(8) Damage to or inadvertent movement of aerodynamic surfaces (e.g.. flaps, slats, stabilizers, ailerons, spoilers, thrust reversers, elevators, rudders, strakes, winglets, etc.) and the resultant effect on safe flight and landing.

c. Safety Analysis Objectives. It is considered that the objective of minimizing hazards will have been met if:

(1) The practical design considerations and precautions of Paragraphs 7 and 8 have been taken;

(2) The safety analysis has been completed using the engine/APU model defined in Paragraph 9;

(3) For part 25 transport and part 23 commuter category airplanes, the following hazard ratio guidelines have been achieved:

(i) Single One-Third Disc Fragment. There is not more than a 1 in 20 chance of catastrophe resulting from the release of a single one-third disc fragment as defined in Paragraph 9a.

(ii) Intermediate Fragment. There is not more than a 1 in 40 chance of catastrophe resulting from the release of a piece of debris as defined in Paragraph 9.

(iii) Multiple Disc Fragments. (Only applicable to any duplicated or multiplicated system when all of the system channels contributing to its functions have some part which is within a distance equal to the diameter of the largest bladed rotor, measured from the engine centerline). There is not more than 1 in 10 chance of catastrophe resulting from the release in three random directions of three one-third fragments of a disc each having a uniform probability of ejection over the 360° (assuming an angular spread of ±3° relative to the plane of the disc) causing coincidental damage to systems which are duplicated or multiplicated.

NOTE: Where dissimilar systems can be used to carry out the same function (e.g. elevator control and pitch trim), they should be regarded as duplicated (or multiplicated) systems for the purpose of this subparagraph provided control can be maintained. The numerical assessments described above may be used to judge the relative values of minimization. The degree of minimization that is feasible may vary depending upon airplane size and configuration and this variation may prevent the specific hazard ratio from being achieved. These levels are design goals and should not be treated as absolute targets. It is possible that any one of these levels may not be practical to achieve.

(4) For newly designed non-commuter part 23 airplanes the chance of catastrophe is not more than twice that of Paragraph 10c(3)(i), (ii) and (iii) for each of these fragment types.

(5) A numerical risk assessment is not requested for the single fan blade fragment, small fragments, and APU and engine rotor stages which are qualified as contained.

d. APU Analysis For APU's that are located where no hazardous consequences would result from an uncontained failure, a limited qualitative assessment showing the relative location of critical systems/components and APU impact areas is all that is needed. If critical systems/components are located within the impact area, more extensive analysis is needed. For APU's which have demonstrated rotor integrity only, the failure model outlined in Paragraph 9g(1) should be considered as a basis for this safety assessment. For APU rotor stages qualified as contained per the TSO, the airplane safety analysis may be limited to an assessment of the effects of the failure model outlined in Paragraph 9g(2).

e. Specific Risk The airplane risk levels specified in Paragraph 10c, resulting from the release of rotor fragments, are the mean values obtained by averaging those for all rotor on all engines of the airplane, assuming a typical flight. Individual rotors or engines need not meet these risk levels nor need these risk levels be met for each phase of flight if either--

(1) No rotor stage shows a higher level of risk averaged throughout the flight greater than twice those stated in Paragraph 10c.

NOTE: The purpose of this Paragraph is to ensure that a fault which results in repeated failures of any particular rotor stage design, would have only a limited effect on airplane safety.

