FAA
Transport Airplane Directorate
ANM-100

Transport Airplane Risk Assessment Methodology (TARAM) Handbook

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1 Scope

This handbook describes the Transport Airplane Risk Assessment Methodology (TARAM). It outlines a process for calculating risk associated with continued-operational-safety (COS) issues in the transport-airplane fleet. It explains how to use such risk-analysis calculations when making determinations of unsafe conditions, and selecting and implementing corrective actions.

1.1 Audience

This handbook is intended for use by Aviation Safety Engineers (ASE) performing or overseeing transport-airplane risk analysis as part of the Order 8110.107, *Monitor Safety – Analyze Data (MSAD)*, process. MSAD is a safety-management process to promote continuing operational safety throughout the life cycle of aviation products. The TARAM handbook is only applicable within the context of the overall COS process contained in FAA Order 8110.107.

1.2 Application

FAA safety determinations, as described throughout Title 14, Code of Federal Regulations (14 CFR) part 21 and part 39, are an important function of the Administrator, yet the Administrator has a great deal of flexibility and latitude when making safety determinations. Furthermore, safety determinations are separate from determinations of rule compliance or design conformity. The CFR places no requirements or restrictions on the Administrator's prerogative to make safety determinations. This handbook provides guidance for considering risk as a factor when determining whether a condition found in the transport-airplane fleet is safe or unsafe, and for selecting the appropriate corrective action when a condition is determined to be unsafe. This guidance is only one facet of the safety decision-making process. It is not the sole basis for determining unsafe conditions, nor does it limit, in any way, the Administrator's prerogative to make such determinations.

When a higher-level policy or regulation requires that the FAA write an Airworthiness Directive (AD), do not use TARAM results as part of the safety decision-making process. The FAA made the policy decision to require corrective action in those cases during the course of rulemaking or other policy decisions, which override the TARAM risk guidelines. Examples of this include:

- widespread-fatigue-damage rule requirement for mandatory modifications
- changes to Airworthiness Limitation Inspections
- maintenance and inspection instructions developed under Special Federal Aviation Regulation 88

Caution: This handbook is neither intended nor appropriate for use as a means of finding compliance with any airworthiness rule. Do not use this handbook as a method of validating or invalidating previous airworthiness-rule compliance findings.

1.3 Foreign Manufactured Aircraft, Engines, and Airborne Equipment

In line with the International Civil Aviation Organization (ICAO) Annex 8 obligations of the United States, as well as its bilateral agreements, the FAA is responsible for COS decision-making for domestically manufactured aircraft, engines, and airborne equipment worldwide. In most cases, based on the same ICAO Annex 8 obligations and bilateral agreements, the applicable foreign airworthiness authorities are responsible for worldwide COS decision-making for foreign-manufactured aircraft, engines, and airborne equipment. Accordingly, for most foreign-manufactured aircraft, engines, and airborne equipment, bilateral agreements govern safety-issue resolution. In such cases, the MSAD process is abbreviated, and product-specific risk-analysis processes/guidelines are not applied. Use the MSAD process in full when a safety issue arises from an aircraft, an engine, or airborne equipment manufactured in a country that does not have a bilateral agreement with the United States, or when the FAA is considering unilateral FAA airworthiness action on foreign-manufactured transport-airplane products. In these cases, use the applicable product-related risk-management process to justify and guide corrective action.

However, in most cases, only affected aircraft under United States registry need be considered when determining the associated risk and corrective action.

1.4 Supported Processes

This TARAM handbook supports the risk-analysis and risk-level guidance requirements of Order 8110.107.

1.5 Providing Feedback

It is important that users of this handbook communicate their experiences in applying the risk-analysis/management methods contained here, especially in situations that are difficult to analyze with this process. Send user comments, suggestions, and other feedback to:

FAA Transport Airplane Directorate
Safety Management Branch, ANM-117
Attn: Continued Operational Safety Program Manager
1601 Lind Ave. SW
Renton, WA 98057

Note: Call the FAA Transport Airplane Directorate (TAD) at 425-227-2100 for contact information as this may change over time.

2 Background

2.1 Safety Management System

A safety-management system (SMS) is a broad, systematic approach to managing safety across the complete life-cycle of a product or process. In an SMS, goals and objectives are defined in terms of safety, and those goals are achieved through adherence to systematic processes, procedures, practices, and policies.

2.2 Monitor Safety – Analyze Data

In 2004, the FAA Aircraft Certification Service (AIR) began an initiative to revise internal processes to introduce an SMS philosophy and structure. As part of that initiative, AIR issued FAA Order 8110.107, *Monitor Safety – Analyze Data* (MSAD), on March 12, 2010. This order became effective September 15, 2010. The order provides direction and guidance for a structured, standardized, COS management process for use throughout AIR. The order is based on and adheres to the SMS concepts and precepts required of an AIR SMS process.

In line with AIR SMS requirements, the MSAD process requires that each AIR product directorate develop a risk-analysis methodology and accompanying risk guidelines. The risk-analysis methodology must be quantitative or able to evolve to being quantitative. The result of the analysis processes must be convertible to risk in terms of the probability of a fatal accident, so risk can be compared across AIR products and services. Also, in line with the comparability and conversion requirements, the risk-analysis process must be applicable to any potentially unsafe COS issue, e.g., airplane systems, structures, flight controls, etc.

The MSAD Order also requires that certain risk factors be calculated and recorded when a safety issue reaches the risk-analysis stage of the process. Those risk factors defined in the MSAD Order are: Total Uncorrected Fleet Risk, Uncorrected Individual Risk, Control-program fleet Risk, and Control-Program Individual risk. The Order establishes a Corrective Action Review Board (CARB) at each ACO to review the risk results and make informed safety decisions.

TARAM provides the guidance necessary to perform MSAD-Order-required risk analysis and risk management for transport-airplane COS issues. The TARAM handbook fully supports and complies with all of the risk-analysis requirements in the MSAD. The handbook defines a risk-analysis process that is quantitative to the extent possible for each situation, and it will become more quantitative as additional supporting data is obtained. The TARAM handbook also contains risk guidelines structured to reflect the goals of the FAA in terms of risk (reduce the present accident rate), while also limiting the risk to individuals aboard transport airplanes. The risk values calculated using the TARAM are directly convertible to the risk of a fatal accident as required by AIR SMS and the MSAD Order.

2.3 Differences between Continued Operational Safety (COS) and Design Certification

2.3.1 Compliant vs. Safe

Part 21 provides the regulatory requirements that direct FAA type design, manufacturing, and airworthiness approvals. Paraphrasing § 21.21, the FAA issues a type certificate when the applicant shows that the product meets all the applicable 14 CFR requirements, and that “no feature or characteristic makes it unsafe for the category in which certification is requested.” No 14 CFR regulations limit, in any way, the criteria the FAA can or should use to make determinations of unsafe design features or characteristics. Assuring compliance to the airworthiness regulations is a very important part of aviation safety; however, compliance with the airworthiness regulations alone is not sufficient to establish the safety of an aircraft. Through § 21.21(b)(2), the FAA can require elimination of any known unsafe features prior to certification, even when those features comply with the airworthiness regulations. When the FAA identifies an unsafe condition after type certification, the provisions contained in part 39 apply to require corrective action.

TAD policy states that corrective action can and should be required when the FAA identifies an unsafe condition on a type-certified transport-airplane model. Conversely, we do not remedy a discovered airworthiness-standard noncompliance on existing airplanes by mandatory corrective action unless the noncompliance is determined to be unsafe.

2.3.2 Risk Assessment Pre- and Post-Certification

There is a fundamental difference between assessing risk pre- and post-certification. Quantitative safety assessments of airplane systems during development and certification of designs are typically based on the conservative estimate of the probability of severe, adverse functional effects, as portrayed in broad hazard categories. The resulting values are compared to the quantitative values provided in AC 25.1309-1A. The FAA evaluated the possibility of using the design risk assessments and design thresholds for COS, but determined that the level of conservatism is widely variable from one analysis to another, which blurs differences between hazards. We were not able to develop a way of achieving consistent comparative MSAD-Order-compliant risk values using design-certification risk-assessment methods.

The quantitative values provided as part of the § 25.1309 compliance process, outlined in Advisory Circular (AC) 25.1309-1A, are not and have never been FAA goals or thresholds for the actual risk of as-built transport airplanes. Per the AC, the quantitative values "may" be compared to risk values derived using the explicitly conservative analytical methodology outlined in the AC. The comparison, again as outlined in the AC, is **"…*used to support experienced engineering and operational judgment and to supplement qualitative analysis*"** during certification of certain airplane systems.

The process defined in AC 25.1309-1A is qualitative and based on the "fail safe" design philosophy. The process includes consideration of design documentation (drawings, test results, etc.), qualitative analysis (common cause, failure modes and effects, human factors, etc.), and design assurance (software, complex hardware, etc.). The overall finding "may" be supported by a prescriptively conservative quantitative analysis. The result is a finding that each catastrophic-failure condition that could result from the functionality of the system being analyzed, alone, is "extremely improbable" and, likewise, each major failure condition is improbable.

As defined in the AC, "extremely improbable" means that a (functional) catastrophic-failure condition is **"…not anticipated to occur during the entire operating life of all airplanes of one type."** The finding ***does not*** mean that the likelihood of a "catastrophe" is less than 10^{-9} per flight hour. We expect that, due to all the additional considerations and the conservative, quantitative-analytical approach, the actual probability of a particular failure condition will be far less that those listed in the AC. Further, we expect that the probability of an actual airplane outcome that might be termed a "catastrophe," as the result of a "catastrophic failure condition," to be even more remote. This expectation has been validated by the operational history of systems certified, based on the means of compliance provided in AC 25.1309-1A. Accordingly, declaring the AC numbers to be safety thresholds, even in certification, would be a step back from the actual safety level achieved.

In accordance with the intent and actual wording of AC 25.1309-1A, the TAD has published policy stating that a solely quantitative analysis that compares favorably to the quantitative values in the AC is not sufficient to show compliance for the requirements in § 25.1309(b). Just as the TAD does not recognize the quantitative values in AC 25.1309-1A as the expected probability of occurrence of system failure conditions, or definitive of the qualitative safety requirements in § 25.1309, those values are not accepted as definitive safety thresholds in COS decision-making for transport-category airplanes.

The difference between assessing risk pre- and post-certification for airplane structures is even greater. Airplane structures are designed to be fail-safe, fatigue resistant, and damage tolerant to the extent possible. A "section 25.1309 type" of risk assessment is not performed during aircraft structure design. Risk assessment of fatigue cracks found in aircraft structures in-service should be compared to fatigue and crack-growth analyses, if available, to ensure consistency.

3 Introduction to TARAM Risk

3.1 The TARAM Concept of Risk

To use this handbook properly, you must understand how risk is characterized. This handbook defines the following measures of risk:

- **Fleet risk**. The number of weighted events or fatalities expected in a defined time period if no action is implemented to correct the identified, potentially unsafe condition.
- **Uncorrected Individual risk**. The probability of individual fatal injury per flight hour.

3.2 Fleet Risk

"Fleet risk," as used in the TARAM, is:

- the number of times a condition under study is likely to occur (e.g., the statistical expectation of the condition),
- the conditional probability of an outcome as a result of that condition (the likelihood that the condition under study will result in an outcome of known severity),
- and the severity of the outcome, either in terms of weighted outcomes or the anticipated number of fatalities per outcome, if no action[1] is taken during a defined time period.

This concept of fleet risk is shown in Figure 1.

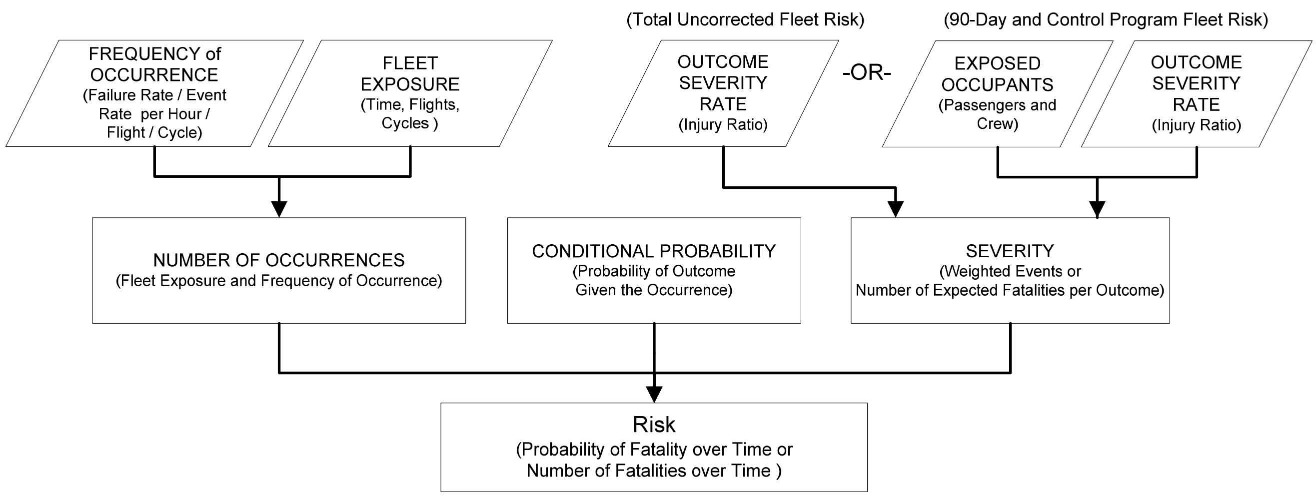

Figure 1. Components of Fleet Risk

3.3 Individual Risk

Individual risk, as used in the TARAM, is the:

- largest result of the number of times a condition under study is likely to occur,
- conditional probability of an outcome as a result of that condition, and
- fatality rate per outcome if no action[1] is taken during a specified time.

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[1] When calculating uncorrected risk values, non-mandatory changes to the fleet that can be reasonably expected to occur, such as voluntary service-bulletin incorporation, operator-directed maintenance, etc., should be included. Realistic estimates of the scope and effect of non-mandatory changes should be used.

When “special conditions and combinations of conditions” that will occur, during a reasonable number of future flights, cause individual risk to be significantly higher than average, the larger value is used.[2] This concept of individual risk is shown in Figure 2.

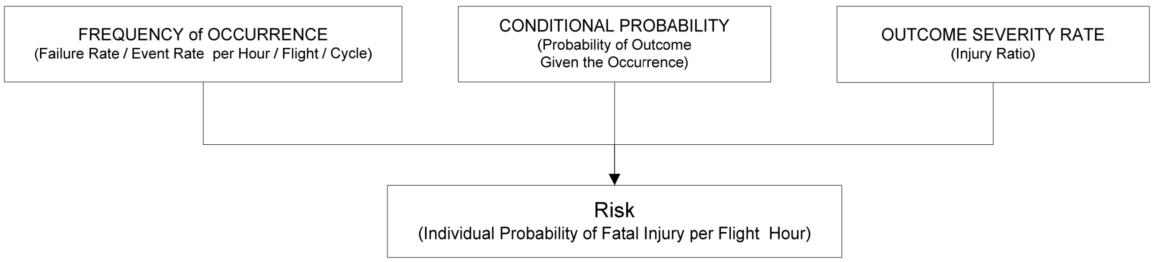

Figure 2. Components of Individual Risk

3.4 Non-Fatal Injuries

This handbook addresses analysis and management of risk in terms of the cumulative probability of outcome-related fatalities within a fleet, the number of fatalities expected in a specific period of time, and the individual risk of fatal injury per flight. However, unsafe-condition determination can result from an unacceptable rate of passenger or crew injuries that are not expected to be fatal. Even though such injuries are not the focus of the TARAM, conditions that would result in routine injuries and/or life-threatening injuries to passengers or crew are unacceptable. Such cases should be addressed by applying the MSAD process, with the risk calculated as described in this handbook, and the particular injuries used as the severity. Applying the process in this way produces data representing the cumulative probability of non-fatal injuries, the number of specific non-fatal injuries expected in the timeframes defined for each risk factor, and the per-flight-hour probability of individual non-fatal injury. Because the type and nature of such injuries vary, it is not feasible to establish acceptable-risk guidelines. Each office, in consultation with the TAD Safety Management Branch, ANM-117, determines, on a case-by-case basis, whether the risk of injury associated with any given condition justifies corrective action.

