 1/100 factor. Initially we tried very complex models which became so sophisticated that they defeated their own purpose. In the end we decided to revert to a simple model even though, as would be expected, it would be somewhat arbitrary - that is to say that we would never claim that it represents the actual way in which any given engine is most likely to fail - only that it provides a yard-stick against which the aircraft design can be measured.

One of the obvious pieces of debris to be considered seemed to be the 1/3rd disc piece (this being very near the mathematically maximum energy of translation sector and also coinciding with current FAA thinking on FAR 25.903(d)). We then studied the distribution of debris which had been shed in a selection of previous non-containment incidents and chose one further piece to represent the mean of all the residual pieces which could not be considered to be covered by the 1/3rd piece.

Thus, starting with the distribution of the size of non-containment debris from a number of incidents where Rolls-Royce were able to recover the debris and assess the mass (and this is not a common state of affairs - often, thank goodness, a lot of the debris disappears into thin air!) we were able to construct a probability curve. (FIG 15). Having decided already that one of the model pieces should be the 1/3rd disc, and wishing to represent the remainder by one other arbitrary piece, it can be shown that this should be of 1/20 disc mass. From the probability of each of these types of failure occurring, we could then devise a figure which described the desired level of invulnerability of the aircraft design such that if engines continue to fail at the sort of rate which has applied in the past, the aircraft will have an acceptable level of airworthiness against this particular hazard.

Reference back to the data shows that the probability of the smaller (1/20 disc mass) piece is about twice that of the larger piece. We therefore had the equation : there is a significant non-containment (ie one causing damage outside the nacelle) every million aircraft hours, two out of three of which may be regarded as releasing a 1/20 piece, and one in three a piece getting into the 1/3rd disc size ballpark. If the target risk from this cause for catastrophe is to be less than 10^{-8} per aircraft hour, simple mathematics show that the invulnerability factors if the allowance is equally proportioned must be 1/133 for the smaller and 1/66 for the larger piece respectively.

$$\text{ie} \quad \frac{2}{3}(1 \times 10^{-6}) \times \frac{1}{133} + \frac{1}{3}(1 \times 10^{-6}) \times \frac{1}{66} \approx 1 \times 10^{-8}$$

We tested these factors against as much experience as we could and we concluded they were a bit tough since even aircraft which had good records could not meet them. We felt that this was probably because in estimating 'catastrophe', honest people were forced to be somewhat pessimistic, and that aircraft did on occasion survive incidents which any prudent engineer would have graded catastrophic. As a result we issued a paper for discussion with factors of 1/100 and 1/30, to test as it were, the temperature of the water.

Discussion with the aircraft industry still left doubt whether these figures were within the state of the art. Fortunately, in the course of our general work in dealing with incidents of a type which were potentially catastrophic when they occurred but which could be expected to occur at a low, unpredictable, frequency (ie of a type which have become to be described as 'unlikely though possible') we had been developing the idea that they can be dealt with by ensuring that if the unpredictable low frequency event does occur, there must be a 'reasonable' chance of a survival, enabling the problem to be exposed and corrected so as to avoid any possibility of a second occurrence. The choice of a number for such a 'chance' is arbitrary and subjective and depends to some extent on the <u>average</u> risk applicable to the 'unpredictable' event, but we had concluded that a chance of survival of 19 out of 20 was not unreasonable.

Taking the above into account, it was therefore decided we could reduce the 1 in 30 figure to 1 in 20 and the 1 in 100 to 1 in 60. It is this figure that now appears in our Requirements. It is expected that it will result in airworthiness risks in line with our target, but it cannot be too strongly emphasised that the risks are not intended to apply for the life of the aircraft, but assume that IMMEDIATE CORRECTIVE ACTION WILL BE TAKEN SHOULD ANY INCIDENT OCCUR. There must be no question of continuous exposure, or of living with a problem once it is exposed.

Of course, we would be naive if we assumed that in real life failures will cause debris like our model. We are not, and they won't. What we have done is created a requirement against which a non-subjective estimate of a design can be made. It is no more likely to represent the exact truth than an aircraft is likely to fly through a flock of exactly 4oz birds all perfectly spaced at 1 per 50 sq in. We do feel the requirement will act as a good yardstick against which the non-containment danger can be assessed.

One or two further refinements serve to make the requirement complete:-

(a) Dimensions. In many cases the debris will not be stopped but will lead to what I call the infinite hole - that is the part passes through all intervening structure. In this case, the cross section area of the hole is important, and can of course in theory be as large as the section of the failed rotor. Here again we have been arbitrary and assumed that some blade bending will take place and that as a mean the two model pieces should be assigned maximum dimensions of R and ½R (R being the <u>bladed</u> disc radius) respectively. FIG 16 summarises in pictorial form the sort of analysis which results.

(b) Energy. We have made the simplified assumption that the prescribed pieces will leave the engine with their full, theoretical, energy of translation intact. This means that we have struck a rough balance between the casing absorption and the neglected energy of rotation. I would be glad to have any ideas for improvement on this if better generalised assumptions would be preferable.

(c) Averaging. Since the non-containment rate used has been per engine and not per disc, we are saying that a disc will fail at the frequency quoted, but we don't know which. It therefore seemed fair to allow a certain amount of averaging in assessing the overall risk, allowing a disc presenting a relatively high vulnerability to be offset by one with a low potential. Further, the same sort of thinking seemed permissible, and is allowed, over the various phases of flight, whereby the risk which varies depending for example on whether the fuselage is pressurised or not can be averaged over the various regimes provided the through flight total meets the requirement.