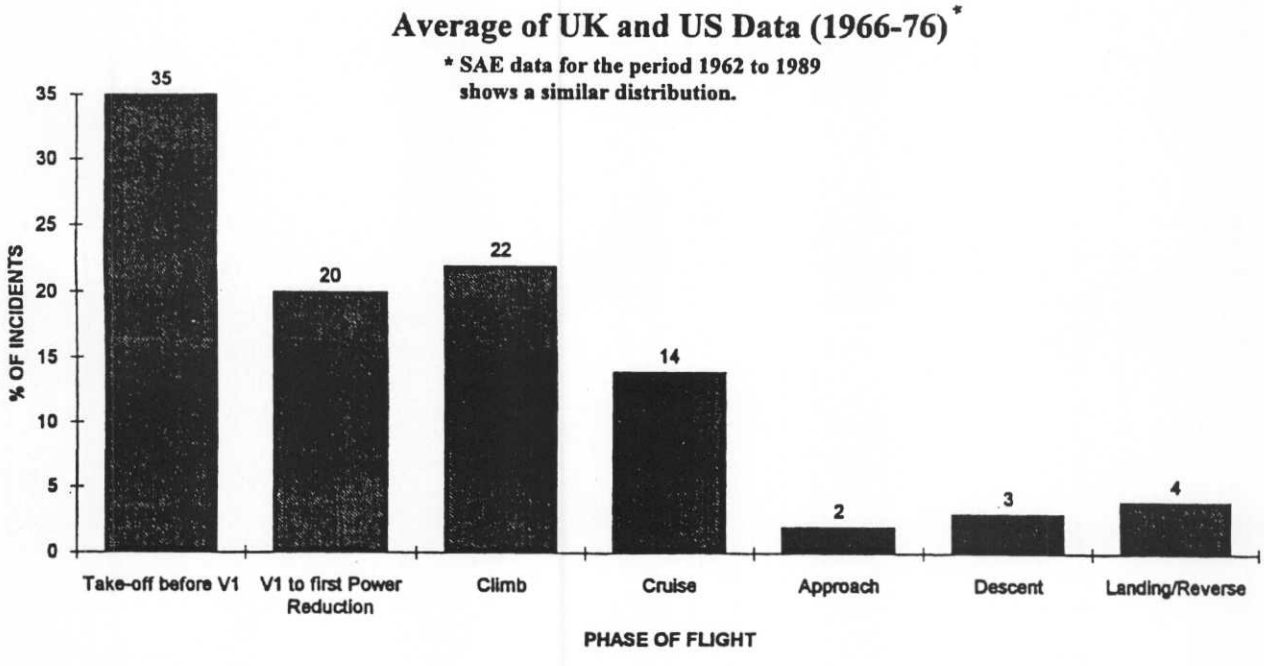

FIGURE 6 - ALL NON-CONTAINMENTS BY PHASE OF FLIGHT

(2) Where failures would be catastrophic in particular portions of flight, allowance is made for this on the basis of conservative assumptions as to the proportion of failures likely to occur in these phases. A greater level of risk could be accepted if the exposure exists only during a particular phase of flight e.g., during takeoff. The proportional risk of engine failure during the particular phases of flight is given in SAE Papers referenced in Paragraph 4d. See also data contained in the CAA paper "Engine Non-Containments - The CAA View", which includes Figure 6. This paper is published in NASA Report CP-2017, "An Assessment of Technology for Turbo-jet Engine Rotor Failures", dated August 1977.

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APPENDIX 1

AC-20-128A USER'S MANUAL

RISK ANALYSIS METHODOLOGY for UNCONTAINED ENGINE/APU FAILURE

INDEX

1.0 GENERAL

1.1 The design of airplane and engine systems and the location of the engines relative to critical systems and structure have a significant impact on survivability of the airplane following an uncontained engine failure. Sections 23.903(b)(1) and 25.903(d)(1) of the Federal Aviation Regulations (FAR) require that design precautions be taken to minimize the hazard to the airplane due to uncontained failures of engine or auxiliary power unit (APU). Advisory Circular 20-128A provides guidance for demonstrating compliance with these requirements.

1.2 As a part of this compliance demonstration, it is necessary to quantitatively assess the risk of a catastrophic failure in the event of an uncontained engine failure. This User's Manual describes an acceptable method for this purpose.

1.3 The objective of the risk analysis is to measure the remaining risk after prudent and practical design considerations have been taken.
Since each airplane would have unique features which must be considered when applying the methods described in this manual, there should be some flexibility in the methods and procedures.

1.4 It is a preferred approach to use these methods throughout the development of an airplane design to identify problem areas at an early stage when appropriate design changes are least disruptive. It is also advisable to involve the Federal Aviation Administration (FAA) in this process at an early stage when appropriate interpretation of the methodology and documentation requirements can be established.

1.5 It should be noted that although the risk analysis produces quantitative results, subjective assessments are inherent in the methods of the analysis regarding the criticality of specific types of airplane component failures. Assumptions for such assessments should be documented along with the numerical results.

1.6 Airplane manufacturers have each developed their own method of assessing the effects of rotor failure; as there are many ways to get to the same result. This User's Manual identifies all the elements that should be contained in an analysis so that it can be interpreted by a person not familiar with such a process.

1.7 The intent of this manual therefore is to aid in establishing how an analysis is prepared, without precluding any technological advances or existing proprietary processes or programs.

1.8 Advisory Circular 20-128A makes allowance for the broad configuration of the airplane; as such damage to the structure due to rotor failure generally allows for little flexibility in design. System lay-out within a rotor burst zone, however, can be optimized.

1.9 Damage to structure, which may involve stress analysis, generally can be analyzed separately, and later coordinated with simultaneous system effects.

1.10 For an analysis of the effects on systems due to a rotor failure the airplane must be evaluated as a whole; and a risk analysis must specifically highlight all critical cases identified which have any potential to result in a catastrophe.

1.11 Such an analysis can then be used to establish that reasonable precautions have been taken to minimize the hazards, and that the remaining hazards are an acceptable risk.

1.12 A safety and a risk analysis are interdependent, as the risk analysis must be based on the safety analysis.

The safety analysis therefore is the starting point that identifies potential hazardous or catastrophic effects from a rotor failure, and is the basic tool to minimize the hazard in accordance with the guidelines of AC 20-128A.

1.13 The risk analysis subsequently assesses and quantifies the residual risk to the airplane.

2.0 SCOPE

The following describes the scope of analyses required to assess the airplane risk levels against the criteria set forth in Paragraph 10 of AC 20-128A.

2.1 Safety

Analysis is required to identify the critical hazards that may be numerically analyzed (hazards remaining after all practical design precautions have been taken).

Functional criticality will vary by airplane and may vary by flight phase.

Thorough understanding of each airplane structure and system functions is required to establish the criticality relative to each fragment trajectory path of the theoretical failure model.

Assistance from experts within each discipline is typically required to assure accuracy of the analysis in such areas as effects of fuel tank penetration on leakage paths and ignition hazards, thrust level control (for loss of thrust assessment), structural capabilities (for fuselage impact assessment), airplane controllability (for control cables impact assessment), and fuel asymmetry.

2.2 Risk

For each remaining critical hazard, the following assessments may be prepared using the engine/APU failure models as defined in Paragraph 9 of AC 20-128A:

(a) Flight mean risk for single 1/3 disk fragment.

(b) Flight mean risk for single intermediate fragment.

(c) Flight mean risk for alternate model (when used as an alternate to the 1/3 disk fragment and intermediate fragment).

(d) Multiple 1/3 disk fragments for duplicated or multiplicated systems.

(e) Specific risk for single 1/3 disk fragment and single intermediate fragment.

(f) Specific risk for any single disk fragment that may result in catastrophic structural damage.

The risk level criteria for each failure model are defined in Paragraph 10 of AC 20-128A.

3.0 FUNDAMENTAL COMPONENTS OF A SAFETY AND RISK ANALYSIS

3.1 The logical steps for a complete analysis are:

(a) Establish at the design definition the functional hazards that can arise from the combined or concurrent failures of individual systems, including multiplicated systems and critical structure.