3.5 The Causal Chain

Figure 3 is an illustrative condition model showing:

- the condition under study,
- its frequency of occurrence, and
- each condition and associated conditional probability that lead from the condition under study to reasonably possible unsafe outcomes of known severity.

The condition under study could be any airplane-related, potentially unsafe condition. Figure 3 shows two unsafe outcomes: unsafe outcome “A” and unsafe outcome “B.” The probability of unsafe outcome A occurring, as the result of the condition under study, is the product of the probability of occurrence or frequency of the condition under study (PC) and all the conditional probabilities (PA(x)) leading from the condition under study to unsafe outcome A. Similarly, the probability of unsafe outcome B is the product of conditional probabilities leading to unsafe outcome B. The total risk usually can be estimated as the sum of the risks associated with each unsafe outcome (Risk A + Risk B).

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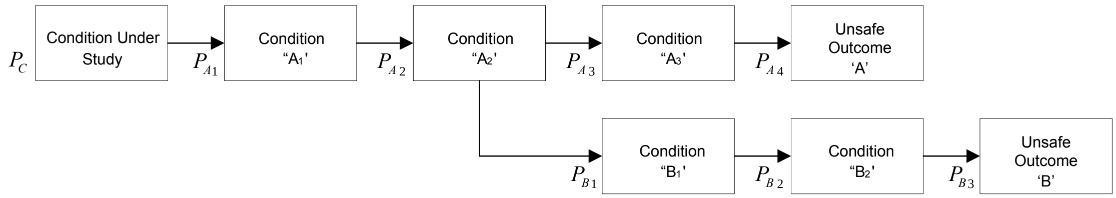
[2] Individual risk is not based on the “worst case” that can be hypothesized. It represents the actual frequency of known conditions that can reasonably be expected to occur during a reasonable number of actual flights, e.g., 10 or more.



P_C = the probability of occurrence of the condition under study

$P_{A(X)}$ and $P_{B(X)}$ = the conditional probabilities leading to unsafe outcomes A and B

$S_{(X)}$ = the severity of unsafe outcomes A and B

Risk = Probability x Conditional Probability x Severity

Risk A = $P_C \times (P_{A1} \times P_{A2} \times P_{A3} \times P_{A4}) \times S_A$

Risk B = $P_C \times (P_{A1} \times P_{A2} \times P_{B1} \times P_{B2} \times P_{B3}) \times S_B$

Total Risk = Risk A + Risk B

Figure 3. The Causal Chain

In performing a transport-airplane risk analysis of the example condition under study, the analyst obtains, to the extent possible, quantitative data to define the frequency of occurrence (Pc) and all the conditional probabilities associated with all the conditional factors leading to the unsafe outcomes. The conditional probabilities might be determined separately or captured in the data as a combined value.

Often the quantitative data needed to determine the probability and severity of various outcomes is available from historical data. If enough historical data is not available, it is sometimes necessary to rely on other data sources, including tests, analysis, or expert opinion.

TAD compiled historical data on the severity (in terms of fatalities) associated with common transport airplane unsafe outcomes, and developed a measure called the Injury Ratio (IR). The IR is the single event probability that those exposed to a condition or outcome will suffer fatal injury. If the IR is known for an intervening condition, only the conditional probability(s) that lead from the condition under study to the intervening condition are needed, because IRs capture the combined conditional probabilities of all subsequent unsafe outcomes. If, for example, the condition under study is a landing-gear strut failure, and condition A1 is a landing-gear collapse for which a known IR is available, the analyst would only need to determine the conditional probability (PA1) that a strut failure would result in a landing-gear collapse. No knowledge of the conditional probabilities and severities of subsequent conditions or outcomes, such as runway overruns, high-speed rejected takeoff, emergency evacuation, fire, etc., would be necessary, because all subsequent probabilities would be captured in the injury ratio for condition A1. Historical injury ratios for a variety of conditions and outcomes are available on the internal TAD ANMINFO website, http://webapps.anm.faa.gov/anminfo/menu.asp?opt=cosm2 and from the TAD Safety Management Branch, ANM-117.

3.6 Incremental Risk

Most risk analysis involves study of a condition (e.g., a failure, defect, etc.) that is a direct cause of an unsafe outcome. In other words, elimination of the condition would eliminate the unsafe outcome. However, in some cases, the condition of interest may be a secondary factor that does not directly cause an unsafe outcome, but, rather, increases the probability or severity of the outcome. For example, a latent failure of a cargo-fire suppression system does not directly cause a cargo fire, but if a cargo fire occurs due to some other cause, the failure of the cargo-fire suppression system will result in an increased probability of an unsafe outcome.

For cases where the unsafe outcome is not directly caused by the condition under study, but is exacerbated by it, the calculation of risk should only be for the incremental increase in risk due to the condition under study, not the total risk of an unsafe outcome due to some other independent cause. In other words, do not count fatalities or weighted outcomes that would have occurred despite the condition under study; only count the additional fatalities or weighted outcomes due to the condition under study. In the example of a latent failure of a cargo-fire suppression system, you need to calculate the incremental addition to risk, due to the absence of the system, by calculating the increment (delta) in risk factors, such as the injury ratio, conditional probability (CP), or frequency.

3.7 TARAM Risk

In the TARAM process, five risk values are calculated for varying time periods: three fleet risk values and two individual risk values, as shown in Table 1. TARAM supports the risk-management phase of MSAD by identifying how ACOs use these risk values to establish the need for corrective actions and nature and priority of necessary corrective actions.

If, based on initial risk values and/or other considerations, a decision is made that corrective action is not necessary, then control-program or 90-day risk does not need to be calculated.

Table 1. Risk Value Definition and Purpose

Risk Value	Definition	Purpose
Total Uncorrected Fleet Risk	The number of weighted events statistically expected in the remaining life of the affected fleet if no corrective action is taken as a result of the identified potential unsafe condition. The events are weighted by the injury ratio (IR).	Provides a long-term forecast of future risk if no corrective action is taken. This helps determine whether an unsafe condition might exist and is used to guide the decision for corrective action.
Uncorrected Individual Risk	The highest probability per flight hour, expected to occur during a reasonable number of future flights, that an exposed individual will be fatally injured if no action is taken.	Used in cases where low fleet exposure or severity results in acceptable, total uncorrected fleet risk, as defined above, but the risk to individuals flying in high-risk airplanes is not acceptable. This risk calculation helps determine whether an unsafe condition may exist, and is used to guide the decision for corrective action.
90-Day Fleet Risk	The short-term average fleet risk in terms of fatalities within the affected fleet over the next 90 days if no corrective action is taken.	Provides a short-term risk forecast, and helps determine how urgently corrective action might be needed. The 90-day fleet-risk value provides management information for use in resource allocation.
Control-Program Fleet Risk	The risk within the affected fleet during the control program (the period when corrective action is being accomplished) in terms of fatalities.	Helps risk managers evaluate the acceptability of candidate corrective actions. Use the Risk Guideline in Table 3 to identify risk levels when more urgent action may be needed.
Control-Program Individual Risk	The highest probability per flight hour, expected to occur during a reasonable number of future flights, that an exposed individual will be fatally injured that is before corrective action is accomplished.	Used in cases where low fleet exposure or severity results in acceptable control-program fleet risk, as defined above, but the risk to individuals flying in those airplanes indicates that more aggressive action should be taken. It is used to guide the decision for the urgency of the corrective action.

3.7.1 Total Uncorrected Fleet Risk

When analyzing a constant-failure-rate issue, calculate the total uncorrected fleet risk by computing the product of the frequency of the condition under study per flight or flight hour (based on the estimated remaining affected fleet life), the conditional probability that the condition under study will result in a defined outcome, and the average severity probability (injury ratio) of the outcome. See Chapter 4 for details on risk calculation. A comparable calculation using failure forecasts is performed for wear-out issues. See Chapter 5 for discussion of risk calculation for wear-out issues.

This computation is performed for each reasonably expected outcome for which an injury ratio is known. The result of the total uncorrected fleet-risk computation for each outcome is usually summed together to obtain the total uncorrected fleet risk associated with the condition under study.

3.7.2 Uncorrected Individual Risk

To calculate the uncorrected individual risk, compute the product of the frequency of the condition under study, the conditional probability that the condition under study will result in the defined outcome, and the probability of fatal injury associated with the outcome (injury ratio). This computation is performed for each reasonably expected outcome for which an injury ratio is known and the result of the uncorrected individual-risk computation for each outcome is usually summed together to obtain the uncorrected individual risk associated with the condition under study.

Depending on the nature of the issue, uncorrected individual risk may be calculated as an average. "However, there may be circumstances where you can calculate individual risk, including risk values for special conditions and combinations of conditions, or for subsets of the fleet,"[3] in which case the individual risk is calculated as the highest, reasonably expected value. If no significant variation occurs between flights, use the average value.

When calculating individual risk as the highest, reasonably expected value accounting "for special conditions and combinations of conditions," do not stack unrealistic worst-case combinations of conditions. The individual-risk calculation results in a value that reflects the actual risk associated with a reasonable number of expected future flights, i.e., 10 or more.

3.7.3 90-Day Fleet Risk

For a constant-failure-rate issue, calculate the 90-day fleet risk by computing the product of the frequency of the condition under study per flight or flight hour (flights or flight hours estimated within the next 90 days), the conditional probability that the condition under study will result in the defined outcome(s), the average severity of the outcome, and the number of persons expected to be exposed to that outcome. A comparable calculation using failure forecasts is performed for wear-out issues. This computation is performed for each reasonably expected outcome for which an injury ratio is known. The results of the 90-day computations for each outcome are usually added together to obtain the 90-day fleet risk associated with the condition under study.

3.7.4 Control-Program Fleet Risk

For a constant-failure-rate issue, calculate the control-program fleet risk by computing the product of the frequency of the condition under study per flight or flight hour (flights or flight hours estimated over the corrective-action accomplishment time period as outlined below), the conditional probability that the condition under study will result in the defined outcome, the average severity of the outcome, and the number of persons expected to be exposed to that outcome. A comparable calculation using failure forecasts is performed for wear-out issues. This computation is performed for each reasonably expected outcome for which an injury ratio is known. The results of the control-program fleet risk computation for each outcome are usually added together to obtain the control-program fleet risk associated with the condition under study.

In calculating control-program fleet risk or control-program individual risk, the time period is the time from completion of the risk analysis through the total AD processing time, any time after AD release when operators will not have sufficient parts or information to accomplish the necessary changes, plus the average incorporation time period based on the incorporation rate. If the incorporation rate is unknown and cannot be better estimated, the average incorporation time period can be estimated as one-half of the time that operators are able to incorporate the required changes.

[3] See FAA Order 8110.107, paragraphs 2-9.d and 2-14.b.

3.7.5 Control-Program Individual Risk

To calculate the control-program individual risk, compute the product of the frequency of the condition under study, the conditional probability that the condition under study will result in the defined outcome, and the probability of fatal injury associated with the outcome (injury ratio). Perform this computation for each reasonably expected outcome for which an injury ratio is known. The results of the control-program individual-risk computations for each outcome are usually added together to obtain the control-program individual risk associated with the condition under study.

Depending on the nature of the issue, uncorrected individual risk may be calculated as an average. "However, there may be circumstances where you can calculate individual risk including risk values for special conditions and combinations of conditions, or for subsets of the fleet,"[3] in which case the individual risk is calculated as the highest reasonably expected value If there isn't significant variation between flights, the average value is used.

When calculating individual risk as the highest reasonably expected value accounting "for special conditions and combinations of conditions", do not stack unrealistic worst-case combinations of conditions. The individual risk calculation results in a value that reflects the actual risk associated with a reasonable number of expected future flights, i.e., 10 or more.

