Federal Aviation Administration

Transport Airplane Risk Assessment Methodology (TARAM) Handbook

Draft PS-AIR-25-05-R1

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1 SCOPE

1.1 This Transport Airplane Risk Assessment Methodology (TARAM) Handbook is used for calculating risk associated with transport category airplanes whenever continued operational safety (COS) issues occur in the fleet. It provides and explains a risk analysis methodology and associated guidelines required by, and used in, the safety decision-making process defined by the Federal Aviation Administration (FAA) in FAA Order 8110.107B, “Monitor Safety/Analyze Data.”

Note: This handbook supports the risk analysis and risk level guidance requirements of the Monitor Safety/Analyze Data (MSAD) process outlined in FAA Order 8110.107B. Risk analysis is a factor used as part of the FAA-IR-M-8040.1C, “Airworthiness Directives Manual.”

1.2 The contents of this document do not have the force and effect of law and are not meant to bind the public in any way. This document is intended only to provide information to the public regarding existing requirements under the law or agency policies.

1.3 This handbook cancels TARAM Handbook, dated November 4, 2011.

2 AUDIENCE

FAA Aircraft Certification Service (AIR) aviation safety engineers (ASEs) can use this handbook to perform or review transport category airplane risk analyses as part of the MSAD process outlined in FAA Order 8110.107B. Design approval holders (DAHs) may assist AIR ASEs by providing TARAM data and/or analyses.

3 APPLICATION

3.1 FAA ASEs and DAHs

FAA ASEs and DAHs use the guidance in this handbook to accomplish the risk analysis related requirements of the MSAD process outlined in FAA Order 8110.107B. The TARAM Handbook is only applicable within the context of the overall COS process contained in the MSAD process. Do not use the TARAM Handbook as a method of validating/invalidating previous certification under 14 CFR part 25, “Airworthiness Standards: Transport Category Airplanes,” for example.

3.2 Foreign Manufactured Aircraft

In accordance with International Civil Aviation Organization (ICAO) Annex 8 obligations and bilateral agreements, responsibility for the COS of the worldwide fleet of foreign-manufactured aircraft resides with the State of Design Authorities (SoDA). When the FAA is considering unilateral action to address potential safety issues on products designed and manufactured outside the United States, use the defined process in FAA Order 8110.107B, Chapter 4; FAA Order 8040.5, “Airworthiness Directive Process for Mandatory Continuing Airworthiness Information”; and TARAM analyses outlined in this Handbook. TARAM analyses can be very useful in reaching a resolution with foreign authorities. Unilateral action in this context includes FAA airworthiness directive (AD) action with significant differences in corrective actions, the corrective action period, or decisions to take no action in response to mandatory continued airworthiness information by the SoDA.

4 BACKGROUND

4.1 FAA Order 8110.107B provides direction and guidance to all AIR organizations for a structured, standardized COS process that adheres to FAA AIR, Safety Management System (SMS) concepts and requirements. The order requires (with a few noted exceptions) that the risk analysis methodology used in the TARAM Handbook be used to calculate the quantitative probability, severity, and risk value for each important outcome, and the results must be in units convertible to fatal accidents.

4.2 The MSAD process requires that a time value (time until the Control Program Risk guideline is reached) and specific risk values be calculated and recorded when an issue reaches the risk analysis stage of the process. In this handbook, the term for the time value is Management Time for Control Program (*MTCP*). The required risk values in the MSAD process are Total Uncorrected Fleet Risk, Uncorrected Individual Risk, Control Program Fleet Risk, and Control Program Individual Risk.

4.3 This handbook provides the guidance necessary to perform FAA Order 8110.107B required risk analyses and provides risk guidelines for comparison to the required risk values during the resolution of transport category airplane COS issues. The TARAM Handbook fully complies with, and supports the requirements of, the order and does not introduce additional COS process requirements. In any case, where the guidance in this handbook conflicts, or is interpreted to conflict, with the requirements of FAA Order 8110.107B, the order requirements take precedence. Contact the Continued Operational Safety Systems Section (AIR-633) if the guidance in this handbook is inconsistent with the FAA Order 8110.107B.