(b) Establish a Functional Hazard Tree (see Figure 1), or a System Matrix (see Figure 2) that identifies all system interdependencies and failure combinations that must be avoided (if possible) when locating equipment in the rotor burst impact area.

In theory, if this is carried out to the maximum, no critical system hazards other than opposite engine or fuel line hits would exist.

(c) Establish the fragment trajectories and trajectory ranges both for translational and spread risk angles for each damage. Plot these on a chart or graph, and identify the trajectory ranges that could result in hazardous combinations (threats) as per the above system matrix or functional hazard analysis.

(d) Apply risk factors, such as phase of flight or other, to these threats, and calculate the risk for each threat for each rotor stage.

(e) Tabulate, summarize and average all cases.

3.2 In accordance with AC 20-128A the risk to the airplane due to uncontained rotor failure is assessed to the effects, once such a failure has occurred.

The probability of occurrence of rotor failure, as analyzed with the probability methods of AC 23.1309 and AC 25.1309-1a (i.e. probability as a function of critical uncontained rotor failure rate and exposure time), does not apply.

3.3 The total risk level to the airplane, as identified by the risk analysis, is the mean value obtained by averaging the values of all rotor stages of all engines of the airplane, expressed as Flight Mean Risk.

4.0 ASSUMPTIONS

4.1 The following conservative assumptions, in addition to those in Paragraphs 10(a) (1), (2) and (3) of AC 20-128A, have been made in some previous analyses. However, each airplane design may have unique characteristics and therefore a unique basis for the safety assessment leading to the possibility of different assumptions. All assumptions should be substantiated within the analysis:

(a) The 1/3 disk fragment as modeled in paragraph 9(a) of AC 20-128A travels along a trajectory path that is tangential to the sector centroid locus, in the direction of rotor rotation (Refer to Figure 3).

The sector fragment rotates about its centroid without tumbling and sweeps a path equal to twice the greatest radius that can be struck from the sector centroid that intersects its periphery.

The fragment is considered to possess infinite energy, and therefore to be capable of severing lines, wiring, cables and unprotected structure in its path, and to be undeflected from its original trajectory unless deflection shields are fitted. However, protective shielding or an engine being impacted may be assumed to have sufficient mass to stop even the most energetic fragment.

(b) The probability of release of debris within the maximum spread angle is uniformly distributed over all directions.

(c) The effects of severed electrical wiring are dependent on the configuration of the affected system. In general, severed wiring is assumed to not receive inadvertent positive voltage for any significant duration.

(d) Control cables that are struck by a fragment disconnect.

(e) Hydraulically actuated, cable driven control surfaces, which do not have designated "fail to" settings, tend to fail to null when control cables are severed. Subsequent surface float is progressive and predictable.

(f) Systems components are considered unserviceable if their envelope has been touched. In case of an engine being impacted, the nacelle structure may be regarded as engine envelope, unless damage is not likely to be hazardous.

(g) Uncontained events involving in-flight penetration of fuel tanks will not result in fuel tank explosion.

(h) Unpowered flight and off-airport landings, including ditching, may be assumed to be not catastrophic to the extent validated by accident statistics or other accepted factors.

(i) Damage to structure essential for completion of flight is catastrophic (Ref. AC 20-128A, Paragraph 10.b(1)).

(j) The flight begins when engine power is advanced for takeoff and ends after landing when turning off the runway.

5.0 PLOTTING

5.1 Cross-section and plan view layouts of the airplane systems in the ranges of the rotor burst impact areas should be prepared, either as drawings, or as computer models.

These layouts should plot the precise location of the critical system components, including fuel and hydraulic lines, flight control cables, electric wiring harnesses and junction boxes, pneumatic and environmental system ducting, fire extinguishing components; critical structure, etc.

5.2 For every rotor stage a plane is developed. Each of these planes contains a view of all the system components respective outer envelopes, which is then used to generate a cross-section. See Figure 4.

5.3 Models or drawings representing the various engine rotor stages and their fore and aft deviation are then generated.

5.4 The various trajectory paths generated for each engine rotor stage are then superimposed on the cross-section layouts of the station planes that are in the range of that potential rotor burst in order to study the effects (see Figure 5). Thus separate plots are generated for each engine rotor stage or rotor group.

To reduce the amount of an analysis the engine rotor stages may also be considered as groups, as applicable for the engine type, using the largest rotor stage diameter of the group.

5.5 These trajectory paths may be generated as follows and as shown in Figure 6:

(a) Two tangent lines T1 are drawn between the locus of the centroid and the target envelope.

(b) At the tangent line touch points, lines N1 and N2 normal to the tangent lines, are drawn with the length equal to the radius of the fragment swept path (as also shown in Figure 1).

(c) Tangent lines T2 are drawn between the terminal point of the normal lines and the locus of the centroid. The angle between these two tangent lines is the translational risk angle.

5.6 The entry and exit angles are then calculated.

5.7 The initial angle of intersection and the final angle of intersection are recorded, and the trajectories in between are considered to be the range of trajectories in which this particular part would be impacted by a rotor sector, and destroyed (i.e. the impact area).

5.8 The intersections thus recorded are then entered on charts in tabular form so that the simultaneous effects can be studied. Refer to Figure 8.

Thus it will be seen that the total systems' effects can be determined and the worst cases identified.

5.9 If a potentially serious multiple system damage case is identified, then a more detailed analysis of the trajectory range will be carried out by breaking the failure case down into the specific fore-aft spread angle, using the individual rotor stage width instead of combined groups, if applicable.

6.0 METHODOLOGY - PROBABILITY ASSESSMENT

6.1 Those rotor burst cases that have some potential of causing a catastrophe are evaluated in the analysis in an attempt to quantify an actual probability of a catastrophe, which will, in all cases, depend on the following factors:

(a) The location of the engine that is the origin of the fragment, and its direction of rotation.