(d) Dispersion. FIG 17 shows a distribution made of particle sizes against the angle through which they had been deflected during their flight from the engine. We chose ± 3° for the 1/3rd disc mass piece and ± 5° for the smaller one. These may appear a little on the small side, but we feel that deflection is likely to be greatest as the speed and energy drops, and that the damaging energy is likely to be confined within these limits.

(e) Duplication. One last consideration completes the model. Since we have settled for a stylised failure involving only single pieces, it is obvious that an automatic solution would be to duplicate any vital part. To prevent this being possible in a foolish way, we have added a further clause requiring consideration of three pieces, dispersed randomly to each other, in respect of duplicated items only. The required factor for the 3 piece case has been adjusted accordingly.

SUMMARY

Present turbine engine non-containments happen too frequently for comfort, although fortunately the world-wide fatal accident level from this cause has not been excessive.

By far the majority of turbine engine induced accidents lie in non-containments, and therefore if the engine industry is to contribute to improved airworthiness, this is the problem it must tackle.

Because -

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(b) there seems to be no immediately obvious engineering avenues which will confidently lead to a quick reduction of incidents.

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the only valid solution for the immediate future seems to be to provide an adequate level of aircraft invulnerability.

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ACKNOWLEDGEMENTS

I would like to thank the CAA for permission to publish this paper. It is conventional to dissociate one's employers from any views expressed. In this case I am happy to say I do not need to. I would however express my thanks to all my colleagues who have contributed whether directly or through their normal work, to whatever merit this paper may possess.

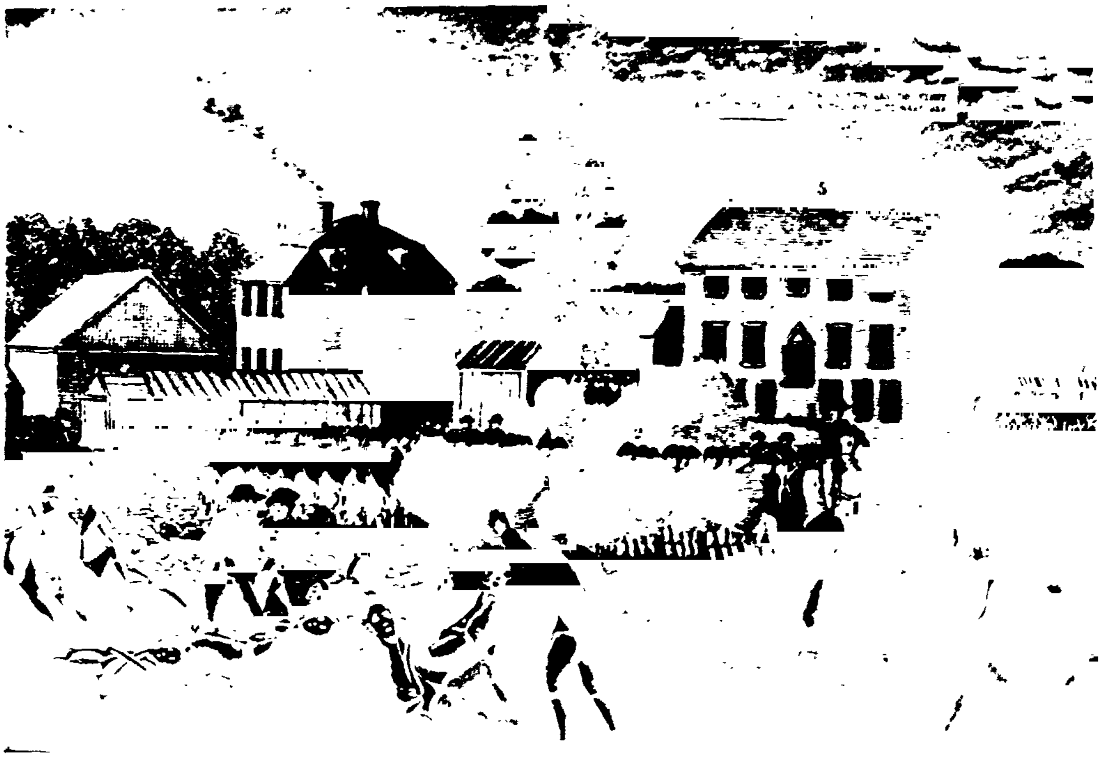


Figure 1. - Debris circa 1775.