3.8 Process Overview

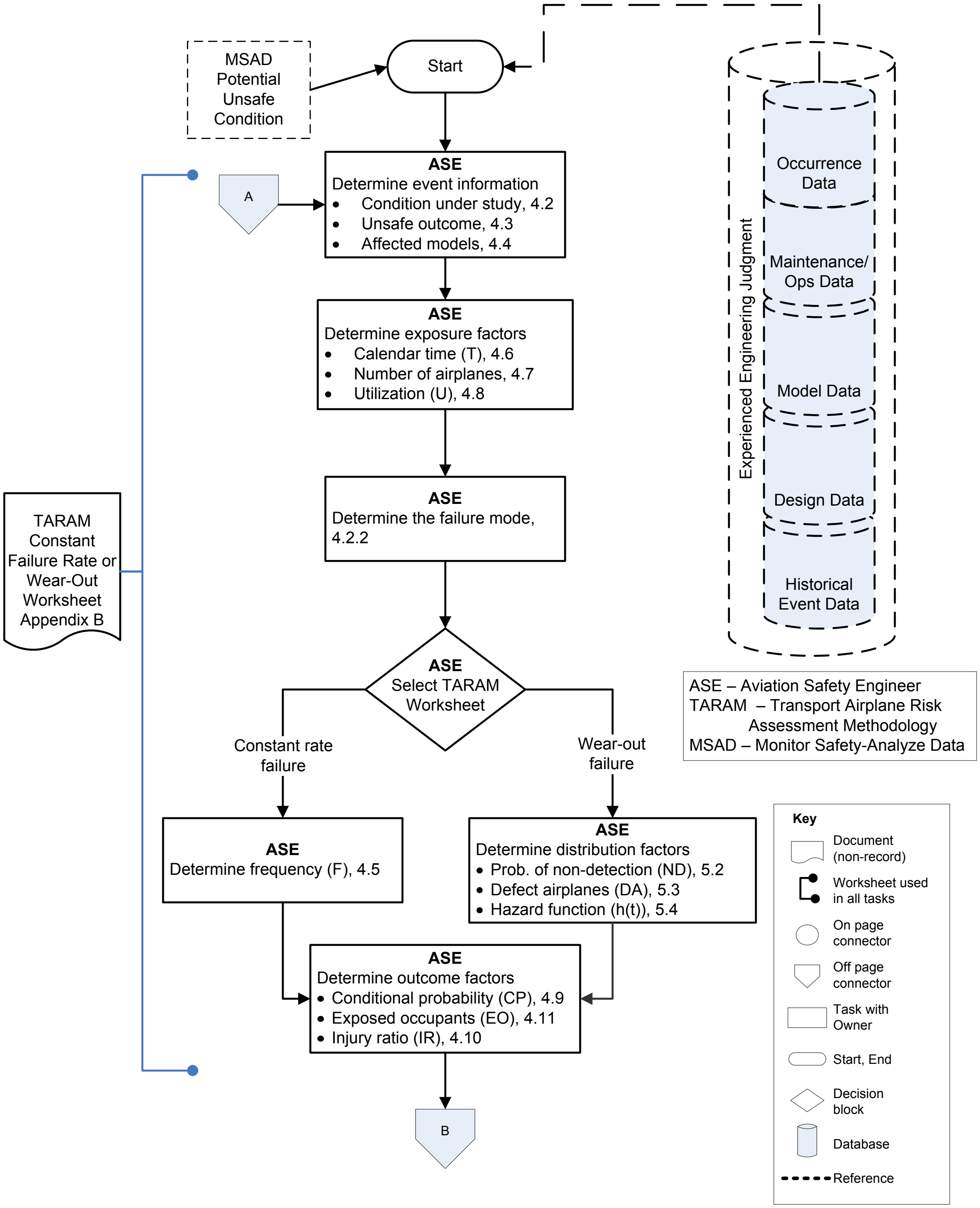


Figure 4. TARAM Process Flowchart

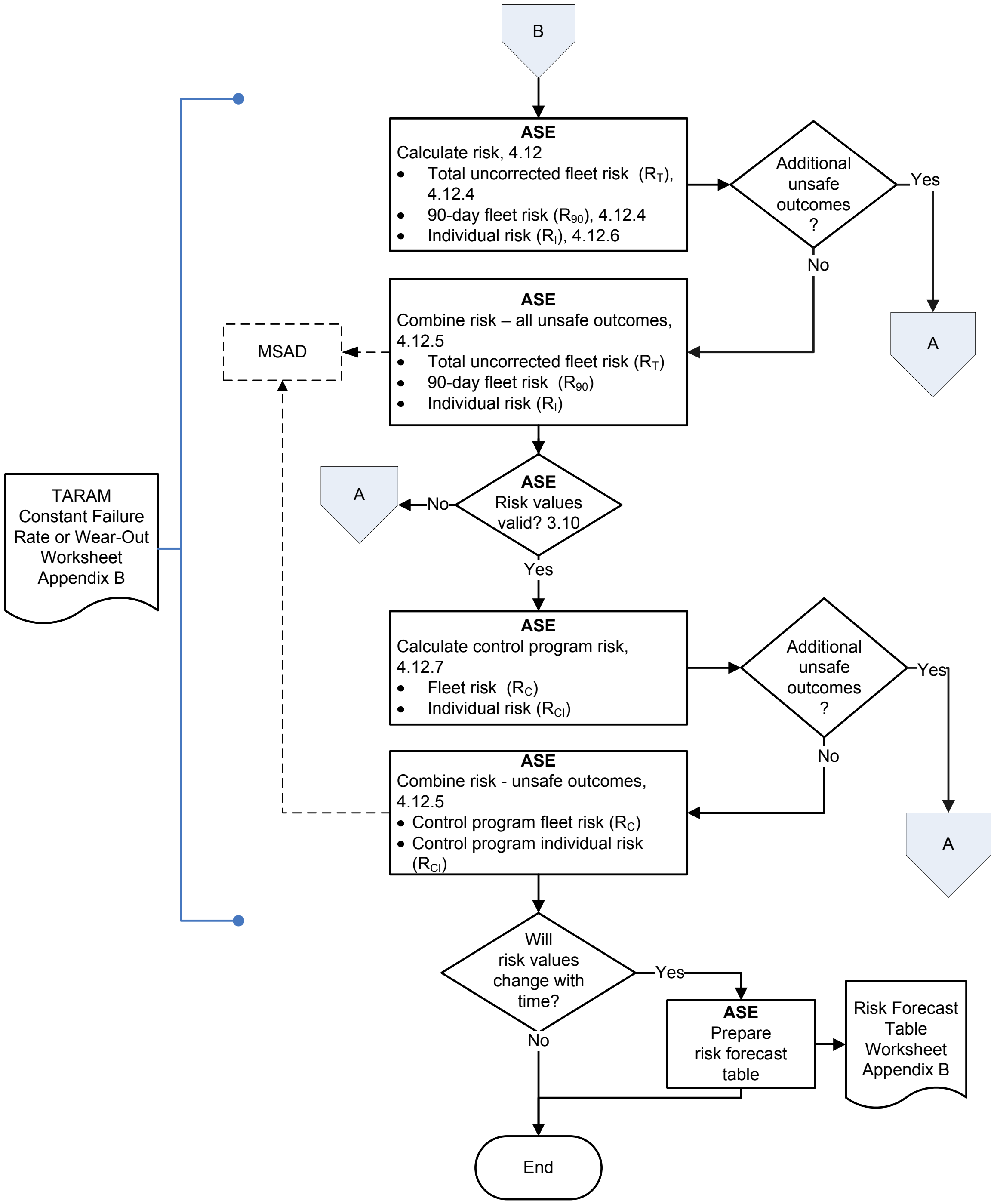


Figure 4. TARAM Process Flowchart (continued)

3.9 Definitions and Formulas

Table 2 provides the basic risk formulas. Definitions associated with both severity and probability variables are provided immediately following the table. The formulas in Table 2 use elements of Weibull analysis to support risk analysis of wear-out failure modes. Detailed guidance for determining risk values is provided in Chapters 4 and 5 of this handbook.

The major airplane, engine, and systems manufacturers can assist in determining many of the severity and probability variables necessary for this analysis. ANM-117 collects and makes available data such as injury ratios, historical analyses, and statistical tools.

ANM-117 maintains risk analysis worksheets to help ASEs with developing and presenting risk results. The worksheets and supporting data and records are available at http://webapps.anm.faa.gov/anminfo/menu.asp?opt=cosm:

- Transport Airplane Constant Failure Rate Worksheet
- Transport Airplane Wear-Out Worksheet
- Transport-Airplane Risk Forecast Table

Additionally, the Aviation Safety Information Analysis and Sharing (ASIAS) system is available to all FAA employees, and provides access to aviation databases such as Ascend™, the Service Difficulties Reporting System (SDRS), the National Transportation Safety Board (NTSB) database, and the Accident Incident Database System (AIDS).

Table 2. Basic Risk Formulas and Variables

Total Uncorrected Fleet Risk	90-Day Fleet Risk	Control-program fleet Risk	Uncorrected Individual Risk	Control-Program Individual Risk
For random failures: R_T = [U x T x Σ x F] x [CP] x [IR]	For random failures: R_{90} =[U_{90} x T_{90} x $Σ_{90}$ x F] x [CP_{90}] x [EO x IR]	For random failures: R_C = [U_C x T_C x $Σ_c$ x F] x [CP_c] x [EO x IR]	For random failures: R_I = F x CP_I x IR	For random failures: R_I = F x CP_I x IR
For wear-out failures: R_T = [ND x DA] x [CP] x [IR]	For wear-out failures: R_{90} =[ND x DA_{90}] x [CP_{90}] x [EO x IR]	For wear-out failures: R_C = [ND x DA_C] x [CP_C] x [EO x IR]	For wear-out failures: R_I = ND x h_I x CP_I x IR	For wear-out failures: R_I = ND x h_{CP} x CP_I x IR
U = Utilization in hours/day, cycles/day, or flights/day[4]	U_{90} = Utilization in hours/day, cycles/day, or flights/day over the next 90 days	U_C = Utilization in hours/day, cycles/day, or flights/day over the control program	N/A	N/A
T = Remaining fleet life of the affected fleet in days[5]	T_{90} = 90 days	T_C = Control program duration in days (see paragraph 4.6.4)	N/A	N/A
Σ = Number of airplanes in the affected fleet during the remaining fleet-life [5]	$Σ_{90}$ = Number of airplanes in the affected fleet over the next 90 days	$Σ_C$ = Number of airplanes in the affected fleet over the time span of the control program	N/A	N/A
F = Frequency of occurrence of the condition under study	F = Frequency of occurrence of the condition under study	F =Frequency of occurrence of the condition under study	F_I = The highest Frequency of occurrence of the condition under study expected during a reasonable number of future flights	F_{CI} = Frequency of occurrence of the condition under study expected during a reasonable number of future flights
ND = Average probability that an occurrence of a defect is not detected before an unsafe condition or outcome throughout the life of the affected fleet (See section 5.2 in this handbook)				
DA = Predicted number of airplanes with the subject failure during the life of the affected fleet	DA_{90} = Predicted number of airplanes with the subject failure during the next 90 days	DA_C = Predicted number of airplanes with the subject failure during the control program	h_I = Hazard function of the oldest airplane at retirement	h_{CP} = Hazard function of the oldest airplane at the end of the control program.
CP = Conditional probability(s)	CP_{90} = Conditional probability(s) over the next 90 days	CP_C = Conditional probability(s) during the control program	CP_I = The highest conditional probability(s) expected during a reasonable number of future flights.	CP_{CI} = The highest conditional probability(s) expected during a reasonable number of future flights.
N/A	EO = Exposed occupants	EO = Exposed occupants	N/A	N/A
IR = Injury ratio(s)				

[4] U x T x Σ equals the estimated total number of flights or flight-hours remaining in the affected fleet.

[5] In a constant-failure-rate analysis, either T or Σ, but not both, is averaged to obtain the estimated total number of flights or flight hours remaining in the affected fleet.

The variables used in determining the transport-airplane risk values are defined as follows:[6]

Conditional Probability (CP)— the probability that an unsafe outcome, for which an injury ratio is known, will result from a particular condition under study. The conditional probability is the product of the individual conditional probabilities for all of the conditions that must occur, after the condition under study, to result in the defined unsafe outcome.

Defect Airplanes(s) (DA) — the predicted number of airplanes that would have the subject failure if the condition under study is left undetected during the timeframe being analyzed.

Exposed Occupants (EO) — the average number of persons expected to be exposed to fatal injury during an unsafe outcome or condition.

Frequency of Occurrence (F) — the rate at which the condition under study is expected to manifest itself within the affected fleet or sub fleet. For non-constant failure rates, such as wear-out failures, Weibull and log-normal analysis techniques are helpful in determining the distribution of failures over time.

Hazard Function (h(t))— the instantaneous failure rate of a unit. Hazard function is analogous to the frequency of occurrence.

Injury Ratio (IR) — the average single-event probability that those exposed to a particular condition or outcome will suffer fatal injury.

Utilization (U) — the airplane's flight hours or flight cycles per defined-unit time period (e.g., per day).

Not Detected (ND) — the probability that an occurrence of a defect will not be detected before the defect leads to an unsafe condition or outcome. ND is a conditional probability, but it is defined separately because of its importance in certain wear-out issues, such as structural fatigue.

Number of Aircraft (Σ) — the number of airplanes in the affected fleet during the time period under study.

Time Period (T) — the time period over which risk is calculated. See Paragraph 4.6 for specific guidance on time period determination.

Note: The term "fleet" refers to all airplanes on which the condition under study could occur, and which are similar enough in equipage, design, and/or operation that they can be considered together in a risk analysis. The term can refer to all transport-category airplanes or a subset of airplanes of a particular model. Occasionally, the condition under study may affect airplanes that are not similar enough in equipage, design, and/or operation to be considered together in a single risk analysis. In those cases, the risk associated with the condition under study must be analyzed for each sub-fleet, and added together to determine the "fleet" risk. Results of each individual sub-fleet analysis can then be used, if necessary, to communicate and justify different corrective actions and corrective-action timeframes for each sub-fleet. Normally, airplane issues and resulting corrective actions focus on one model or on a subgroup within one model.

[6] See Appendix A for the definition of general terms not related to risk variables.

3.10 Estimates Based on Engineering Judgment

An important element of good analysis is ensuring that, when practicable, all judgments and estimates are based on empirical data—data based on observation, test, or experience. When sufficient empirical data is lacking, accepted engineering practices will need to be used to determine the "best estimate" of the actual quantitative values needed for risk determination. If you are an analyst making such estimates, you should document the basis for your estimates on the risk-analysis worksheet. This information can then be considered when determining the appropriate response for the potential unsafe condition. Intentionally conservative estimates or arbitrarily inflated risk factors, to account for uncertainty, will result in less-effective overall risk management. Conservative estimates and the resulting conservative risk values will cause safety issues with lower actual risk to be prioritized and addressed at the same time as, or even ahead of, safety issues with higher actual risk. Conversely, unrealistically optimistic risk values should be avoided for the same reason.

Good quantitative analysis is meant to provide the best estimate of risk based on available information. You should not avoid quantitative analysis simply because the data are incomplete. Risk analyses invariably depend on sound engineering judgment, even though this introduces an element of subjectivity into the analysis. You should document uncertainties in the details of the analysis on the risk-analysis worksheet. The CARB needs complete information to consider when determining the appropriate response for each potential unsafe condition.

3.11 Validation

To ensure the quality of the risk-analysis process, and whenever possible, compare the risk values produced by an analysis against the historical record associated with the condition under study and its effects to see if the calculated values appear reasonable. If the risk values are considerably higher or lower than expected based on knowledge of the historical impact of the issue, review the data, estimates, and associated technical assumptions used. Determine whether all considerations were properly assessed and make sure that overly conservative or overly optimistic assumptions were not introduced. It may be possible and necessary in some cases to apply the data, estimates, and associated technical assumptions in the analysis to predict past events, then compare the result to the actual historical record to validate the predicted risk values.

You should not adjust risk variables or values for the sole purpose of making the result match individual or commonly held (but unproven) perceptions, or to align with past, qualitatively based safety decisions.

4 TARAM Risk-Assessment Guidance

This chapter provides specific guidance to be used when determining the risk variables used in the TARAM. To produce consistent risk-analysis results, the severity and probability variables used in the TARAM are defined in a standardized manner to simplify the tasks associated with calculating risk.

4.1 Understanding the Causal Chain

The first step in using the TARAM is to develop and/or understand the causal chain that leads directly from the condition under study to foreseeable unsafe outcomes for which an injury ratio is known (see Figure 3). In cases where the relationships between the condition under study and associated outcomes are complex or not well-understood, you may need to formally construct a representative causal chain or other similar event model, such as a fault tree, event tree, concept diagram, etc., to fully understand the nature and effect of the condition under study.

Based on knowledge drawn from the causal chain, if more than one unsafe outcome is foreseeable for the condition under study, a TARAM worksheet should be filled out for each unsafe outcome, and Part 2 of an additional, constant-failure-rate summary worksheet should be prepared. Use this additional summary worksheet to document the risk factors associated with all of the unsafe outcomes, for that specific condition, added together (or, if the outcomes are not independent, combined as appropriate). Only Part 2 need be filled out on the additional summary worksheet. The additional summary worksheet is not necessary if there is a single outcome with a known injury ratio in the causal chain leading to all subsequent unsafe outcomes.

As an example, if the only injury ratios known were those associated with unsafe outcomes A and B in Figure 3, the analyst would prepare a worksheet for each of those unsafe outcomes, then add (or combine as appropriate) the results together on a summary worksheet Part 2 to obtain the combined risk. If an injury ratio for Condition A1 is known, only one worksheet would be necessary with the Condition, A, listed in the unsafe-outcome-description block of the worksheet.

4.2 Condition Under Study

4.2.1 Condition Under Study – General Guidance

The analyst must clearly define the base condition, failure, defect, error, or event that is intended to serve as the condition under study for the analysis. In the context of the MSAD process, the condition under study would normally be one of the following—

- A potential unsafe condition identified by the MSAD process
- The subject of a 14 CFR 21.3 report
- The subject of a certificate-holder notification
- The subject of a service-difficulty report
- The subject of another aviation-problem notice
- A contributory condition or conditions in the root-cause analysis of an accident or incident

The MSAD potential unsafe condition will often be the "condition under study" in a TARAM risk analysis, but in some cases, using another point in the causal chain as the condition under study will simplify or improve the risk analysis. When the MSAD potential unsafe condition is not used as the focus of the risk analysis, the condition chosen should have a direct analytical relationship to the identified MSAD potential unsafe condition. Record or attach a description of that relationship to the TARAM worksheet.