(b) The location of critical systems and critical structure.

(c) The rotor stage and the fragment model.

(d) The translational trajectory of the rotor fragment,

(e) The specific spread angle range of the fragment.

(f) The specific phase of the flight at which the failure occurs.

(g) The specific risk factor associated with any particular loss of function.

6.2 Engine Location

The analysis should address the effects on systems during one flight after a single rotor burst has occurred, with a probability of 1.0. As the cause may be any one of the engines, the risk from each engine is later averaged for the number of engines.

The analysis trajectory charts will then clearly show that certain system damage is unique to rotor fragments from a particular engine due to the direction of rotation, or, that for similar system damage the trajectory range varies considerably between engines.

A risk summary should table each engine case separately with the engine location included.

6.3 Rotor Element

The probability of rotor failure is assumed to be 1.0 for each of all rotor stages. For the analysis the individual risk(s) from each rotor stage of the engine should be assessed and tabled.

6.4 Translational Risk Angle

The number of degrees of included arc (out of 360) at which a fragment intersects the component/structure being analyzed. Refer to Figure 6 and Figure 7.

6.5 Trajectory Probability (P)

The probability of a liberated rotor fragment leaving the engine case is equal over 360°, thus the probability P of that fragment hitting a system component is the identified Translational Risk Angle Φ in degrees °, divided by 360, i.e.

$$P = \Phi/360$$

or,

$$\frac{\Phi 1 - \Phi 2}{360}$$

6.6 Spread Angle

If the failure model of the analysis assumes a (fore and aft) spread angle of ± 5°, then the spread angle is a total of 10°. If a critical component can only be hit at a limited position within that spread, then the exposure of that critical component can then be factored according to the longitudinal position within the spread angle, e.g.:

$$\frac{\psi 2 - \psi 1}{\text{spread angle}}$$

If a component can only be hit at the extreme forward range of +4° to +5°, then the factor is .1 (for one degree out of 10).

6.7 Threat Window

The definition of a typical threat window is shown in Figure 7.

6.8 Phase of Flight

Certain types of system damage may be catastrophic only during a specific portion of the flight profile, such as a strike on the opposite engine during take-off after V1 (i.e. a probability of 1.0), while with altitude a straight-ahead landing may be possible under certain favorable conditions (e.g. a probability of less than 1.0). The specific case can then be factored accordingly.

6.8.1 The most likely time for an uncontained rotor failure to occur is during take-off, when the engine is under highest stress. Using the industry accepted standards for the percentage of engine failures occurring within each flight phase, the following probabilities are assumed:

Take-off before V1	35%
V1 to first power reduction	20%
Climb	22%
Cruise	14%
Descent	3%
Approach	2%
Landing/Reverse	4%

6.8.2 The flight phase failure distribution above is used in the calculations of catastrophic risk for all cases where this risk varies with flight phase.

$$Dp = \frac{\text{P flight phase \%}}{100}$$

6.9 Other Risk Factors

Risks such as fire, loss of pressurization, etc., are individually assessed for each case where applicable, using conservative engineering judgment. This may lead to a probability of catastrophe (i.e., risk factor) smaller than 1.0.

6.9.1 The above probabilities and factors are used in conjunction with the critical trajectory range defined to produce a probability of the specific event occurring from any random rotor burst.

This value is then factored by the "risk" factor assessed for the case, to derive a calculated probability of catastrophe for each specific case.

Typical conditional probability values for total loss of thrust causing catastrophic consequences are:

Phase	Dp		Risk
T.O.-V1 to first power reduction	0.20	-	1.0
Climb	0.22	-	0.4
Cruise	0.14	-	0.2
Descent	0.03	-	0.4
Approach	0.02	-	0.4

6.10 All individual case probabilities are then tabled and summarized.

6.11 The flight mean values are obtained by averaging those for all disks or rotor stages on all engines across a nominal flight profile.

The following process may be used to calculate the flight mean value for each Failure Model:

(a) Establish from the table in Figure 8 the threat windows where, due to combination of individual damages, a catastrophic risk exists.

(b) For each stage case calculate the risk for all Critical Hazards

(c) For each stage case apply all risk factors, and , if applicable, factor for Flight Phase-Failure distribution

(d) For each engine, average all stages over the total number of engine stages

(e) For each airplane, average all engines over the number of engines.

7.0 RESULTS ASSESSMENT

7.1 An applicant may show compliance with §§ 23.903(b)(1) and 25.903(d)(1) of the FAR using guidelines set forth in AC 20-128A. The criteria contained in AC 20-128A may be used to show that:

(a) Practical design precautions have been taken to minimize the damage that can be caused by uncontained engine debris, and

(b) Acceptable risk levels, as specified in AC 20-128A, Paragraph 10, have been achieved for each critical Failure Model.

7.2 The summary of the applicable risk level criteria is shown in Table 1 below.

Table 1 Summary of Acceptable Risk Level Criteria

Requirement	Criteria
Average 1/3 Disk Fragment	1 in 20
Average Intermediate Fragment	1 in 40
Average Alternate Model	1 in 20 @ ± 5° Spread Angle
Multiple Disk Fragments	1 in 10
Any single fragment (except for structural damage)	2 x corresponding average criterion

7.3 Section 25.571(e) of the FAR requires the structure to meet damage tolerance requirement for likely structural damage caused by an uncontained engine failure. Guidance for demonstrating compliance to this section is currently the subject of an ARAC harmonization effort and will be issued at a later date.