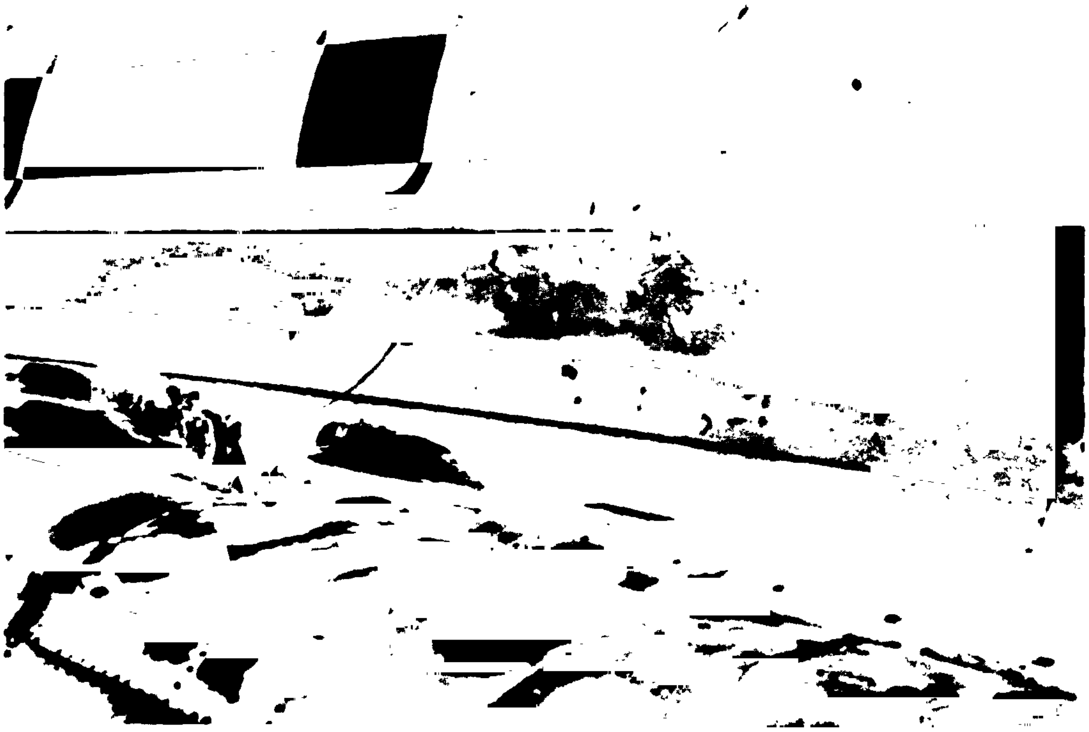


Figure 2. - Debris circa 1975.

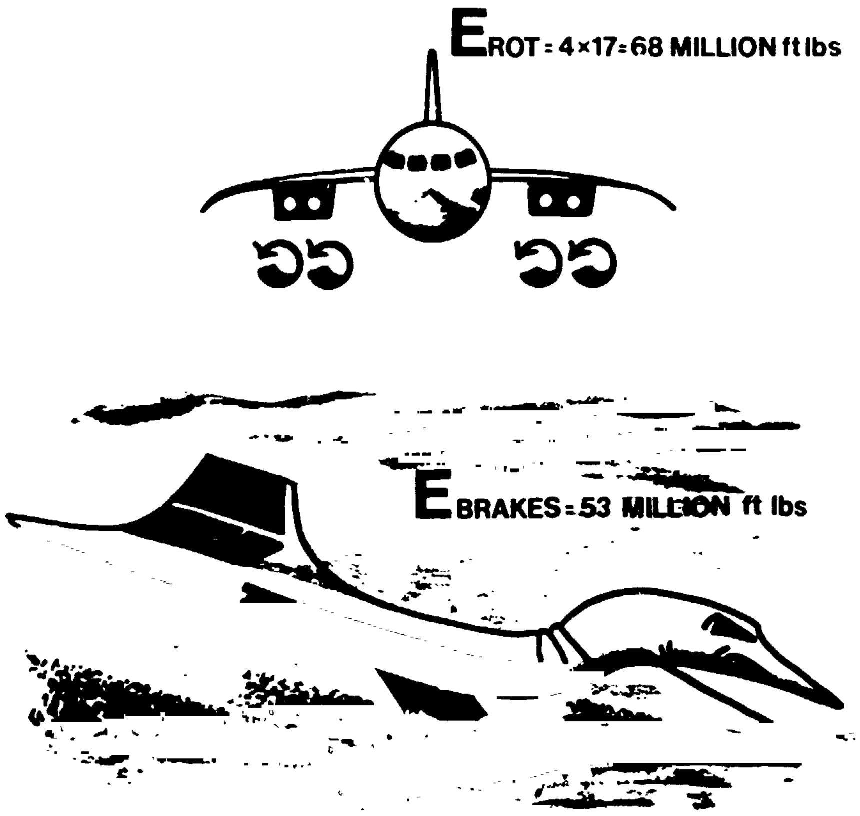


Figure 3. - Comparison of Energy of Rotation of Engines with Energy Rejected to Brakes on Abandoned Take-off.

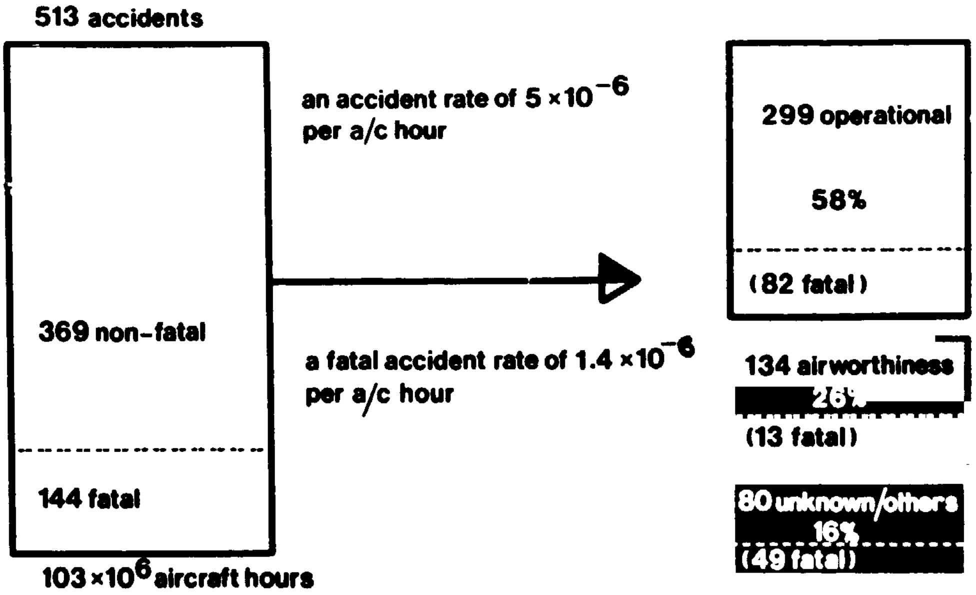


Figure 4. - Reasons for Jet Aircraft Accidents 1966-76.