4.2.2 Determining the Type of Risk Analysis (Constant Failure Rate or Wear-out)

Failures can be categorized into three types:

- **Early failures**—those situations where parts are more likely to fail early in their life. (These failures are sometimes referred to in risk-analysis literature as “infant mortality” failures.)
- **Random (constant-rate) failures**—in which parts are equally liable to fail, whatever their age. Fan-blade failures due to bird strike are an example of random failures.
- **Wear-out failures**—the category of failures that are increasingly likely as parts age.

Although the risk-analysis formulas are similar for each type, the complexity of determining the frequency of occurrence varies significantly enough between the constant failure rate (random) and the logarithmic failure models (early and wear-out) that the types are treated separately in this handbook.

Early-failure distributions are rare in transport-airplane COS and are not discussed separately in this handbook. If an early-failure issue is found, it can be analyzed and the associated risk determined using the wear-out guidance and worksheet. However, be careful to include in the analysis only the sub-fleet of airplanes known (or estimated) to have the early-failure condition. Contact the FAA TAD Safety Management Branch, ANM-117, if necessary, for additional guidance and/or information regarding early-failure analysis.

If the analyst isn’t sure of the failure mode involved, and the failure distribution of the condition under study is unknown, the ASE can perform a Weibull analysis (or use another suitable analytical method) to determine the failure mode, and thus the associated risk analysis methodology necessary. The slope of the Weibull plot, beta (β), indicates which class of failures is present:

- $\beta < 1.0$ indicates early-failure distribution
- $\beta \cong 1.0$ means random-failure distribution (independent of age)
- $\beta > 1.0$ indicates wear-out-failure distribution

Many commercial, off-the-shelf software packages are available to simplify analysis. The type-certificate holder may also be able to provide results of a Weibull or log-normal analysis performed in the past to aid in the failure-type determination.

See Chapter 5 of this handbook for guidance in assessing the risk associated with wear-out concerns.

The units of time used in the analysis are chosen to attain the best correlation with the data. An understanding of the physics of the problem under study often simplifies this selection. For example, the unit of time used in evaluating structural-fatigue problems is usually flight cycles. Flight hours are another common time unit. Other problems, such as corrosion, may be related most directly to chronological time, so the best Weibull units of time in those cases are calendar hours, days, or years. After a unit of time is chosen, it must be used consistently throughout the risk analysis.

4.3 Unsafe Outcomes

4.3.1 General Guidance

You should clearly identify the foreseeable airplane-level outcome(s) with a known injury ratio closest in the causal chain to the condition under study. Identifying the closest outcomes with a known injury ratio will minimize the analytical complexity and data requirements in the risk analysis, as illustrated in Figure 3, and will also tend to improve the accuracy of the analysis.

4.3.2 Unsafe Outcome Guidance for Total Uncorrected, 90-Day, and Control Program Risk Analysis

Consider only those identified unsafe outcomes with a potential to occur during the prescribed time period. For example, if an unsafe outcome requires a particular environmental condition, such as icing, and the affected fleet clearly will not encounter the condition during the period under consideration, then that unsafe outcome need not be considered for 90-day and control-program risk calculations. The condition must still be considered appropriately in determining total uncorrected fleet risk. You should document, on the risk forecast worksheet in Appendix B, the additional calculation for a future 90-day risk, and delayed control-program risk, with the environmental condition considered. Many different scenarios could cause the predicted risk to change over time, including such factors as changes in airplane production rates, wear-out failures, and seasonal environmental effects.

4.4 Affected Models

List all airplane models for which the result of an unsafe outcome from the condition under study is foreseeable. If certain listed models are not covered by the corrective-action program associated with the analysis because differing geographic responsibilities place them under a different FAA organization, note this on the worksheet and transmit a copy of the worksheet, along with pertinent COS-issue data, to the responsible office.

4.5 Frequency of Occurrence (F)

4.5.1 Frequency of Occurrence – General Guidance

The frequency of occurrence is the rate at which the condition under study is expected to manifest itself within the affected fleet (or sub-fleet) during the time period of interest (one flight, next 90 days, fleet life, etc.). For example, given a constant-failure rate, and the associated basic-probability equation of $P = \lambda t$, (i.e., probability is failure rate times exposure time), frequency of occurrence means the same as failure rate and is equivalent to λ.

You must first determine whether or not the frequency of occurrence is expected to be constant (i.e., random) over the time period of interest. When the frequency of occurrence increases with time, a wear-out-failure mode may exist. Weibull analysis techniques are often useful in helping to make this determination.

If the condition is determined to be random, then the frequency of occurrence will be expressed as a single value. For random conditions, the average frequency can be estimated by dividing the number of occurrences to date by the total number of flight hours or flight cycles, as appropriate for the parts in the suspect fleet. While any units of measurement can be used, they must be consistent with those used to express fleet exposure, or an appropriate conversion factor must be applied when computing the frequency of occurrence. When occurrences of the condition under study are few, you can estimate frequency with statistical methods. Only use such methods, however, if they will result in the “best estimate” of the actual probability, e.g., 50% confidence.

4.5.2 Frequency of Occurrence for Individual Risk (F_I, F_{CI})

Sometimes, when calculating individual risk and due to “special conditions and combinations of conditions,” the frequency of occurrence is anticipated to be significantly higher than average on a “few” future flights. Accordingly, for individual risk, select the value for frequency that, when coupled with the conditional-probability, results in the largest individual-risk value that is anticipated to actually occur on a reasonable number of future flights, e.g., 10 or more.

4.6 Time Period (T)

4.6.1 Time Period – General Guidance

In a constant-failure-rate analysis, the time period used in calculating fleet exposure with the TARAM will either be the *average time period* over which the *total (existing and future) fleet* will operate or the *total time period* over which the *average number of (existing and future) airplanes* will operate. (See paragraph 4.12 for additional guidance.)

4.6.2 Time Period for Total Uncorrected Risk (T)

If no production change has been developed to address the safety issue, the average age of the affected fleet can be used to account for future production of uncorrected airplanes.

The average airplane age at retirement from service must be established for each affected fleet, and will typically need to be based on the retirement history of airplanes of similar design, mission, and utilization. If age at retirement is not expected to vary, a single value can be used for all airplanes of one type, a specific sub-fleet, or all affected airplanes. Age at retirement can be assumed to be at least 35 years unless a lower (or higher) value can be justified.

For fleets that are close to retirement, it is often possible to estimate an attrition schedule to use in determining the remaining exposure of the fleet. For example, the attrition schedule could be a linear reduction in the fleet over the remaining fleet life.

4.6.3 Time Period for 90-day Risk (T_{90})

For 90-day risk, the time period is 90 days. Note that units must remain consistent throughout the analysis, so if “days” is used for this time period, use “days” for all time periods.

4.6.4 Time Period for Control Program Risk (T_C)

For the control-program fleet risk or control-program individual risk, the time period is the time from completion of the risk analysis through the total AD processing time, any time after AD release when operators will not have sufficient parts or information to accomplish the necessary changes, plus the average incorporation time period based on the incorporation rate. If the incorporation rate is unknown and cannot be better estimated, the average incorporation time period can be estimated as one-half the portion of the AD-compliance time within which operators are able to incorporate the required changes.

4.7 Number of Airplanes (Σ)

This variable is the number of FAA type-certified transport-category airplanes for which safety could be adversely affected by the condition under study. In a constant-failure-rate analysis, the number of airplanes used in calculating fleet exposure with the TARAM will either be the *total number of (existing and future) affected airplanes* operating over the *average time period* or the *average number of (existing and future) affected airplanes* operating over the *total time period*. (See paragraph 4.12 for additional guidance.) In a wear-out analysis, all existing and future airplanes, along with their respective ages, are considered.

Affected airplanes could include—

- Airplanes of a substantially similar design for common design problems, and
- Airplanes within a certain serial-number range for batch production/material problems.

If multiple airplane types are exposed to the same safety issue, the affected fleet will normally include all affected airplane types. There may be occasions when it is appropriate or necessary to divide the overall affected fleet into distinct sub-fleets and treat each separately. For example, if different certification offices or authorities are responsible for different portions of the affected fleet, it may be more practical for each affected office to deal with its own affected sub-fleets. Also, if the risk associated with different sub-fleets within the overall affected fleet is predicted to be substantially different, it may be appropriate to treat each of these sub-fleets separately. If a service bulletin is available for the corrective action, then the number of airplanes listed in the service bulletin is indicative of the affected fleet size.

If no production change is currently planned or foreseen to correct the condition being evaluated, then the affected fleet size includes the total number of airplanes expected to be produced. However, once a feature of the airplane has been determined to be unsafe and the airplane is still being manufactured with the unsafe feature, a production fix will be required.

Airplane manufacturers, operators, and/or airplane operations data providers such as Ascend™ can aid in establishing the value of Σ. Ascend™ data is available through the FAA Aviation Safety and Information Analysis and Sharing (ASIAS) system.

4.8 Utilization (U)

4.8.1 Utilization – General Guidance

Utilization is the average airplane operation (flights or flight hours, as appropriate) within a time period, divided by calendar time, in days, within the time period.

$$U = {}^{OT}\!/_{CT}$$

Utilization is the operational exposure of a particular airplane, or the average operational exposure of a fleet of airplanes within a given continuous time period. If the utilization varies widely within the fleet of airplanes under study, the weighted average utilization can be used for random-failure distribution issues (for wear-out, consider using actual or estimated utilizations by airplane). Utilization is expressed in flight hours per day or flights per day. Regardless of the units of measurement selected, be sure to use compatible units or appropriate conversions throughout the risk analysis. Airplane manufacturers, operators, and/or airplane-operations data providers, such as Ascend™, can aid in establishing the value(s) of U.

4.8.2 Utilization for Total Uncorrected and Control-Program Risk Analyses (U, U_C)

An anticipated value for each airplane, or the average value for each airplane type, sub-fleet, or all airplanes in the affected fleet, can be used as applicable. Regardless of the approach used, take care to ensure consistency when computing the risk. If no change in utilization is expected over the remaining fleet life, then the most recent value for utilization can be used. However, factor into the analysis any significant changes in the utilization expected to occur on some or all of the airplanes within the affected fleet during the time period under study.

4.8.3 Utilization for 90-Day Risk Analysis (U_{90})

The most recent utilization rate for each airplane, or the current average value for each airplane type, sub-fleet, or all airplanes in the affected fleet, can be used.

4.9 Conditional Probability (CP)

4.9.1 Conditional Probability – General Guidance

Conditional probability is the likelihood that the condition or event under consideration will result in a particular outcome. The conditional probability includes all the individual conditional probabilities for all the conditions leading to the airplane-level unsafe outcome. The conditional probability is not, however, related to the frequency of occurrence of the condition or event. Take care to ensure that the conditional probability is not included in either the frequency of occurrence or the severity of the condition being assessed.

Use historical operating data or test data, when available, to determine CP. Expert opinion, analysis, and simulation may be used if sufficient historical data are unavailable. ANM-117 can assist with development of simulation models, such as Monte Carlo analyses. Lacking historical or test data, you can estimate CP with related design or certification fault-tree analyses, although assumptions made at the time of certification (e.g., any conservative factors) may not be relevant to the condition under study, or acceptable for use in a TARAM analysis. Such information may be helpful in determining the likely conditional probabilities of any contributory conditions necessary for the condition under study to result in an unsafe outcome(s). When neither sufficient data nor analytical estimations are available, CP can be estimated based on informed engineering judgment.

The overall CP may consist of several conditional probabilities that are *most often* multiplied together to obtain a single condition-to-outcome CP. **The method used to combine CPs depends on the extent that they are independent**—their probabilistic relationship. In those cases where conditional probabilities cannot be assumed to be independent, the TAD standards staff can be consulted regarding the best analytical approach.

Be aware that Injury Ratios associated with a particular condition or outcome capture all subsequent conditional probabilities in the causal chain. Take care not to "double count" conditional probabilities in both CP and IR.

4.9.2 Conditional Probability for Total Uncorrected and Control-Program Risk Analysis (CP, CP_C)

The average conditional probability anticipated, over the entire fleet life of all airplanes in the affected fleet (or sub-fleet), can be used. When the injury ratio and exposed occupants are known for each unsafe outcome, different outcomes with substantially similar consequences can be combined into a hybrid outcome using the collective time-weighted-average conditional probability. Otherwise, the conditional probability for each unsafe outcome must be treated separately.

4.9.3 Conditional Probability for 90-Day Risk Analysis (CP_{90})

The average conditional probability for the affected fleet (or sub-fleet) over the next 90 days can be used. This may be different from the overall average when a conditional probability is expected to change due to seasonal operational differences, age of the fleet, etc.

4.9.4 Conditional Probability for Individual Risk Analysis (CP_I, CP_{CI})

Sometimes, when calculating individual risk and due to "special conditions and combinations of conditions," the frequency of occurrence is anticipated to be significantly higher than average on a "few" future flights. Accordingly, for individual risk, select the value for conditional probability that, when coupled with the frequency, results in the largest individual-risk value anticipated to actually occur on a reasonable number of future flights, e.g., 10 or more.

4.10 Injury Ratio (IR)

The injury ratio is the average rate of fatality per person exposed to a specific airplane outcome or condition. Lists of historical injury ratios for a range of transport-airplane unsafe outcomes have been compiled and are available on ANMINFO, under the "TAD COS" section at http://webapps.anm.faa.gov/anminfo/menu.asp?opt=cosm2. If this list does not contain the injury ratio for a foreseeable unsafe outcome, contact the TAD Safety Management Branch, ANM-117. Useful injury ratios can be derived from the historical record of the unsafe outcome for which an injury ratio is needed. This can be done by dividing the total number of fatalities (*including people on the ground*) in each unsafe outcome by the total number of people exposed (airplane passengers and crew). For most outcomes, the number exposed is the total number of people *aboard* the airplanes involved. For local-threat unsafe outcomes, a more specific value for the number of people exposed will need to be determined based on the specific circumstances associated with the threat involved.

When no data is available on which to base an injury ratio for a specific unsafe outcome, the ASE will need to establish that value based on either similarity to other outcomes with known injury ratios or expert engineering judgment. Research and development initiatives are under way to develop additional data to better support future transport-airplane risk analyses.

4.11 Exposed Occupants (EO)

For those unsafe outcomes that pose a general threat to all the occupants of the airplane, the exposed occupants are the average airplane total capacity (passengers and crew) of the affected fleet. Airplane-operations data providers, such as Ascend™, can be used to establish the value of EO. For localized events, such as electrical-shock danger, an evaluation of the scope of the threat will be needed to establish the EO. This value will normally be the same for total uncorrected, 90-day, and control-program risk analysis.

The threat to persons outside the airplane is captured in the calculation of TARAM injury ratios.

4.12 Computing Risk

4.12.1 Fleet Exposure – General Guidance

Fleet exposure, which is used in the analysis of random-failure distribution issues, represents the total exposure of the affected fleet to the condition under study during a specific time period.

$$FleetExposure = U \times T \times \Sigma$$

Where:

U = Utilization (see paragraph 4.8)

T = the time period under study (See paragraph 4.6)

Σ = Number of airplanes in the affected fleet during T (See paragraph 4.7)

4.12.1.1 Handling Sub-fleets

Fleet exposure can usually be determined directly for an entire affected fleet. However, when utilization (U) is expected to vary significantly among sub-fleets, use the following equation. (See paragraph 4.12.2 for more information on sub-fleets.)

$$FleetExposure = (U_1 \times T \times \Sigma_1) + (U_2 \times T \times \Sigma_2) + (U_3 \times T \times \Sigma_3)$$

4.12.1.2 Fleet Exposure for Total Uncorrected Risk Calculations

To properly account for the total accumulated risk over the remaining fleet life, the number of affected future aircraft and the remaining fleet life must be determined. The following formula is used to determine the T x Σ term for total uncorrected-risk calculations.

$$T \text{ x } \Sigma = [(\text{Retirement Age} - \text{Average Fleet Age}) \text{ x Present Fleet Size}] + (\text{Number of affected future aircraft x Retirement Age})$$

Assume a retirement age of 35 years unless a better estimate of the retirement age is available.