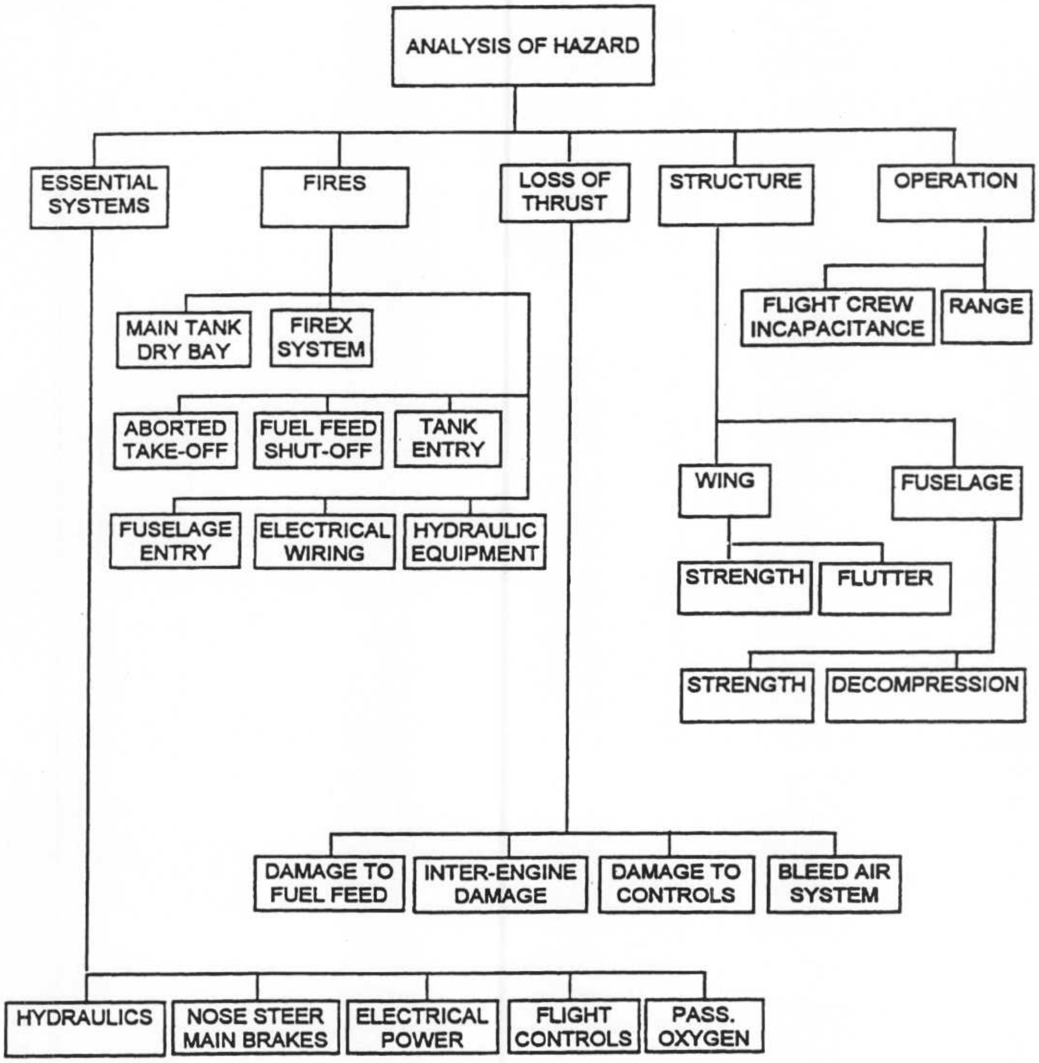


FIGURE 1

EXAMPLE - HAZARD TREE

LOC	COMPONENT	DAMAGE TO	SYSTEM LOADED	DETAIL
LEFT	AILERON	CABLES/SURFACE	HYDRAULIC POWER	#1 & #3
RIGHT	AILERON	CABLES/SURFACE	HYDRAULIC POWER	#2 & #3
LEFT	SPOILER - OUTBD MULTI-FUNCTION	CONTROL/SURFACE	HYDRAULIC POWER	#1
RIGHT	SPOILER - OUTBD MULTI-FUNCTION	CONTROL/SURFACE	HYDRAULIC POWER	#1
LEFT	FLAP-OUTBD	TRACK/SURFACE	ELECTRICAL POWER	AC BUS1 AC ESS
RIGHT	FLAP-OUTBD	TRACK/SURFACE	ELECTRICAL POWER	AC BUS1 AC ESS
LEFT	RUDDER	CABLE	HYDRAULIC POWER	#1,#2&#3
RIGHT	RUDDER	CABLE	HYDRAULIC POWER	#1,#2&#3
LEFT	ELEVATOR	CABLES Note 1	HYDRAULIC POWER	#1 & #3
RIGHT	ELEVATOR	CABLES Note 1	HYDRAULIC POWER	#2 & #3
CHAN1	PITCH TRIM	CONTROL/POWER Note 2	ELECTRICAL POWER	AC BUS1 DC BUS1
CHAN2	PITCH TRIM	CONTROL/POWER Note 2	ELECTRICAL POWER	AC ESS DC ESS

FLIGHT CONTROLS - SYSTEM LOADING

Note 1:
Same fragment path must not sever:
ON-SIDE cables + OFF-SIDE hydraulic system + HYDRAULIC PWR #3

e.g.: Left elevator cable and HYDRAULIC PWR #2 and #3
or,
Right elevator cable and HYDRAULIC PWR # 1 and # 3

Note 2:
Same fragment path must not sever:
- Both CHAN1 and CHAN2 circuits
- ON-SIDE control circuit + OFF-SIDE power circuit
- OFF-SIDE control circuit + ON-SIDE power circuit