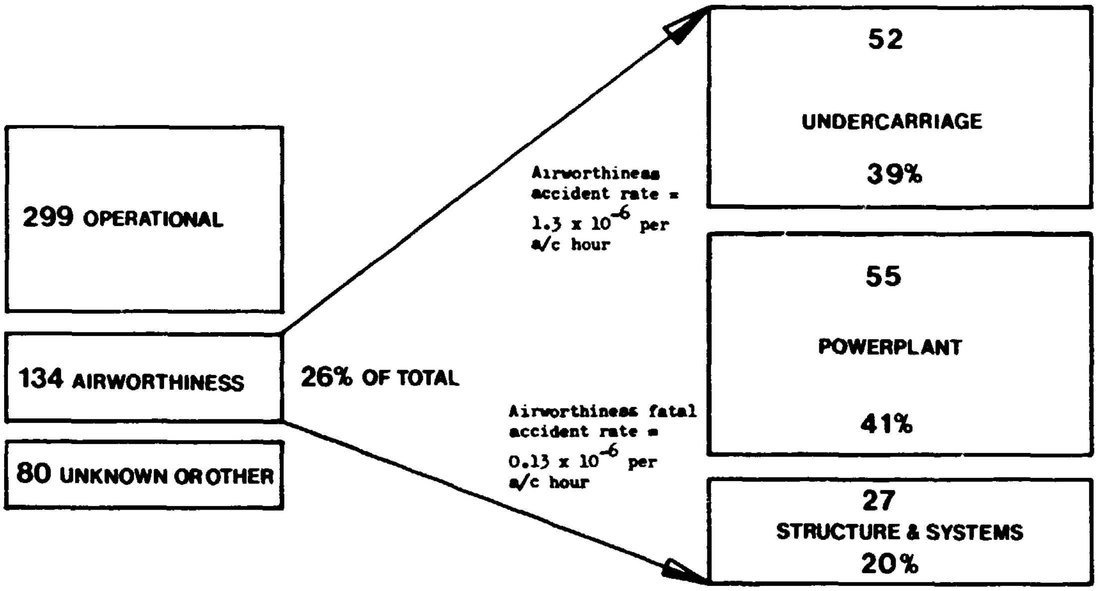


Figure 5. - Causes of 'Airworthiness' Accidents, Jet Aircraft 1966-76.

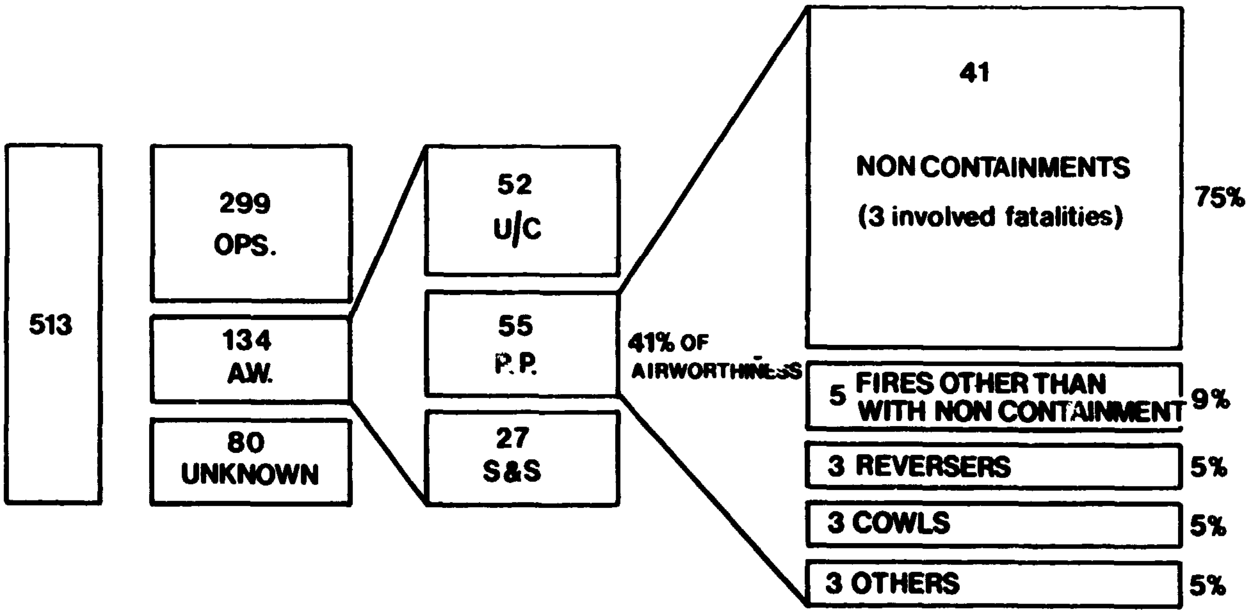


Figure 6. - Causes of Airworthiness Accidents Attributable to Powerplant, Jet Aircraft 1966-76.

> ***"Any significant improvement to the overall accident scene by virtue of action in the Powerplant area must best lie in the direction of diminishing the danger arising from Non-Containment"***

Figure 7. - Statement Deriving from Engine Accident Statistics.