The number of affected future aircraft is:

$$(\text{Estimated total fleet size} - \text{Present fleet size})$$

Alternately, fleet data can be used to estimate the total remaining life of the affected fleet (T) and the average number of airplanes (Σ) expected to be in service during that total remaining fleet life. These values can then be used to calculate fleet exposure in the total uncorrected-risk computation.

The resulting T x Σ value is then multiplied by utilization, U, to calculate the total fleet exposure for determining total uncorrected fleet risk.

4.12.1.3 Fleet Exposure for 90-Day Risk Calculations

90-day fleet exposure can be adequately calculated using 90 days for the time period, the total number of airplanes operating at the time of analysis for Σ, and the average utilization during that period for U.

4.12.1.4 Fleet Exposure for Control Program Risk Calculations

Control-program fleet exposure is based on the guidance of paragraph 4.6.4 and paragraph 4.12.1.2, unless the total AD processing time, plus the average corrective action time period, is so short that fleet size changes are not significant. In such a case, control-program fleet exposure can be calculated based on the guidance of paragraph 4.6.4 and paragraph 4.12.1.3.

4.12.2 Computing the Predicted Number of Occurrences (U x T x Σ x F)

For random-failure-distribution issues, the predicted number of occurrences equals the product of the fleet exposure, i.e., U x T x Σ, and frequency of occurrence F. Predicted number of occurrences represents the number of times the condition under study is expected to occur during the time period under study. See Chapter 5 for guidance on wear-out-failure distribution analysis.

The predicted number of occurrences can usually be determined directly for an entire affected fleet. However, when frequency (F) is expected to vary significantly among sub-fleets, the exposure of each sub-fleet is determined separately, multiplied by the associated sub-fleet frequency of occurrence, and each separate sub-fleet value added together to obtain the predicted number of occurrences in the fleet. As an example, the predicted number of occurrences of a condition under study, with significantly varying frequency in three sub-fleets, would be calculated as:

$$\begin{aligned}&\textit{Predicted Number of Occurrences}\\&=\left(F_1\times U_1\times T\times\Sigma_1\right)+\left(F_2\times U_2\times T\times\Sigma_2\right)+\left(F_3\times U_3\times T\times\Sigma_3\right)\end{aligned}$$

4.12.3 Computing Severity (S)

The severity of a defined outcome or condition, as defined in this handbook, is calculated either as the probability of fatal injury, i.e., injury ratio (for uncorrected fleet risk and individual risk), or as fatalities per occurrence (for 90-day and control-program risk).

For uncorrected fleet risk and individual risk: $S = IR$

For 90-day and control-program risk: $S = IR \times EO$

Where:

EO = exposed occupants (from paragraph 4.11)

IR = injury ratio (from paragraph 4.10)

4.12.4 Determining Fleet Risk (R)

For random-failure issues, risk is the product of the predicted number of occurrences, conditional probability(s), and severity. (See Chapter 5 for guidance on wear-out-failure distribution analysis.)

$$R = \left(U \times T \times \Sigma \times F\right) \times CP \times S$$

Where:

U x T x Σ x F = Predicted number of occurrences (see paragraph 4.12.2)

CP = Conditional probability (see paragraph 4.9)

S = Severity (see paragraph 4.12.3)

4.12.5 Multiple Outcomes

If the elements of risk have been calculated by sub-fleet(s), or if more than one unsafe outcome is associated with the condition under study, the fleet risk factors are combined (usually added) together in this step to cover the entire affected fleet and/or all the risk associated with the condition under study. Individual risk from multiple outcomes is not combined, but instead is the largest individual-risk value of the sub-fleet(s) or outcomes.

4.12.6 Determining Individual Risk (R_I)

Individual risk is the product of the frequency of occurrence (or hazard function), the injury ratio of the undesired outcome, and conditional probabilities (including ND—the average probability that an occurrence of a defect is not detected before the defect leads to an unsafe condition or outcome—when applicable).

For constant-failure-rate issues: $R_I = F \times CP_I \times IR$

For wear-out issues: $R_I = ND \times h_I \times CP_I \times IR$

Depending on the nature of the issue, uncorrected individual risk may be calculated as an average. "However, there may be circumstances where you can calculate individual risk including risk values for special conditions and combinations of conditions, or for subsets of the fleet,"[3] in which case the individual risk is calculated as the highest reasonably expected value. If no significant variation exists between flights, the average value is used.

When calculating individual risk avoid stacking unrealistic worst-case combinations of conditions. The goal in an individual risk calculation is a value for risk actually anticipated to occur on a reasonable number of future flights.

4.12.7 Control Program Risk

Calculate Control-Program Fleet Risk (R_C) and Control-Program Individual Risk (R_{CI}) if, as part of the MSAD process, a determination has been made that AD is needed. If the condition under study may result in more than one unsafe outcome, use the same method as used in paragraph 4.12.5 to combine the control-program risk to establish the total control-program risk associated with the condition under study.

Control-Program Fleet Risk (for constant-failure-rate issues):

$$R_C = (U_C \times T_C \times \Sigma_C \times F) \times CP_C \times (IR \times EO)$$

Control-Program Individual Risk (for constant-failure-rate issues):

$$R_{CI} = F_{CI} \times CP_{CI} \times IR$$

Control-Program Individual Risk (for wear-out issues):

$$R_{CI} = ND \times h_{CI} \times CP_{CI} \times IR$$

5 TARAM Risk-Assessment Guidance – Wear-Out

This chapter provides additional guidance for those safety issues related to wear-out. Although the risk values used in assessing wear-out-related failures are the same as those used for constant-failure-rate issues, the TARAM wear-out worksheet is different from the worksheet for constant-failure rate and involves additional variables. This chapter provides guidance for deriving the risk variables that are unique to wear-out issues. Those risk variables are—

- **ND** – the probability that an occurrence of the defect will not be detected before it results in an unsafe condition or unsafe outcome;
- **DA** – the number of airplanes predicted to experience the subject failure, if left undetected, during the time period under study; and
- **h(t)** – the hazard function.

For variables and guidance involved in determining the other TARAM risk values, see Table 2 and Chapter 4.

5.1 Distribution Analysis

For wear-out problems such as structural fatigue, a Weibull or similar analysis can be used during the risk analysis. Failures often can be fit to a 2-parameter Weibull distribution. Other distributions may be used if they can accurately represent the behavior of the population, and allow calculation of the cumulative-distribution function and the hazard function. The ASE can use a Weibull analysis to determine the shape parameter, β, and the characteristic life, η. This handbook does not provide information on how to conduct a Weibull analysis. The ASE should be fully trained in the use of Weibull analysis and understand the various parameters used in that analysis. Many commercial, off-the-shelf software packages are available to aid in performing a Weibull analysis. The type-certificate holder may also be able to perform a Weibull or log-normal analysis, and provide the results to the ASE.

The choice of time units for the Weibull analysis is dictated by the physics of the problem. If the appropriate time unit is not clear, comparison of a flight-cycle-based Weibull analysis to a flight-hour-based Weibull analysis can help determine the appropriate time unit; the time unit that provides the better correlation to the data would be the best choice. The time unit used in analyzing structural-fatigue problems is typically flight cycles, but there are exceptions. Other problems are related most directly to chronological time and, in those cases, the Weibull units of time are days or years. After you choose a unit of time, use it consistently throughout the risk analysis.

5.2 Not Detected (ND)

For wear-out issues, ND is the probability that an occurrence of the defect will not be detected before resulting in an unsafe condition or unsafe outcome. ND is used in the calculations of each of the risk values. For example, assuming no action is taken, ND is the probability that, during future operation and maintenance, a structural-fatigue crack will not be discovered by any means before the cracked element fails, resulting in an unsafe condition or unsafe outcome. ND could be considered part of the conditional probability, but it is such a unique and important factor in structural-fatigue-cracking issues that it is identified separately for emphasis and visibility.

For structural-fatigue cracking, the determination of ND often can be aided by a damage-tolerance analysis for the safety issue being analyzed. ND will vary considerably from problem to problem.

ND is a factor in any issue where the problem or defect can be anticipated to be detected during future inspection, maintenance, or operational activities. A good estimate of ND is necessary for the risk analysis to be useful for comparing issues and managing risk. The ASE should not "conservatively" assume that ND is 1 if it can be established through empirical evidence, observation, or expert judgment, to be lower.

5.3 Defect Airplanes (DA)

For wear-out issues, the number of airplanes predicted to have the failure, if left undetected, is used in calculating the total uncorrected risk, the 90-day risk, and the control-program risk (see Table 2 in this handbook.) To predict the number of airplanes anticipated to have the wear-out failure, the analyst first determines the affected fleet size, Σ, and the value of the cumulative-distribution function, F(t), for each airplane at various points of time.

Guidance for determining the cumulative-distribution function, F(t), is provided below.

The cumulative-distribution function provides the portion of a population that will fail before time t. Remember: it is not possible to predict whether a given individual part will actually fail, but it is possible to predict the expected number of failures within a given population.

5.3.1 Using the Weibull Distribution Failure Forecast Formula

The characteristic life (η) and the shape parameter (β) from the 2-parameter Weibull distribution can be used to calculate the cumulative-distribution function. For a 2-parameter Weibull, cumulative-distribution functions are shown in Figure 5 and calculated using the following formula—

$$F(t) = 1 - e^{\left[-\left(t/\eta\right)^{\beta}\right]}$$

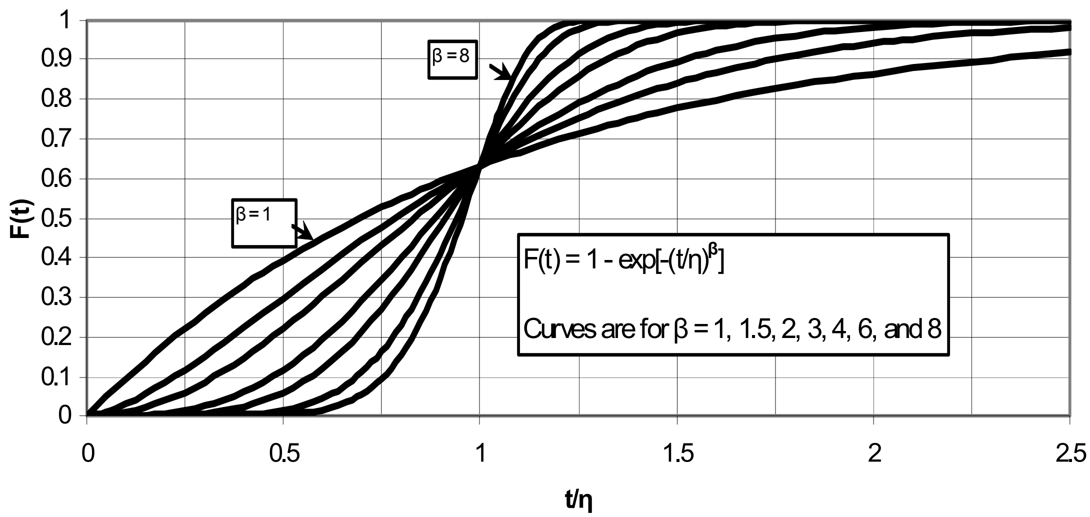


Figure 5. Cumulative-Distribution Function F(t)

The cumulative-distribution function can be used to estimate the expected number of failures through a future time period. The number of forecast failures is obtained by summing over the fleet of affected airplanes that have not yet failed:

$$DA = \sum_{fleet} \frac{\left[F\left(t + \Delta t\right) - F\left(t\right)\right]}{1 - F\left(t\right)}$$

T is the current airplane's age (in the analysis time units, e.g., in flights), and Δt is the amount of time that will elapse for that airplane over the failure-forecast period. Note that Δt will vary from airplane to airplane. The value of Δt will also vary for the same airplane for total uncorrected risk, the 90-day risk, and the control-program risk calculations, as the time period being analyzed (Δt) is different for each of these three risk calculations. For example, when calculating total uncorrected risk, Δt, is the amount of time (e.g., the number of flights) from now until the airplane retires. Δt is a function of the airplane's current age and typically its utilization as well.

When calculating Δt for the control-program risk, if the control program has a threshold and a grace period (for those airplanes already past the threshold), then Δt is the time to reach the threshold for airplanes below the threshold, and the average grace period for airplanes above the threshold. The time entered on the TARAM worksheet (T_C) represents the average control-program compliance time. For affected fleets that are all above the threshold, this would be the average grace period. However, if any airplanes have not reached the threshold, significant errors can be introduced by a poor selection of T_C; in this case, do not use an average T_C in the calculation of DA, but instead use the appropriate Δt calculated for each airplane, depending upon its relation to the threshold and grace period.

5.3.2 Using Reliability Software to Directly Forecast DA

Many reliability-analysis programs can directly forecast the number of parts that will fail during a future time period. If data for the entire affected fleet have been entered into such a program, the resulting failure forecast may be used in the risk calculations.

5.4 Hazard Function h(t)

The hazard function, h(t), is used in calculating uncorrected and control-program individual risk (see Figure 6). This function provides the instantaneous failure rate—the probability of failure of a unit in the next increment of time, assuming survival to time t. The hazard function is analogous to the frequency of occurrence, F, used in the analysis of constant-failure-rate issues.

The characteristic life (η) and the shape parameter (β) from the 2-parameter Weibull distribution can be used in calculating the hazard function (other distributions may also be used). Hazard functions for a 2-parameter Weibull distribution are shown in Figure 6 and can be calculated using the following formula—

$$h(t) = \left(\frac{\beta}{\eta}\right) \cdot \left(\frac{t}{\eta}\right)^{\beta-1}$$

Note: The curves in Figure 6 do not provide the hazard function directly, but provide the hazard function multiplied by η.

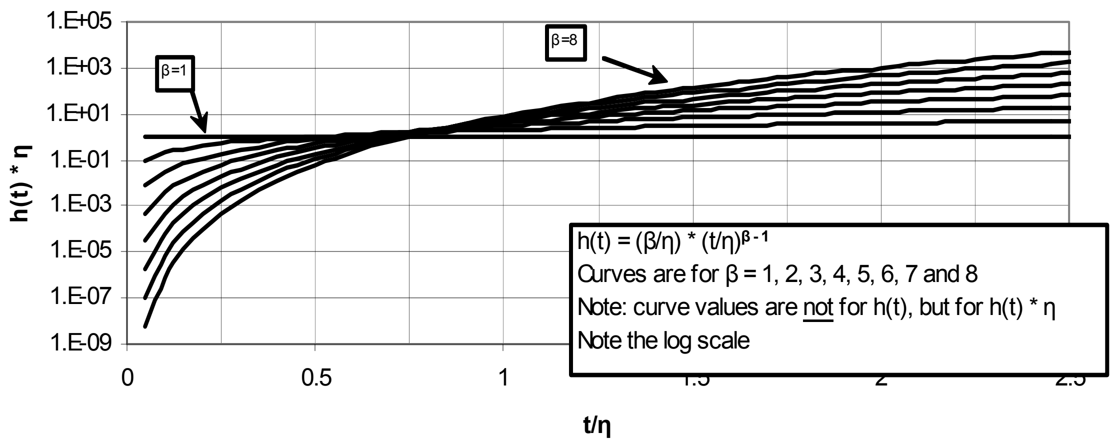


Figure 6. Hazard Function h(t)*η

6 Risk Management

This section provides guidance for applying results of the risk analysis to risk-management decision-making as part of the Order 8110.107 process.