FIGURE 2

EXAMPLE - SYSTEM LOADING MATRIX

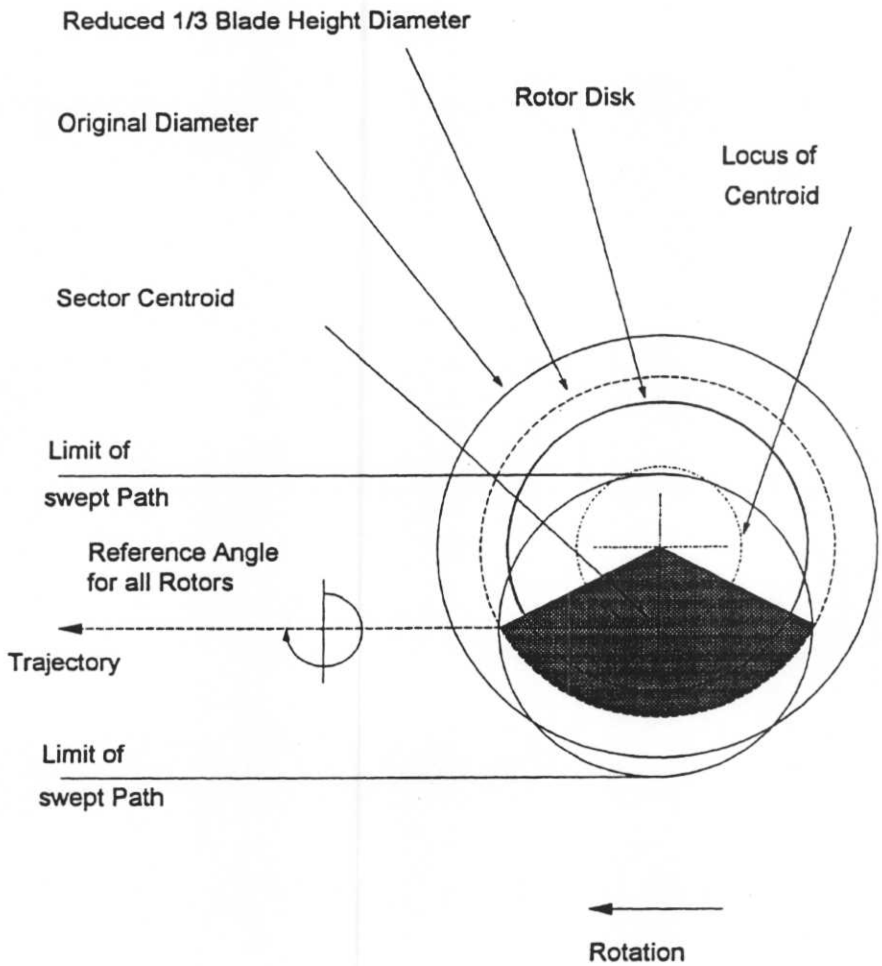


FIGURE 3

TRI-SECTOR ROTOR BURST

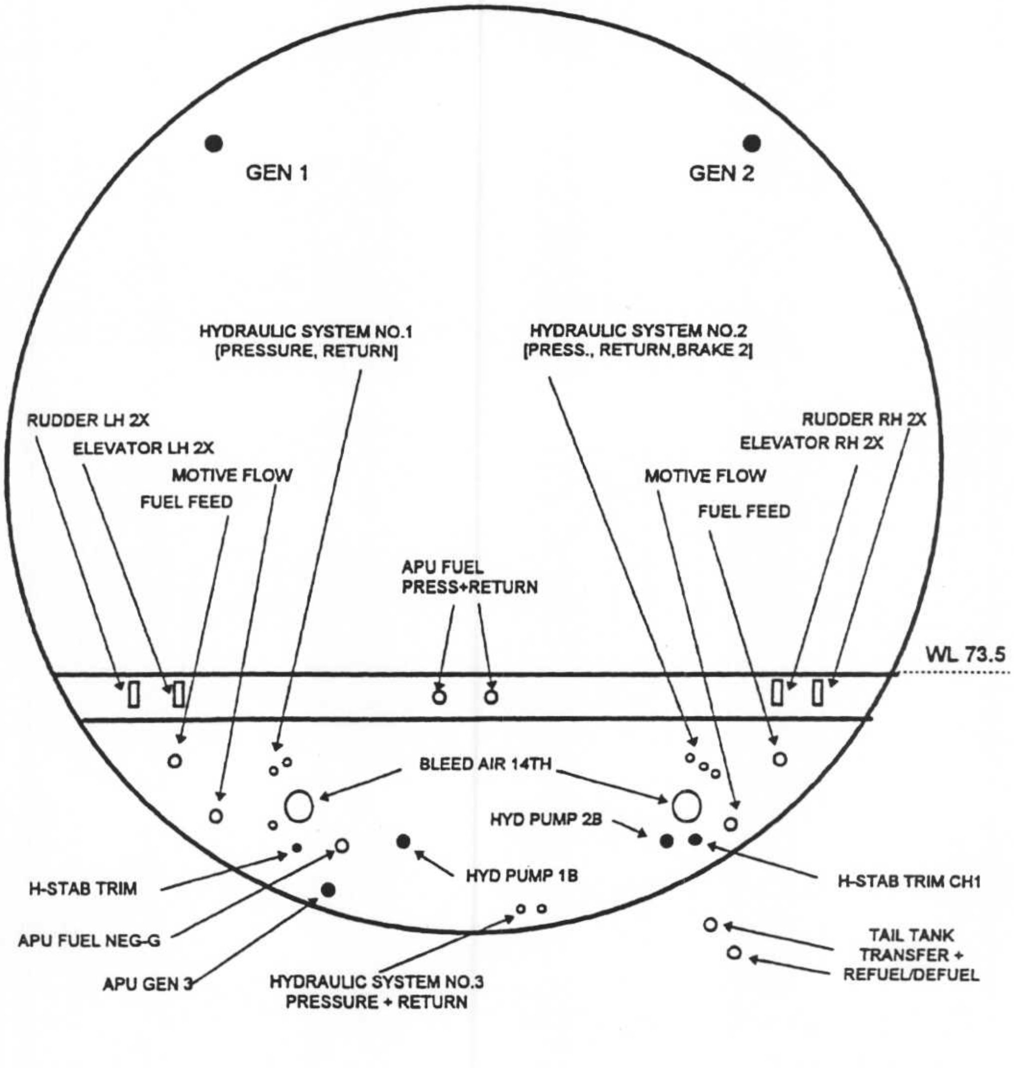
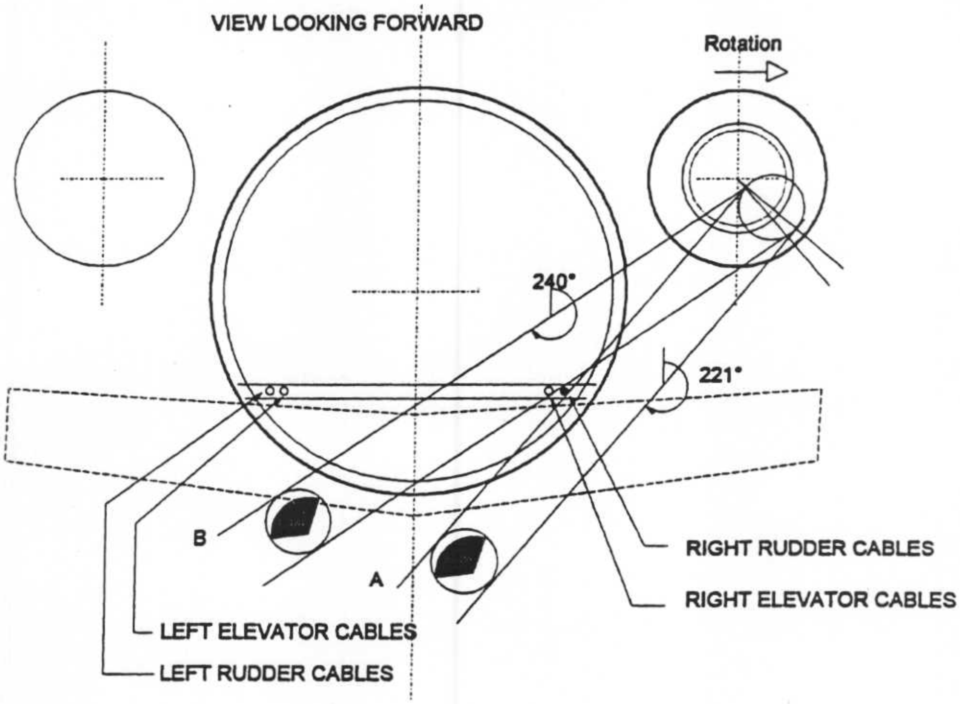