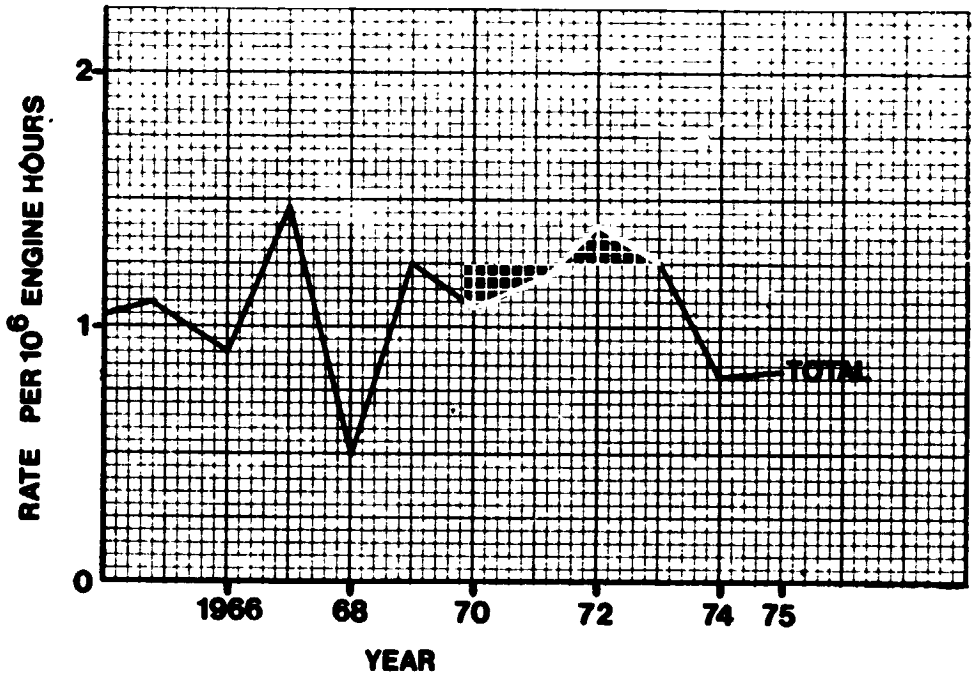


Figure 8. - Combined (World-Wide) & US (USA Register) Engines Total Non-containment Rate.

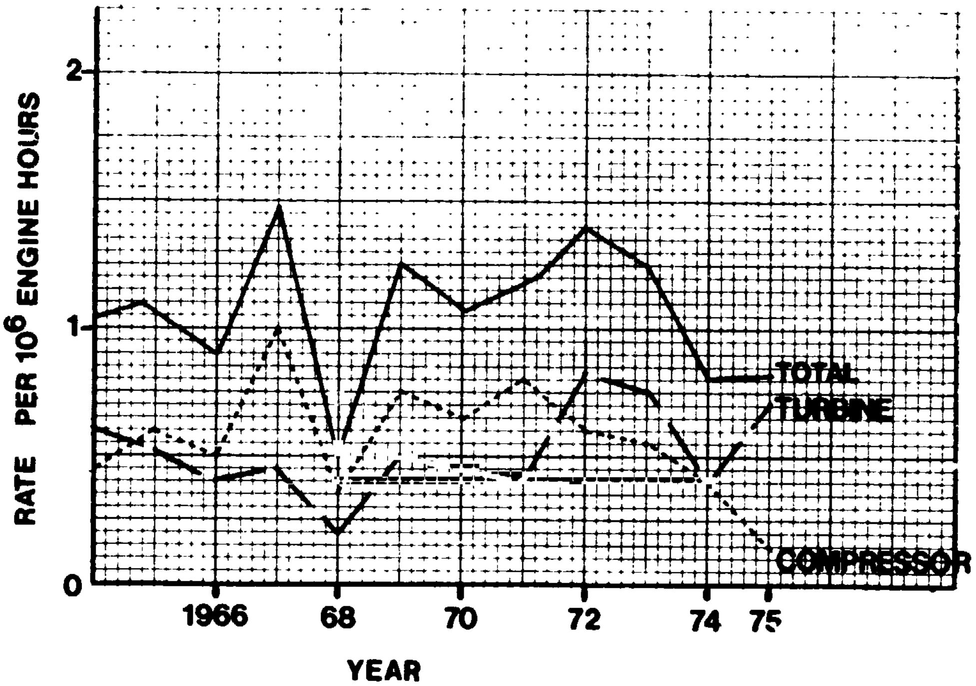


Figure 9. - Combined (World-Wide) & US (USA Register) Engines Total Non-containment Rate (showing rates for turbines and compressors separately).