6.1 Fail-Safe Design

The philosophy of fail-safe design has been an important part of ensuring transport-airplane safety for more than 50 years. A tenet of that philosophy is that the airplane must be designed in such a way that no single failure can prevent continued safe flight and landing, regardless of the probability of the single failure. Some exceptions to this philosophy are made out of necessity at the time of certification, e.g., engine and landing gear parts that have safe-life limits. Other exceptions are made in unusual circumstances at the time of certification, such as when the FAA determines, based on experienced engineering judgment, that such a failure is not a practical possibility (reference AC 25.1309-1A paragraph 7.g.).

The fail-safe design philosophy in the airworthiness rules is expressed in qualitative terms, and compliance is found based on engineering and operational judgment. As a result, it is not feasible to define or correlate the fail-safe 'single failure' criteria directly to the quantitative risk values and guidance in the TARAM. The determination of whether a discovered single failure is a violation of the fail-safe design philosophy, and therefore unsafe, must be based on experienced engineering and operational judgment.

However, if a single-failure condition discovered in service:

- can lead directly to an unsafe outcome with an injury ratio greater than 0.10 (10%), and
- with all known operational/environmental factors, conditional probability (single failure to unsafe outcome) is greater than 0.10 (10%)

then, the failure condition should be suspected of violating fail-safe design requirements and evaluated based on the criteria associated with fail-safe principles. If you determine that the condition violates the fail-safe philosophy, you should consider the condition unsafe regardless of the calculated TARAM uncorrected fleet or individual risk values. However, the urgency of corrective action, and the adequacy of the corrective action timeframe for single-failure issues, should be based on the associated TARAM 90-day fleet risk, control-program fleet risk, and control-program individual-risk values.

Note: For the purpose of TARAM uncorrected-risk analyses, unless the structure is certified as "safe life" [14 CFR 25.571(c)], fatigue cracks are not automatically considered "single failures."

6.2 Risk-Level Guidance

Table 3 provides risk-level guidance for corrective-action decision-making. These values are guidance for the range of risk that may require corrective action. Per 14 CFR part 21, the determination that an airplane design or feature is safe, or that an airplane is safely operable, is an important function of the Administrator, yet the Administrator has a great deal of inherent flexibility and latitude when making safety determinations. The guidance in Table 3 does not define or limit the Administrator's prerogative to make such safety decisions.

The risk values in Table 3 are not risk thresholds. Confidence in the analytically derived values can vary widely, and that confidence must be considered in risk-management decisions. Factors other than risk also are considered in safety decision-making, and the Table 3 values do not limit the scope or weight of those other considerations.

Although some of the TARAM risk values and associated risk-level guidance are expressed in terms of fatalities, they should not be viewed as predictive values. The TARAM risk values and risk-level guidance represent a "level" or "range" and are not expectations of actual events.

Control-program fleet risk-level guidance is used in conjunction with a general philosophy to *correct unacceptable risk as soon as reasonably practical*. The correction-as-soon-as-reasonably-practical philosophy is necessary because the TARAM does not address the cumulative risk in a fleet represented by all known, uncorrected, unsafe conditions. Cumulative risk may be the subject of future revisions to the TARAM. In the interim, cumulative risk is minimized to the extent possible by the correction of each identified unsafe condition *as soon as reasonably practical*.

Table 3. Risk Guidelines

Safety Decision-Making		Priority	Risk Control Decision-Making		
Total Uncorrected Fleet Risk	Uncorrected Individual Risk	90-Day Fleet Risk	Control-program fleet Risk	Control-Program Individual Risk, Urgent Action May be Necessary	Control-Program Individual Risk, Not Airworthy
>.02 or .04	>10^{-7}/flight-hour	N/A	>3	>10^{-6}/flight-hour	>10^{-5}/flight-hour
Guidance: Use .02 guidance for transport-airplane types and fleets primarily used in commercial passenger operations. Use .04 for other types of operations. For "single-failure" issues, see paragraph 6.1 for guidance.	Guidance: Use the uncorrected individual-risk-level guidance when risk variables, such as fleet size, fleet age, or exposed-occupant count, result in acceptable total uncorrected fleet risk, but the individual per-flight-hour risk is unacceptable.	Guidance: Use the 90-day fleet risk factor as a priority measure in comparison to other pending and envisioned corrective actions.	Guidance: Corrective action is required as soon as reasonably practical within the time period associated with the control-program fleet risk-level guidance. The risk-level guidance represents the maximum acceptable risk and is not to be used as a target value.	Guidance: Minimize, to the extent practicable, commercial-passenger service operations at individual risk levels above this level.	Guidance: Transport airplanes should not operate in commercial-passenger service above this level for any period of time.

6.3 Risk-Level Guidance Development

The risk-level guidelines presented here correlate, in general, with those used during an extended period of COS program testing in certain branches, including Mechanical and Electrical Systems, and Propulsion, within the Seattle Aircraft Certification Office (ACO) and Los Angeles ACO. That testing found that risk results align well with safety decisions made by those branches. This alignment with ongoing, continuing, operational-safety programs shows the risk-level guidance presented here to be generally consistent with the historic level of safety maintained by the transport-airplane AD process. As TARAM is employed in the remaining Seattle and Los Angeles ACO branches and in the rest of the ACOs across the country, we will monitor the results of the analyses and associated safety decisions to ensure that the methodology and guidance reflect the risk-management policy of the Transport Airplane Directorate as well as of AIR SMS.

When determining the risk-level guidance for uncorrected individual risk, we considered current aviation-safety levels, as well as the type of life-risk data illustrated in Figure 7. The life-risk data in this figure provides a contrast between individual risk, calculated according to the guidance in this handbook, and the risk associated with various aspects of daily life. Based on NTSB data over the last five years, the average risk of individual fatal injury per flight hour, experienced by passengers on transport airplanes operated within the U.S., is on the order of 10^{-8}/hr. To achieve that average, we assume that commercial airplanes in the U.S. generally operate in a one-order-of-magnitude risk band around that average, e.g., between a fatal-injury risk level of 10^{-9}/hr and 10^{-7}/hr. Accordingly, we did not believe that the risk associated with a single COS issue should result in risk above 10^{-7}/hr. We did not separately factor into the average fatal injury rate the contribution of airplane-related causes. Had we done so, the band would have been at least an order of magnitude smaller.

We then considered what individual risk level might necessitate consideration of urgent action. We did not believe that commercial passengers expect or should be exposed to risk levels on the order of 10^{-5}/hr. That life-risk level is comparable to that experienced by motorcycle riders, and those 80 years old and above. We concluded that urgent action should be considered halfway between the 10^{-5}/hr level and the 10^{-7}/hr safety level, or 10^{-6}/hr. Again, we did not include the lesser contribution of airplane related causes to the average fatal injury rate or the cumulative risk associated with other, uncorrected safety issues.

Transport-airplane risk-level guidance can and will change based on changing agency goals and expectations. We will also make changes based on lessons learned during application.

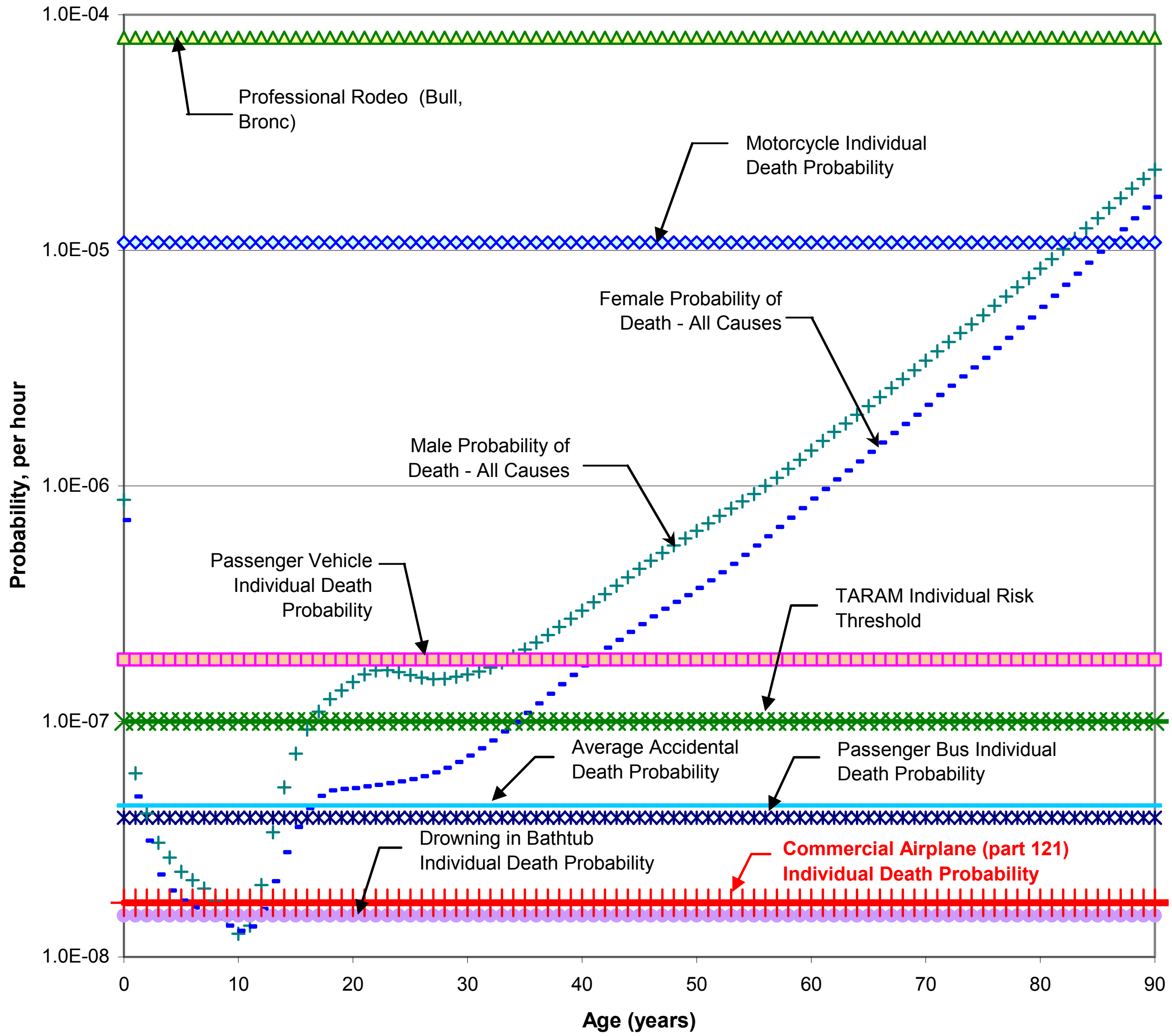


Figure 7. Life Risk

Note: The rates shown in the figure above were derived from data from a variety of sources. The air-carrier and general-aviation rates are based on NTSB data from 2002 through 2006. The other lines in the figure are based on information compiled over the same time period by the Social Security Administration, U.S. Department of Transportation, and the national organizations associated with the identified activity. The death rates shown in Figure 7 are averages and do not show age-related differences, except for the lines indicating male and female probability of death from all causes. Most data sources do not include comprehensive exposure data and the rates shown are based on estimated exposure. All rates shown are per hour of exposure, i.e. while involved in the listed activity. Life risk is presented for illustrative purposes only and should not be used or referenced when precise risk-level values are necessary for any of the activities shown.

6.4 Aviation Safety Engineer (ASE) Risk Management

The risk-assessment methodology presented here will help safety decision-makers, including the ASE, determine whether corrective action, in the form of an AD, is necessary. It will help in selecting the optimal corrective action and compliance time, and in determining what type of AD (i.e., emergency AD, immediately adopted rule, or notice of proposed rulemaking) is necessary.

There may be situations where time is critical in responding to unsafe conditions, and in those cases, emergency ADs or immediately adopted rules will be issued. In such situations, the ASE should take the steps necessary to resolve the unsafe condition, as outlined in Order 8110.107, before completing the risk-analysis process described in this handbook, unless otherwise directed by ACO or TAD management. After taking immediate action to correct the unsafe condition, the ASE will need to complete the risk-analysis-process worksheet to document the risk involved. This will provide information for future use in recognizing and determining risk associated with similar issues.

Within the overall direction and guidance of the applicable FAA Orders, processes, and work instructions, the ASE, in coordination with the responsible certificate holder, is expected to accomplish the following risk-management actions:

1. Determine whether corrective action is necessary, based on engineering judgment and TARAM total uncorrected fleet-risk or uncorrected individual-risk results and associated risk-level guidance.
2. If there are multiple immediate airworthiness issues that must be addressed, prioritize them according to both the TARAM 90-day fleet-risk and the control-program individual-risk values.
3. Develop continued operational safety control program requirements commensurate with TARAM control-program fleet risk results and risk level guidance. Ensure that corrective actions are accomplished *as soon as reasonably practical,* but within the maximum time indicated by the risk results.
4. Prepare and provide the Special Airworthiness Information Bulletin (SAIB) or AD worksheet, associated TARAM worksheet(s), and supporting information for CARB consideration. If the 90-day risk or control-program risk could change significantly during the AD processing time, prepare and provide the risk-forecast table (Appendix B) as well.
5. Alternative method-of-compliance approvals for corrective-action time extensions should be evaluated to ensure the control-program risk is still acceptable.
6. If, before or during the time the corrective action is being carried out, new or substantially different data is discovered or new data casts doubt on the effectiveness of the chosen corrective action, recalculate the TARAM risk values and revisit process steps (1) through (3) above.

6.5 Aircraft Certification Office (ACO) Risk Management

To standardize the way risk is managed for transport airplanes, each ACO, with reference to the applicable FAA orders and work instructions, does the following:

1. Ensures that ASEs responsible for resolving COS issues—
    a. Are trained in the TARAM.
    b. Have the technical knowledge, experience, education, and training to perform the TARAM, and are able to make any necessary assumptions and qualitative determinations either alone or in cooperation with other ASEs and/or informed individuals.

c. Obtain access to available quantitative information and data and use that data, when available, to determine the TARAM risk values associated with transport-airplane COS issues.
d. Are able to integrate engineering judgment with the available data in performing the TARAM and any resulting COS decisions.
e. Know how to perform a structured causal analysis to trace the chain of events, identify contributing factors and develop a list of candidate solutions.
f. Understand that the TARAM is intended to result in risk values that represent the best estimate (at the time of analysis) of actual risk with no intentionally introduced conservatism.
g. Recognize when qualitatively assumed values and/or assumptions, based on sparse data, must be used in risk analysis, and to what extent the assumed values affect the resulting TARAM risk values.
h. Understand the TARAM risk-level guidance values and how the guidance is used to support the MSAD process.

2. Considers the following during review by the CARB—
   a. Can risk-management decisions reasonably be based on the existing risk analysis and associated risk values, or is more risk-analysis work necessary?
   b. Is the proposed corrective action (emergency AD, immediately adopted rule, or notice of proposed rulemaking) and compliance time supported by the identified risk, and does it account for the urgency and importance of the unsafe condition?
   c. Will corrective action be accomplished *as soon as reasonably practical*?
   d. Is the ASE recommending action based on engineering judgment that is not supported by the results of the associated risk analysis? Is the argument for it logical and compelling?
   e. Do the risk values justify the cost of correcting the issue?