FIGURE 4

TYPICAL LAYOUT OF SYSTEMS IN ROTOR PLANE



EXAMPLE:
The right rudder cables are cut by a 1/3 fan fragment from the right engine at all trajectory angles between 221° and 240°. Trajectory range A - B is therefore 19°

FIGURE 5

TRAJECTORY RANGE PLOTTING

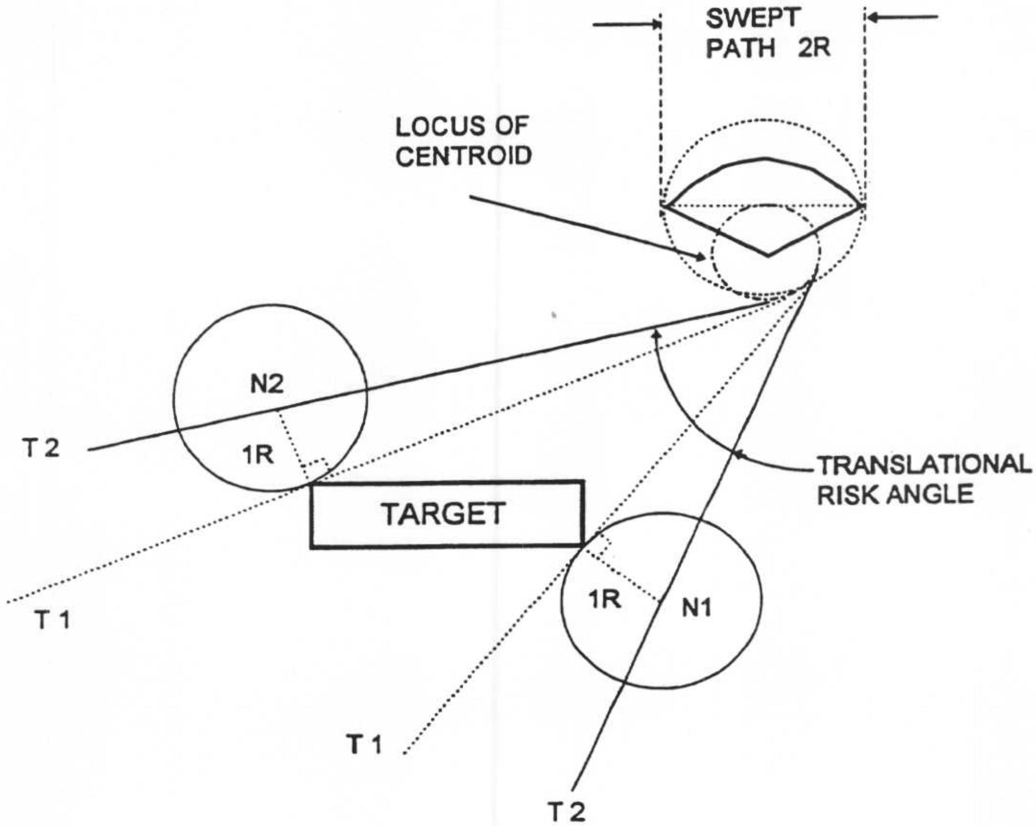


FIGURE 6

TYPICAL TRAJECTORY PLOTTING

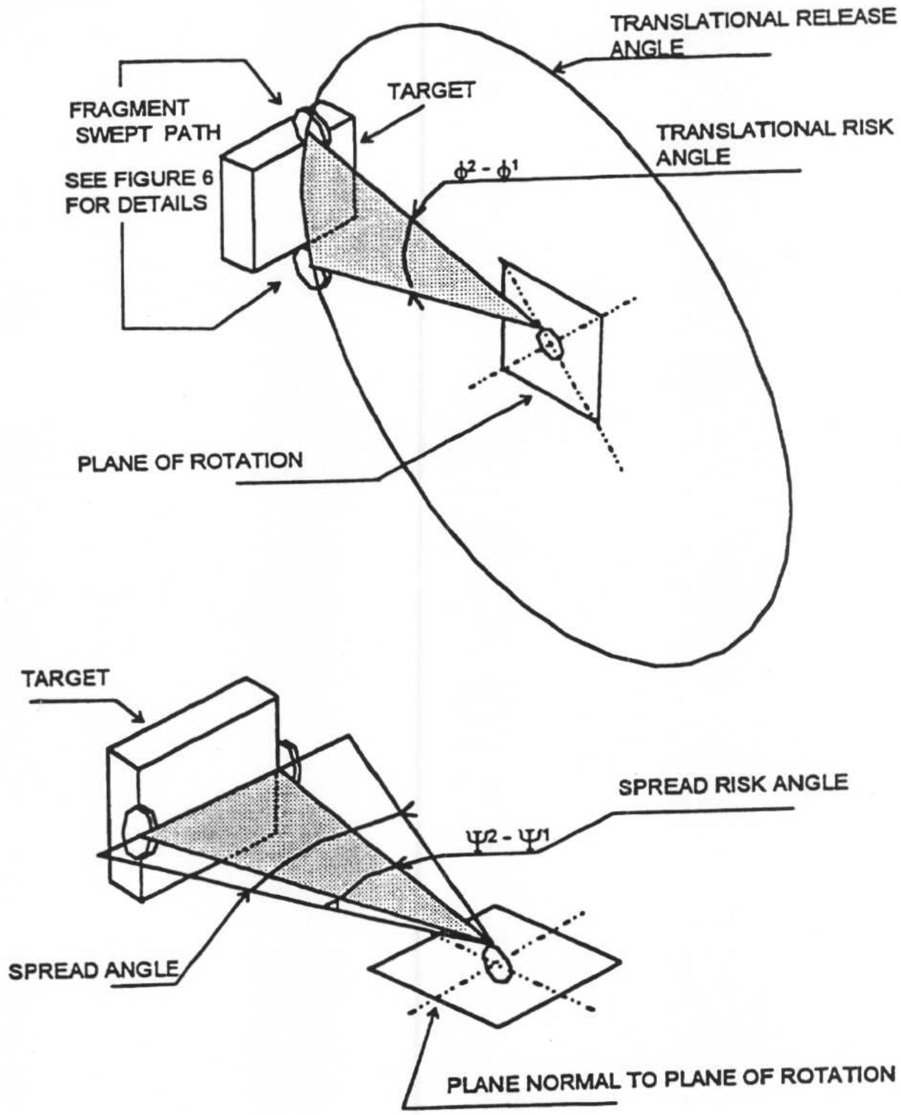


FIGURE 7

DEFINITION - THREAT WINDOW

ENGINE ROTOR FAILURE - SYSTEM EFFECTS

ENGINE: *RIGHT*

COMPONENT: **H.P. TURBINE 1**

SIZE: in.

System	Component			IN	OUT	TRAJECTORY ANGLES IN DEGREES (210 215 220 225 230 235 240 245 250 255 260 265 270 275 280 285 290 295 300 305 310 315)
FLIGHT CONTROLS	RUDDER	CABLES	L	244	252	
			R	225	239	
	ELEVATOR	CABLES	L	243	251	
			R	227	241	
	H-STAB	CHANNEL#	2	252	260	
	TRIM	CHANNEL#	1	228	247	
HYDRAULIC POWER	POWER	# 1	A			0 00000 00000 00000 00
		# 1	B	252	263	
	PLUMBING	# 1		266	279	