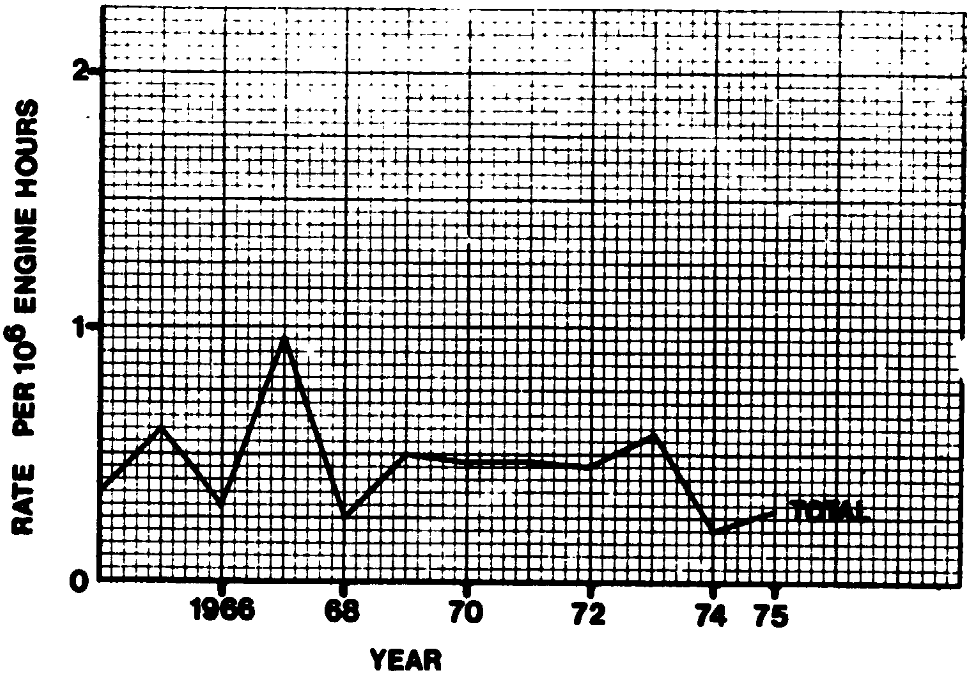


Figure 10. - Combined (World-Wide) & US(USA Register) Engines Disc Fragment Non-containment Rate.

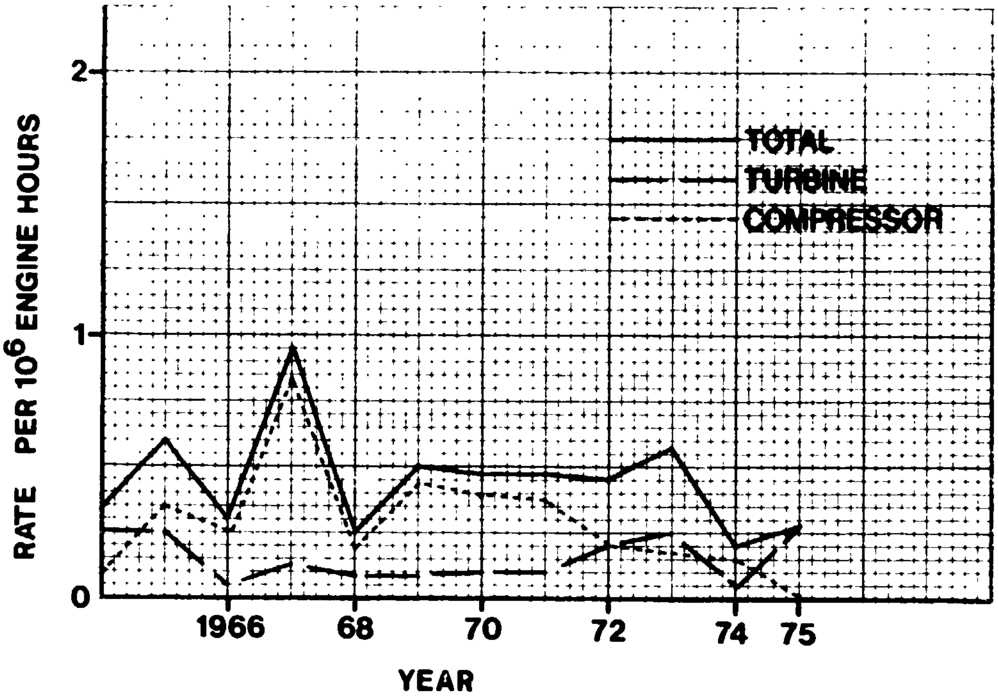


Figure 11. - Combined (World-Wide) & US (USA Register) Engines Disc Fragment Non-containment Rate (showing rates for turbines and compressors separately).

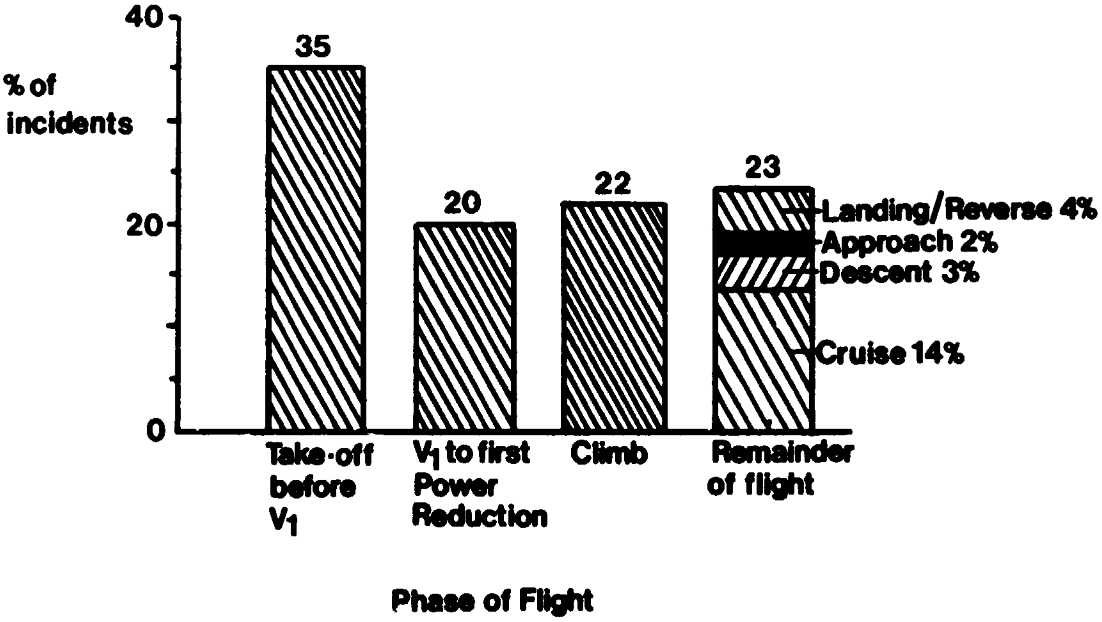


Figure 12 - Non-containments by Phase of Flight.