> **Note:** For issues with risk that is marginally above the total uncorrected risk guideline and that affects extremely large fleet sizes, cost may be a limiting factor, as prescribed in Executive Order 13563.

3. Communicates the corrective action to the TAD by—
   a. Transmitting the AD worksheet or SAIB, and separately transmitting the associated risk-analysis worksheet or summary risk-analysis worksheet to the Airworthiness and Technical Communications Branch, ANM-114. In situations where the 90-day fleet risk or control-program fleet risk could change significantly during the anticipated AD processing time, also provides the risk-forecast table (Appendix B). Neither the risk-analysis worksheet(s) nor the risk-forecast table should be included in the AD Docket.
   b. Supplying a copy of TARAM worksheet(s), risk-forecast table, and supporting documentation (excluding the AD worksheet) to the Transport Airplane Safety Management Branch, ANM-117.
4. Has processes to administer multiple ADs that include the following—
   a. Resources for resolving COS issues allocated according to the TARAM risk values and risk-level guidance.
   b. Prioritization for development of COS-related engineering instructions and service information based on the associated risk values and risk-level guidance.

6.6 Transport-Airplane Risk Management

To standardize how risk is managed for transport airplanes, the following TAD organizations will take these actions in support of the TARAM:

1. Airworthiness and Technical Communication Branch, ANM-114—Allocates resources for drafting and administering ADs based on AD type (emergency AD, immediately adopted rule, or notice of proposed rulemaking) and the associated AD-development flow times, and then on TARAM 90-day fleet-risk values.[7] When ADs of similar type have similar TARAM 90-day fleet-risk values, those with much higher control-program individual-risk values should be accorded higher priority.
2. Transport Standards Staff —
    a. Allocates resources for resolving COS issues within the TAD. This includes supplying TAD staff support for ACO COS issues commensurate with TARAM risk values and risk-level guidance.
    b. Works toward achieving and maintaining the lowest practical transport-airplane risk, consistent with the safety goals of the agency.
3. Safety Management Branch, ANM-117
    a. Provides guidance and assistance in performing the risk assessments described in this handbook.
    b. Modifies guidance and guidelines as necessary to reflect TAD COS policy.

[7] Between January 31, 2011 and January 31, 2012, the existing TAD AD prioritization worksheet will be used by ANM-114, with the 90-day risk value collected as a data point. After that time, the 90-day risk value, or its equivalent, will be used.

Appendix A Definitions [8]

Control Program—The plan, and corrective actions taken, to address an unsafe condition.

Error—An omission or incorrect action by a crewmember or maintenance personnel, or a mistake in requirements, design, or implementation.

Event— Any individual occurrence involving an aircraft or its components. Described in terms of what is observed (the symptoms) or recorded during the occurrence. Events typically trigger investigations that seek causes of a safety issue. The safety issue (or condition) is then evaluated for safety implications.

Exposure—An instance of being subjected to an action or an influence.

Failure—An occurrence that affects operation of a component, part, or element so that it no longer functions as intended. This includes both malfunction and loss of function.

> **Note:** Errors and events may cause failures or influence their effects, but they are not in themselves considered to be failures.

Injury Ratio—As determined from historical data, the single-event probability that those exposed to a condition or outcome will suffer fatal injury.

Outcome—A defined condition, usually at the airplane level, for which an injury ratio is known or can be determined.

Potential Unsafe Condition—A condition that, if uncorrected, is reasonably likely to result in one or more fatalities.

Risk— For the purposes of this handbook, risk is: The probability or expectation that a potential unsafe condition would result in fatalities.

Risk Factor—The result of a risk calculation for a defined period.

Safety—The absence of unacceptable risk or harm.

Safety Concern—Any situation that is suspected of either causing, or being, an unsafe condition.

Suspensions—Non-failed units in a life-distribution analysis.

Severity—The effect of a condition or outcome on the occupants of an airplane.

Single Failure—The occurrence of any condition, or any set of conditions that cannot be shown to be independent from each other, affecting the operation of components, parts, or elements in such a way that they can no longer function as intended. (See *Failure*, above.)

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[8] See paragraph 3.9 for risk variable definitions.

Appendix B TARAM Worksheets

The following pages contain worksheets for engineers to use as they perform the TARAM risk analysis. They break down each major step used to determine the risk values—total uncorrected fleet risk, total uncorrected individual risk (flight-hour risk), 90-day fleet risk, control-program fleet risk, and control-program individual risk—and provide a means to document and communicate the data used, and decisions made, in each step.

In situations where time is critical in issuing an emergency AD or immediately adopted rule, the ASE may, unless otherwise required by the ACO or TAD management, prepare and issue the AD before completing the risk analyses in this handbook. However, after action has been taken to correct the unsafe condition, the ASE should complete the applicable risk-analysis worksheet to document the risk involved. This will aid in future determination of the risk associated with similar issues.

Constant Failure Rate Worksheet

Instructions: Use the Transport Airplane Risk Assessment Methodology Handbook guidance in Chapter 4 to determine the risk values in the table below. Document all assumptions and data sources on the worksheet, or attach a separate, clearly labeled notes page.

Constant Failure Rate Worksheet PART 1

CONDITION DESCRIPTION	PROBABILITY			SEVERITY	
	FREQUENCY OF OCCURRENCE			INJURY RATIO	EXPOSED OCCUPANTS
	F	F_I	F_{CI}	IR	EO
	TIME			UNSAFE OUTCOME DESCRIPTION	
	T	T_{90}	T_C		
	NUMBER OF AIRPLANES				
	Σ	Σ_{90}	Σ_C		
AFFECTED MODELS	UTILIZATION				
	U	U_{90}	U_C		

CONDITIONAL PROBABILITY				
CP	CP_I	CP_{90}	CP_C	CP_{CI}

Constant Failure Rate Worksheet PART 2

RISK VALUES	Applicable Formula R = Probability x Conditional Probability x Severity	VALUE	ASSUMPTIONS/ RATIONALE
Total Uncorrected Fleet Risk (weighted events)	R_T = [F x U x Σ x T] x [CP] x [IR]		
Uncorrected Individual Risk (fatalities per flight hour)	R_I = [F_I] x [CP_I] x [IR]		
90-Day Fleet Risk (fatalities)	R_{90} = [F x U_{90} x Σ_{90} x 90] x [CP_{90}] x [IR x EO]		
Control-Program Fleet Risk (fatalities)	R_C = [F x U_C x Σ_C x T_C] x [CP_C] x [IR x EO]		
Control-Program Individual Risk (fatalities per flight hour)	R_{CI} = [F_{CI}] x [CP_{CI}] x [IR]		

Wear-Out Failure Worksheet

Instructions: Use the Transport Airplane Risk Assessment Methodology Handbook guidance in Chapters 4 and 5 to determine the risk values in the table below. Document assumptions and data sources on the worksheet or attach a separate, clearly labeled notes page.

Wear-Out Worksheet PART 1

CONDITION DESCRIPTION	PROBABILITY						SEVERITY	
	NOT-DETECTED PROBABILITY	DEFECT AIRPLANES TOTAL	DEFECT AIRPLANES 90-DAY	DEFECT AIRPLANES CTRL PR	HAZARD FUNCTION	CNTRL PR HAZARD FUNCTION	INJURY RATIO	EXPOSED OCCUPANTS
	ND	DA	DA_{90}	DA_C	h	h_C	IR	EO

TIME		
T	T_{90}	T_C
	90	

NUMBER OF AIRPLANES		
Σ	Σ_{90}	Σ_C

UNSAFE OUTCOME DESCRIPTION

AFFECTED MODELS

UTILIZATION		
U	U_{90}	U_C

CONDITIONAL PROBABILITY				
CP	CP_I	CP_{90}	CP_C	CP_{CI}

Wear-Out Worksheet PART 2

RISK VALUES	APPLICABLE FORMULA R = Probability x Conditional Probability x Severity	VALUE	ASSUMPTIONS/ RATIONALE
Total Uncorrected Fleet Risk (weighted events)	R_T = [ND x DA] x [CP] x [IR]		
Uncorrected Individual Risk (fatalities per flight hour)	R_I = [ND x h_I] x [CP_I] x [IR]		
90-Day Fleet Risk (fatalities)	R_{90} = [ND x DA_{90}] x [CP_{90}] x [IR x EO]		
Control-Program Fleet Risk (fatalities)	R_C = [ND x DA_C] x [CP_c] x [IR x EO]		
Control-Program Individual Risk (fatalities per flight hour)	R_{CI} = [ND x h_C] x [CP_{CI}] x [IR]		

Risk Forecast Worksheet

Instructions: Based on Transport Airplane Risk Assessment Methodology Handbook guidance, use the Risk Forecast Worksheet to document cases where increasing predicted risk over time could result in higher priority (90-day fleet risk) or more urgent corrective action (control-program fleet risk or individual risk). Extend, expand, or add to this table as needed.

AD Worksheet Number	
Condition Description	**Affected Models**
Key Dates	**90-Day or Control Program Risk**

Appendix C Examples

C.1 Wear-out example

C.1.1 MSAD Potential Unsafe Condition

An MSAD report indicates that an operator of an Aves Airplane Company model 57F, a certified, transport-category cargo airplane, reported finding evidence of a fuel leak (seepage) from the wing rear spar. Further investigation revealed a crack in the spar chord.

Two additional MSAD reports were later received that cracks in two additional airplanes were discovered. They, too, were found by evidence of a fuel leak.

The FAA analyst assigned to these records believes that it is a potential safety issue and is performing a TARAM risk analysis.

C.1.2 Condition under study and unsafe outcome

The analyst described the condition being analyzed as "fatigue cracking in the wing rear spar lower chord and continued propagation in the remaining structure," and the unsafe outcome description as "inability of the wing structure to react to flight loads and subsequent in-flight break-up of the airplane." The condition and outcome are entered on the TARAM worksheet.

The unsafe condition as described by the analyst was anchored to routine flight loads, not limit load. An occasional mistake analyzes risk at limit-load critical crack lengths, and then includes the probability that limit load would occur, which is a rare event. This results in a significant underestimation of the actual risk. Cracks, if left undetected, keep growing past limit-load critical crack length to a point where they do fail at routine in-service loads. The few actual transport-airplane accidents that were caused by structural failure from fatigue cracking attest to this.

The risk that TARAM is estimating is related to a specific airplane outcome for which an injury ratio is known. Do not end the analysis at an intermediate condition prior to reaching an outcome for which an injury ratio is known, unless a conditional probability that goes from the end condition to an outcome with an injury ratio is known or can be reasonably estimated. If the risk is calculated for an intermediate condition, the risk will be overestimated. TARAM risk values should be the best estimate of the actual risk, not conservatively overestimated.

C.1.3 Determine exposure factors

The number of airplanes, their age, and their utilization were obtained from Ascend™ (formerly Airclaims™). Similar information was also received from the Aves Airplane Company. Either could be used in the analysis.

For wear-out problems, Time (T) is not used directly in a formula as is done in random (constant-failure rate) problems. This is due to the risk of failure being a function of time in wear-out problems, so using fleet averages, multiplied by a calendar time, is inappropriate. For wear-out, the risk forecast is performed accounting for each airplane's age, and the length of time (Δt) to go from the airplane's current age to the end of the analysis period being analyzed (retirement of the airplane, 90 days, or the average control-program implementation time).

Average utilizations of 2.4 flights/day and 6.4 flight-hours/day were obtained from Ascend™ data, but these averages were not used in the risk calculation. When analyzing a wear-out issue, the analyst should typically use each airplane's utilization, rather than the fleet-average utilization, when performing the failure forecast to determine Δt for that airplane. The TARAM tool does this, and this can also be done using other analysis programs as well by appropriate data entry.

C.1.4 Determine the failure mode, select appropriate TARAM worksheet

The Aves Airplane Company performed a laboratory analysis of the cracked parts and determined that the cracking was due to fatigue. Fatigue cracking in metallic structure is well-understood to be a wear-out-failure mode. The risk analysis will be performed using the TARAM wear-out methodology and worksheet.

When performing the risk analysis, an appropriate time unit must be chosen. The units of time typically are either flights or flight hours (in rare cases, it could even be in calendar time). Wing fatigue generally correlates best to flights, rather than flight hours, so the Weibull analysis will be performed on a per-flight basis. If you are unsure of which time unit to use and you have sufficient data, perform the Weibull analysis both ways, selecting the time unit that yields the best correlation to the observed failures. If a fleet has extreme sensitivity to utilization, the fleet could be analyzed in groups of similar utilization, then sum the fleet risk, although this typically will not be necessary.

Although the Weibull analysis is performed on a per-flight basis, the individual-risk guidelines are on a per-flight-hour basis, so both flights/day and flight-hours/day utilizations are needed. The initial risk calculations (Weibull analysis and hazard-function calculations) will be performed on a per-flight basis, and then the per-flight individual risk is converted to a per-hour individual risk to allow comparison to the risk guideline.

C.1.5 Determine distribution factors (ND, DA and Hazard Function)

C.1.5.1 Not-Detected (ND)

One of the parameters used in the TARAM analysis of an airplane-structure fatigue issue is ND, which is the probability that an occurrence of the defect (fatigue crack) will not be detected before the defect leads to an unsafe outcome (airplane accident). ND is just another conditional probability, but it is defined separately because of its importance in structural-fatigue wear-out issues.

Analysts may tend to be significantly conservative in their estimates of ND. Historically, almost all fatigue cracks are discovered before they lead to an accident. This is indicative that ND is typically much less than 1. Remember this when making estimates of ND. Remember also that many of the discovered cracks are not found by a directed inspection looking for that particular crack, but instead are discovered incidentally during normal operation and routine maintenance. Incidental discoveries should be included in ND when they contribute to ND. This safety issue is an example of incidental discoveries being a significant contributor to ND, as all of the cracks were found by ramp personnel seeing evidence of a fuel leak (seepage, or wet or dry stains).

In some cases, ND will be close to 1. For example, if the crack-growth time from a detectable crack to critical crack length is short, and a directed NDI inspection is needed to find the crack, but the directed NDI inspection is not currently being performed, ND would be close to 1.

Some factors to consider when estimating ND:

- How many cases of crack findings are there?
- Crack lengths found.
- Estimate of the accident-critical crack size.
- Estimate of time to grow from discovered crack size to accident-critical crack size. Review crack growth curves if they are available (extrapolating a little bit past the limit-load critical crack length if the curve stops there).
- How often is the area visible?
- How was the damage found?
- Are there other ways the damage may be found?

If we suspect that the estimated value of ND is overly conservative, which is a typical mistake, a correlation-to-service-history test should be performed. In this test, the same assumptions and parameters that are used in the risk analysis are used here, but instead of predicting future risk, run the analysis from the delivery of the first affected airplane until today, then obtain the number of accidents predicted. If there have been no accidents, and the predicted expectation is for greater than 0.23 accidents (0.23 is the lower bound on 0.5 accidents using a 50% confidence chi-squared distribution), the analysis is probably conservative. It is certainly conservative if the test predicts multiple accidents when none have, in fact, occurred. If the test indicates that the analysis is conservative, review ND and the other analysis parameters and assumptions, and remove any conservatism found.

For this issue, all three cases were found by the discovery of evidence of a fuel leak. ND was estimated to be 0.05. Rather than estimating ND directly (0.05), it may be helpful to think of it in terms of how many times it may be found before it is missed, e.g., 1 in 20 (0.05), or 1 in 50 (0.02), etc.

For the analysis of this issue, ND is the same for all three time periods (life of the fleet, 90 days, and control program). This is typical. ND would only differ between the different analysis time periods if the existing maintenance program is changing in a significant way with time. Since control-program risk is the risk that accumulates among the uncorrected airplanes while the control program is phased-in, the control-program ND is not different than the other NDs. The phase-in effect is accounted for in DA.