	POWER	#2	A			
		# 2	B	221	241	0 00000 00000 00000 00XXX XXXXX XX
	PLUMBING	# 2		227	244	250 290
	PLUMBING	#3		228	246	
FIRE PROTECTION	ENGINE	FIREX#1		230	273	
	ENGINE	FIREX#2		246	254	
	APU	FIREX		266	280	
FUEL	ENGINE FEED	/MOTIVE-	L	254	272	
	ENGINE FEED	FLOW	R	251	276	
	APU FEED					
	TAIL TANK	REFUEL		223	237	
	/LINES	TRANSFER		223	237	
ELECTRICAL POWER	GENERATOR	#1		272	282	0 00000 00000 00000 00
		#2				
		#3		249	263	
	BATTERY	MAIN		238	250	
		AUX		237	252	
ENVIRON-MENTAL	CABIN PRES URE					
	PNEUMATIC	10TH	L	253	283	
	SUPPLY	STAGE	R	249	289	
	ACU		L	261	284	
	OUTPUT		R	259	291	
POWER PLANT	ENGINE CON ROL		L	266	273	
			R			
	OPPOSITE N CELLE			261	283	
APU	APU ENCLO URE			237	270	

LEGEND: ▬ = DIRECT HIT OOOOO = OPPOSITE ENGINE FUEL LINE XXXXX = OPPOSITE GENERATOR FFFFF = APU FUEL LINE

FIGURE 8 - SAMPLE ROTOR STAGE PLOTTING CHART

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