	DESCRIPTION OF FAILURE	UK ENGINES %	US ENGINES %
PRIMARY	MATERIAL DEFECTS	6	25
	MANUFACTURING DEFECTS	0	
	MISASSEMBLY	0	10
	HIGH CYCLE FATIGUE	33	15
	LOW CYCLE FATIGUE	9	
	COMBINATION HCF/LCF	3	
	OVERHAUL PROCEDURES	16	
SECONDARY	OVERTEMPERATURE	9	50
	FOREIGN OBJECT DAMAGE	3	
	DETACHMENT DUE SHAFT OR BOLT FAILURE	3	
	RUBBING AGAINST STATIC PARTS	9	
	OVERSPEEDING	3	
	HCF DUE BLOCKAGE	6	

NOTE: FOR US ENGINES, 20% 'UNKNOWN CAUSES' HAVE BEEN ALLOCATED IN THE ABOVE SUB-DIVISIONS IN THE SAME PROPORTION AS FOR THE KNOWN ONES.

Figure 13. - Causes of Disc Failures.

1) Eliminate Prime Failures

2) Contain any Released Debris by Suitable Shielding

3) Make Aircraft Invulnerable to Possible Strikes

Figure 14. - Acceptable Airworthiness Solutions Against Non-containment Problem.

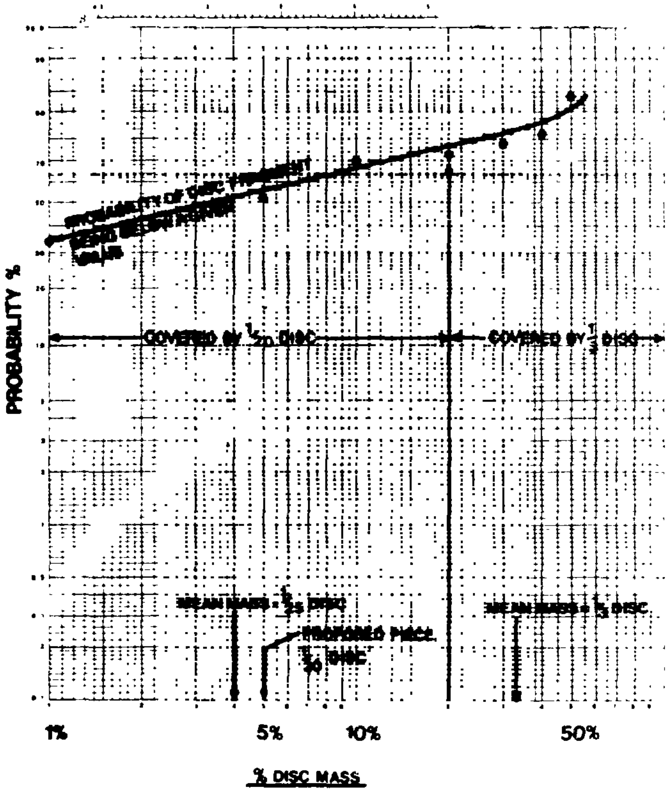
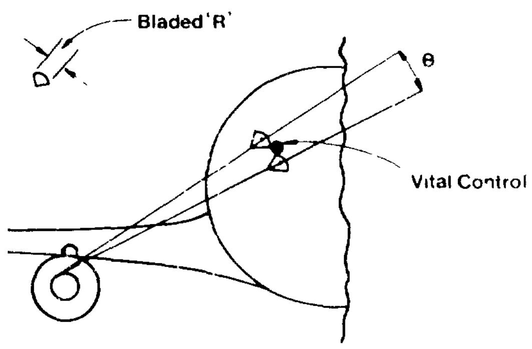


Figure 15 - Probability that Debris Mass is below a Given Proportion of Disc Mass