C.1.5.2 Defect Airplanes (DA)

DA is the predicted number of airplanes that would have the subject failure, if left undetected, during the time period being analyzed. For DA, the time period being analyzed is the remaining life of the fleet. DA is obtained from using the Weibull (or other acceptable) life distribution. DA is just the result of the Weibull life distribution—ND and other conditional probabilities are not part of the DA prediction, so the number of ND predicted accidents will typically be less than DA.

To obtain DA, the fleet information is entered into a risk-analysis program (e.g., the TARAM tool, SuperSmith™, other acceptable commercial software, or your own Excel analysis file). To calculate the predicted number of failures over a time interval Δt, the risk-analysis program sums $[F(t_i+\Delta t) – F(ti)] / [1-F(t_i)]$ over the airplanes still subject to the failure that have survived (no failure) to time t_i. In other words, the probability they will fail during the time interval, given that they haven't failed yet.

This is a mature fleet (the average age of the airplanes is 34.7 years). It is estimated they will retire by age 43. The retirement age is used to obtain Δt for each airplane for use in the failure forecast for total uncorrected fleet risk. The failure forecast (DA) is obtained by summing $[F(t_i+\Delta t) – F(t_i)] / [1-F(t_i)]$ over the fleet of airplanes still subject to the failure. A similar calculation is performed for the 90-day fleet risk (DA_{90}) and the control-program fleet risk (DA_C), using the Δt appropriate for those risks (90 days for DA_{90} and the control-program time for DA_C).

For this issue, it was estimated that the cracks found in-service would continue to propagate for another 5,000 flights before an accident would occur (if the cracks were never detected). We added 5,000 cycles to the age at which the cracks were discovered, and that was entered into the program for the failure points. Note that the analysis of this issue isn't very sensitive to this estimate. If the time that the cracks were discovered were entered as the failure times into the Weibull-analysis program, the characteristic life would be calculated to be 63,506 flights; if the time of discovery plus 5,000 flights is entered as the failure times, the characteristic life would be calculated to be 64,180 flights.

If multiple cracks had been discovered and the discovered cracks had different lengths, the amount of time added to grow from discovered length to accident-critical length could be different for each airplane, less for longer cracks and more for shorter cracks.

Adding the time to grow from the discovery of the crack to the accident-critical crack size (5,000 flights in this example) does two important things: First, it anchors the analysis to an accident, instead of to an intermediate state (e.g., to a 3-inch spar-chord crack). Second, it allows is the use of additional suspension data. If the analysis were performed based on the discovered 3-inch crack lengths, because the remaining fleet has not been inspected, it is unknown if they have any cracks or not. But because the Weibull analysis is anchored to accident-critical damage size, it is a known fact that the remaining fleet have not been involved in accidents, so the remaining aircraft in the fleet can and were entered into the Weibull-analysis program as suspensions.

The residual risk of the control program is not assessed if it has been qualitatively determined that the control program has eliminated the unsafe condition.

C.1.5.3 Hazard Function

The hazard function is used in calculating both uncorrected individual risk and control-program individual risk. Because the individual risk is greater the older the airplane is, the hazard function is evaluated for the oldest airplane at the end of the appropriate time period (at airplane retirement for uncorrected individual risk, and at the end of the control program for control-program individual risk).

The TARAM tool calculates the hazard function appropriately. If using WinSMITH™ you can calculate the hazard function from the formula $h(t) = (\beta / \eta) (t / \eta)^{\beta-1}$ for a two-parameter Weibull. If you are not using a two-parameter Weibull for the failure distribution, use the appropriate formula for the hazard function. If you don't have a closed-form solution for the distribution you are using, the hazard function can be calculated numerically using $h(t) = \lim (\Delta t \rightarrow 0) \{[F(t_i+\Delta t) – F(t_i)] / [1-F(t_i)]\} / \Delta t$

C.1.6 Determine Outcome Factors

Our "condition under study" fatigue cracking in the wing leads directly (if undetected) to the unsafe outcome of in-flight breakup, so the conditional probability CP = 1.0.

This example looked at the single unsafe outcome of massive structural failure leading to in-flight breakup. If other outcomes were envisioned (e.g., fire, fuel exhaustion), then CPs could be estimated based on the percentage of the time that outcome would be expected. Additional CPs could be strung on as needed (e.g., for the fire outcome, what is the CP that the large fuel leak would ignite?).

This cargo airplane has a crew of two. However, it often carries supernumeraries. On average, the exposed occupants (EO) are estimated to be 4.

C.1.7 Calculate and combine risk

The data and results of the analysis are entered on the TARAM wear-out worksheet. Referring to the completed worksheet, you can see that both the uncorrected fleet risk (0.16) and uncorrected individual risk (2.1E-6) are above the guidelines (0.04 and 1E-7, respectively), indicating that this is an unsafe condition from both perspectives.

The control-program fleet risk (0.18) is below the guideline (3), indicating that it is an acceptable control program from a fleet-risk perspective.

The control-program individual risk (1.8E-6) is above the urgent-action guideline (1E-6) for airplanes operated primarily in passenger service, in which case an IAR should be considered. Since this is a freighter only, there is no control-program individual-risk guideline. However, given that the control-program individual risk is above 1E-6, and because almost 1 airplane (DA_C = 0.90) is expected to develop significant-sized damage (if not detected) during the proposed control program, an IAR for inspection is worthy of consideration.

Wear-Out Worksheet PART 1

CONDITION DESCRIPTION	AFFECTED MODELS
Fatigue cracking in the wing rear spar lower chord and continued propagation in the remaining structure.	ACME Airplane Company model 57F

PROBABILITY

NOT-DETECTED PROBABILITY	DEFECT AIRPLANES TOTAL	DEFECT AIRPLANES 90-DAY	DEFECT AIRPLANES CTRL PR	HAZARD FUNCTION	CNTRL PR HAZARD FUNCTION
ND	DA	DA_{90}	DA_C	h	h_C
.05	3.2	.08	.9	4.2E-5	3.5E-5

SEVERITY

INJURY RATIO	EXPOSED OCCUPANTS
IR	EO
1.01	4

TIME

T	T_{90}	T_C
15,705 (retire @ 43)	90	910

NUMBER OF AIRPLANES

Σ	Σ_{90}	Σ_C
53	53	53

UTILIZATION

U	U_{90}	U_C
2.4 flt/day, 6.4 hrs/day	2.4 flt/day, 6.4 hrs/day	2.4 flt/day, 6.4 hrs/day

CONDITIONAL PROBABILITY

CP	CP_I	CP_{90}	CP_C	CP_{CI}
1.0	1.0	1.0	1.0	1.0

UNSAFE OUTCOME DESCRIPTION

Inability of the wing structure to react to flight loads and subsequent in-flight breakup of the airplane.

Wear-out Worksheet PART 2

RISK VALUES	APPLICABLE FORMULA R = Probability x Conditional Probability x Severity	VALUE	ASSUMPTIONS/ RATIONALE
Total Uncorrected Fleet Risk (weighted events)	R_T = [ND x DA] x [CP] x [IR]	0.16	Average utilization shown was not used. Utilization for each individual airplane from Ascend™ was used.
Uncorrected Individual Risk (fatalities per flight hour)	R_I = [ND x h_I] x [CP_I] x [IR]	2.1E-6	
90-Day Fleet Risk (fatalities)	R_{90} = [ND x DA_{90}] x [CP_{90}] x [IR x EO]	0.016	
Control-Program Fleet Risk (fatalities)	R_C = [ND x DA_C] x [CP_c] x [IR x EO]	0.18	
Control-Program Individual Risk (fatalities per flight hour)	R_{CI} = [ND x h_C] x [CP_{CI}] x [IR]	1.8E-6	

Example C1. Wear-out Issue

C.2 Constant Failure Rate Example

C.2.1 MSAD Potential Unsafe Condition

An Aircraft Certification Office (ACO) received a § 21.3 report from the ACME Airplane Company, Inc., about a smoke-and-sparking incident in a passenger-entertainment control unit (PECU) installed above the headliner on ACME transport-airplane Model 10P. The source of the smoke and sparking was found to be a capacitor that short circuited in the control box. The cause of the short circuit was linked, during investigation, to the PECU design.

As part of the Monitor Safety—Analyze Data process in the ACO, the report was determined to be a potential safety issue and assigned to an Aviation Safety Engineer (ASE) for investigation. The ASE found eight other cases of reported short-circuited capacitors in ACME Model 10P airplane PECUs. The ASE also found that although the PECU electrical components were in an industry-standard, line-replaceable-unit container intended to prevent fire propagation, the capacitor failure in two cases (including the § 21.3 reported event) burned through the container, potentially igniting any adjacent flammable materials. The ASE also determined that accumulated dust and other potentially flammable materials were often found in the area where the PECUs were mounted in the Model P10 airplane, and that the units were not readily accessible to the cabin crew.

As a result of these observations the ASE determined, based on engineering judgment, that there was a significant probability of such a capacitor failure resulting in an uncontrolled fire in-flight, and that the investigation should continue through the MSAD-process risk-analysis step.

C.2.2 Condition Description and Unsafe Outcome Description

Due to the nature of the capacitor failure and the potential severity of an in-flight fire, the ASE decided to structure the TARAM analysis based on the assumption that the next capacitor failure that burned through the PECU case would result in a fire in-flight. Accordingly, the ASE entered "ACME model 10P airplane PECU capacitor failure and PECU case burn-through resulting in in-flight fire" in the worksheet's *Condition Description* field, and "In-flight fire" in the worksheet's *Unsafe Outcome Description* field.

C.2.3 Frequency (F)

The physics of the failure, and the distribution of failures, indicated to the ASE that a constant-failure-rate analysis was appropriate. In consultation with the ACME Company, the ASE obtained the model data needed to perform the TARAM analysis. The first value was the accumulated flight hours of the model 10P fleet as of the date of the § 21.3 report. ACME determined that the fleet had approximately 36,000 flight hours on the incident date. Because each ACME 10P airplane has four PECUs, the accumulated PECU flight hours was 4 x 720,000 Flt hrs = 2,880,000 PECU hrs. The ASE then determined the expected time between burn-through failures to be 2,880,000 PECU hrs/2 burn-through failures = 1,440,000 hours between burn-through failures. Assuming the next burn-through would result in fire, the rate of such fires is then 1 fire/(2,880,000 PECU hrs + 1,440,000 hours between burn-through failures) =2.3 e-7 fires/PECU hour. However, because of the fire assumption and resulting small sample, the best expected rate is obtained by determining the Chi-squared 50/50 probability interval, and using the lower value in the interval, i.e., the expectation is weighted toward no fire because in thousands of flight hours, only one fire is assumed. That Chi-squared value, 7.5e-8 fires/PECU hour, or 3.0e-7 fires/flight hour, is the value listed in all the worksheet's *Frequency of Occurrence* fields.

Because there was no known failure, operational, or maintenance issue that would elevate the risk associated with the capacitor failures on specific flights, 3.0e-7 fires/flight hour was also used for the individual-risk frequencies.

C.2.4 Time (T), Airplanes (∑), Utilization (U)

ACME also provided the ASE with Model 10P airplane data. ACME expects the 10P will be in production for another 5 years and that the average retirement age is 30 years. Accordingly, the model will fly another 35 years, or 12775 days, the value listed in the worksheet's *Time (T)* field.

ACME has designed and ordered kits containing replacement circuit boards and engineering instructions, which will be available to correct the problem within one year. They also have proposed a two-year compliance time for 10P operators to incorporate the changes. The ASE expects the Airworthiness Directive Worksheet, associated Notice of Proposed Rulemaking, and the Final Rule to be published within one year concurrently with ACME kit development. As a result, the estimated control-program time in the analysis is 1 year + 2 years/2 = 2 years or 730 days, the value of which is entered in the worksheet's *Time* (T_C) field.

Based on their knowledge of production levels and future orders, ACME estimates that the average fleet size over the remaining life of the 10P fleet will be 483 airplanes; this is the value entered in the worksheet's *Number of Airplanes* ($\sum$) field. They also note, at the time of analysis, that the 10P fleet has 704 airplanes, which is entered in the worksheet's *Number of Airplanes* ($\sum_{90}$) *and* ($\sum_C$) fields.

To determine some of the values necessary for the analysis, the ASE logs onto the Aviation Safety Information Analysis and Sharing (ASIAS) system to access the Ascend ™ database. From Ascend™, the ASE determines that the average utilization of the ACME 10P is 2.1 hours/day, and enters that value in the worksheet's *Utilization (U)* field.

C.2.5 Conditional probability (CP), Injury Ratio (IR), and Exposed Occupants (EO)

Because the condition being analyzed is a PECU-capacitor-failure-induced fire, the conditional probability for both fleet-risk and individual-risk calculations is 1. The ASE enters that value in all the worksheet's *Conditional Probability (CP)* fields.

The ASE consulted with the Transport Standards Staff, System Safety Branch, determined that the injury ratio for in-flight fires is 0.16, and enters that value in the worksheet's *Injury Ratio (IR)* field.

The ASE used the Ascend™ database, as previously noted, to find the average seat configuration for the ACME 10P. The average seat count is 74, with provisions for an average of 4 flightcrew, for a total of 78, which is entered in the worksheet's *Exposed Occupants (EO)* field.

Risk: As a result of the data and assumptions noted above, the risk associated with the ACME Model 10P airplane's PECU capacitor failure is shown below.

Constant Failure Rate Worksheet PART 1

CONDITION DESCRIPTION	AFFECTED MODELS
ACME model 10P airplane PECU capacitor failure and PECU case burn-through resulting in a fire in-flight.	ACME Airplane Company, Inc. Model 10P

PROBABILITY

FREQUENCY OF OCCURRENCE		
F	F_I	F_{CI}
3.0E-7	3.0E-7	3.0E-7

TIME		
T	T_{90}	T_C
12775	90	730

NUMBER OF AIRPLANES		
Σ	Σ_{90}	Σ_C
483	704	704

UTILIZATION		
U	U_{90}	U_C
2.1	2.1	2.1

CONDITIONAL PROBABILITY				
CP	CP_I	CP_{90}	CP_C	CP_{CI}
1	1	1	1	1

SEVERITY

INJURY RATIO	EXPOSED OCCUPANTS
IR	EO
0.16	78

UNSAFE OUTCOME DESCRIPTION
In-flight fire

Constant Failure Rate Worksheet PART 2

RISK VALUES	Applicable Formula R = Probability x Conditional Probability x Severity	VALUE	ASSUMPTIONS/ RATIONALE
Total Uncorrected Fleet Risk (weighted events)	R_T = [F x U x Σ x T] x [CP] x [IR]	.06	Guideline is .02 – Risk exceeds normally accepted value
Uncorrected Individual Risk (fatalities per flight hour)	R_I = [F_I] x [CP_I] x [IR]	4.8E-8	Guideline is 1e-7 – Risk within normally accepted value
90-Day Fleet Risk (fatalities)	R_{90} = [F x U_{90} x Σ_{90} x 90] x [CP_{90}] x [IR x EO]	.5	Max allowable Tc = (3/.5) * 90 = 540 days
Control-Program Fleet Risk (fatalities)	R_C = [F x U_C x Σ_C x T_C] x [CP_C] x [IR x EO]	4.0	Guideline is 3 – Risk exceeds normally accepted value
Control-Program Individual Risk (fatalities per flight hour)	R_{CI} = [F_{CI}] x [CP_{CI}] x [IR]	4.8E-8	Guideline is 1e-7 – Risk within normally accepted value

Example C2. Constant Failure Rate