Probability of Strike in $\frac{1}{3}$ Disc Case = $\frac{\theta}{360}$

Probability of Control Failure leading to *Catastrophe* = $1/y$

Then Vulnerability = $\frac{\theta}{360} \times \frac{1}{y}$

Figure 16 - Vulnerability Analysis

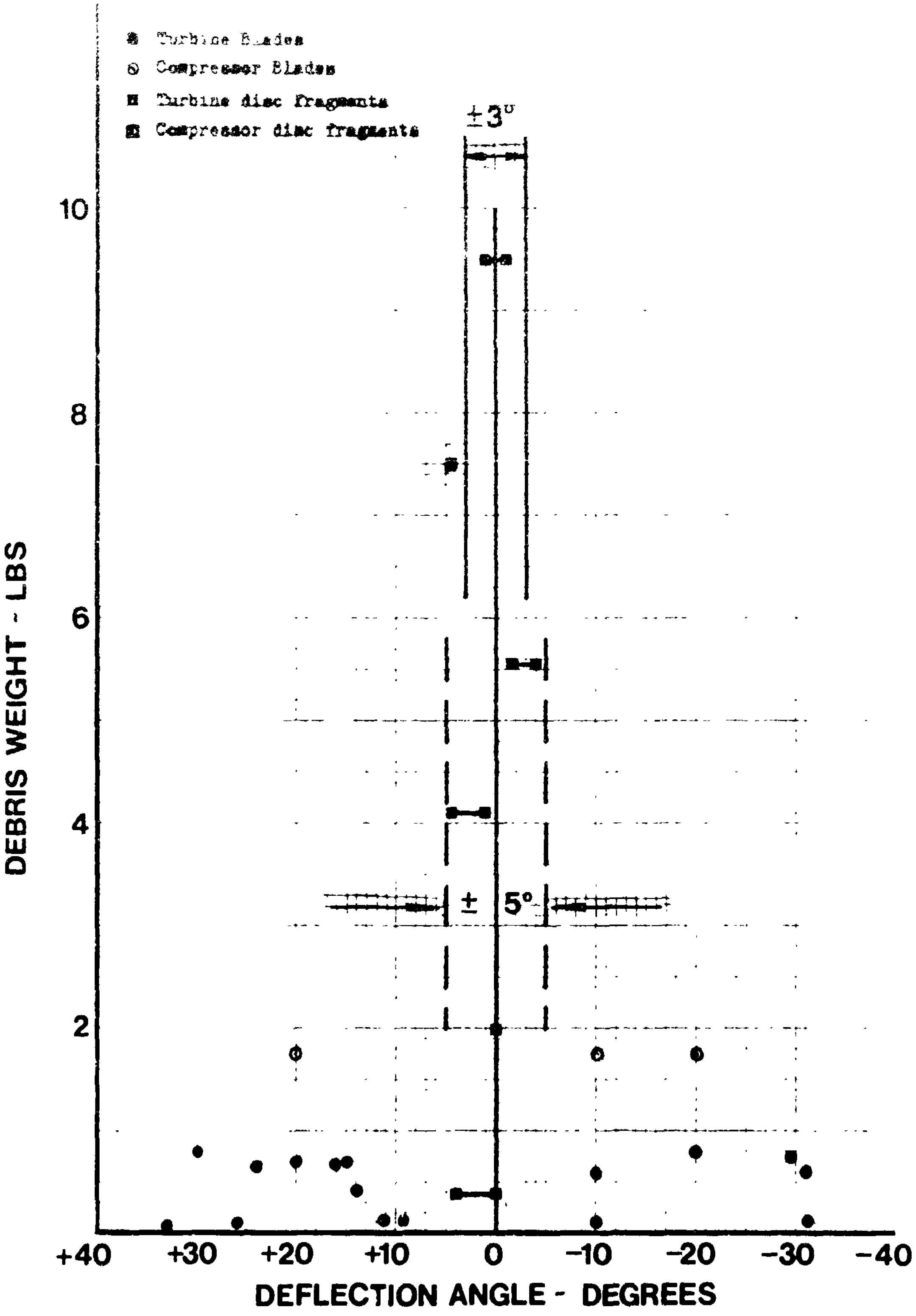


Figure 17. - Deflection of Debris versus Debris Mass.

DISCUSSION

Tom Horeff, FAA

Gordon, in your statistics you referred to 55 accidents due to powerplant reasons, of which 75% involved engine non-containment, or roughly forty in the period between 1966 and 1976. A rather simplistic view would be to say four non-containments per year. You added that one in four non-containments penetrates the cowl, or roughly one per year. My question, Gordon, is do you have corresponding data for passenger fatalities pertaining to the non-containment cowl penetration accidents that you referred to?

G.L. Gunstone, CAA-UK

Well, I think that we have just a slight misunderstanding of my figures. I know that it's been very unfair to push so many figures at you all at once but there are copies of my paper available which I'm sure you'd like to study later. What I would say, Tom, is that in my definition an accident is not necessarily a non-containment and a non-containment is not necessarily an accident. An accident in the ICAO definition is one which causes a serious injury to a passenger or substantial damage to an airplane, and there are very many more non-containments than there are accidents. I think that goes part way to answer your question. I have studied about a hundred million engine hours in the period taken, and in this hundred million engine hours (which could be perhaps 30 million aircraft hours) there have been 41 non-containment accidents and three fatal non-containment accidents. I did not, in the charts show those non-containments which did not become classified as accidents.

J.H. Enders, FAA

Gordon, I have a question that was posed by the "no-improvement" charts you showed. I don't interpret that data as implying that there has been no improvement in engine technology from a containment point of view. Rather, the growth in engines: that is, the larger diameter and larger thrust engines have continually posed a tougher problem to the designer to solve, and he's really improving in an absolute sense. To put it another way, he's really keeping up with the problem, not letting it get worse. Now some people might not agree with me, but truly the large diameter engine of today pose tougher containment design problems than did the smaller aircraft engines of a decade ago.

G.L. Gunstone, CAA-UK

I basically agree. But I think there is in all aircraft engine design a process of "brinksmanship". That is to say you push the design as far as you dare. Your constraints are economics, thrust, ...and so on, and you do not (unfortunately) apply all of the knowledge which you've acquired from previous experience to making an engine or aircraft safer. You use some of it, but the rest goes into making it cheaper. It is a matter of some judgment as to where the proper balance lies, and I was simply quoting what the facts are.

Could I just say, gentlemen, that I could bring only about 30 or so of these papers with me. They are up there for distribution. If anybody can easily share with a colleague I would ask him to do so for the moment. But I will get a clip-board put next to them, and if anybody fails to get a copy but would like one, if he will write his name and address I will have one posted as soon as I get back.