5 TARAM PROCESS OVERVIEW

The following flowchart defines the TARAM process steps necessary to analyze risk for transport category airplanes in support of the MSAD process.

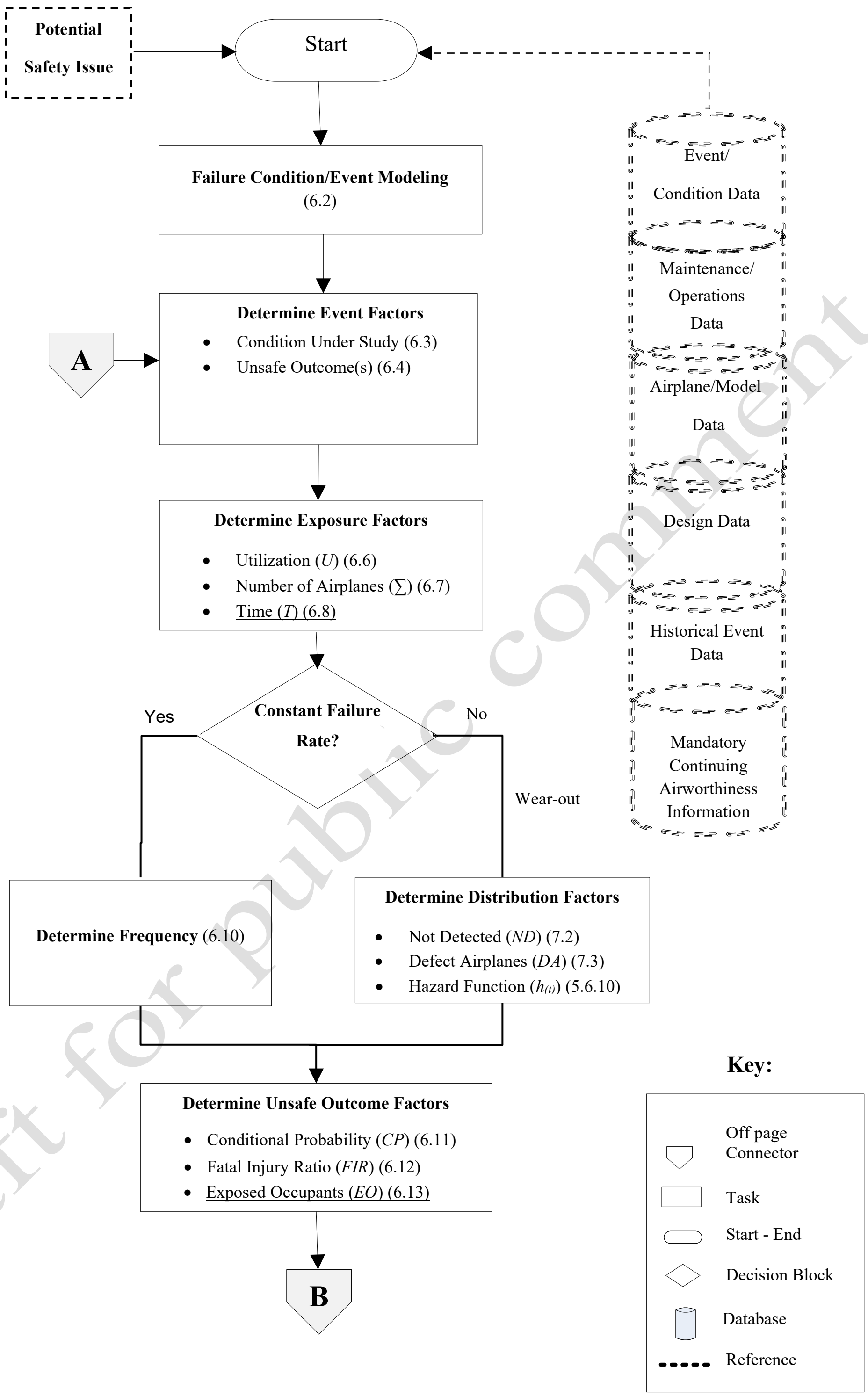

Figure 1. TARAM Process Flowchart

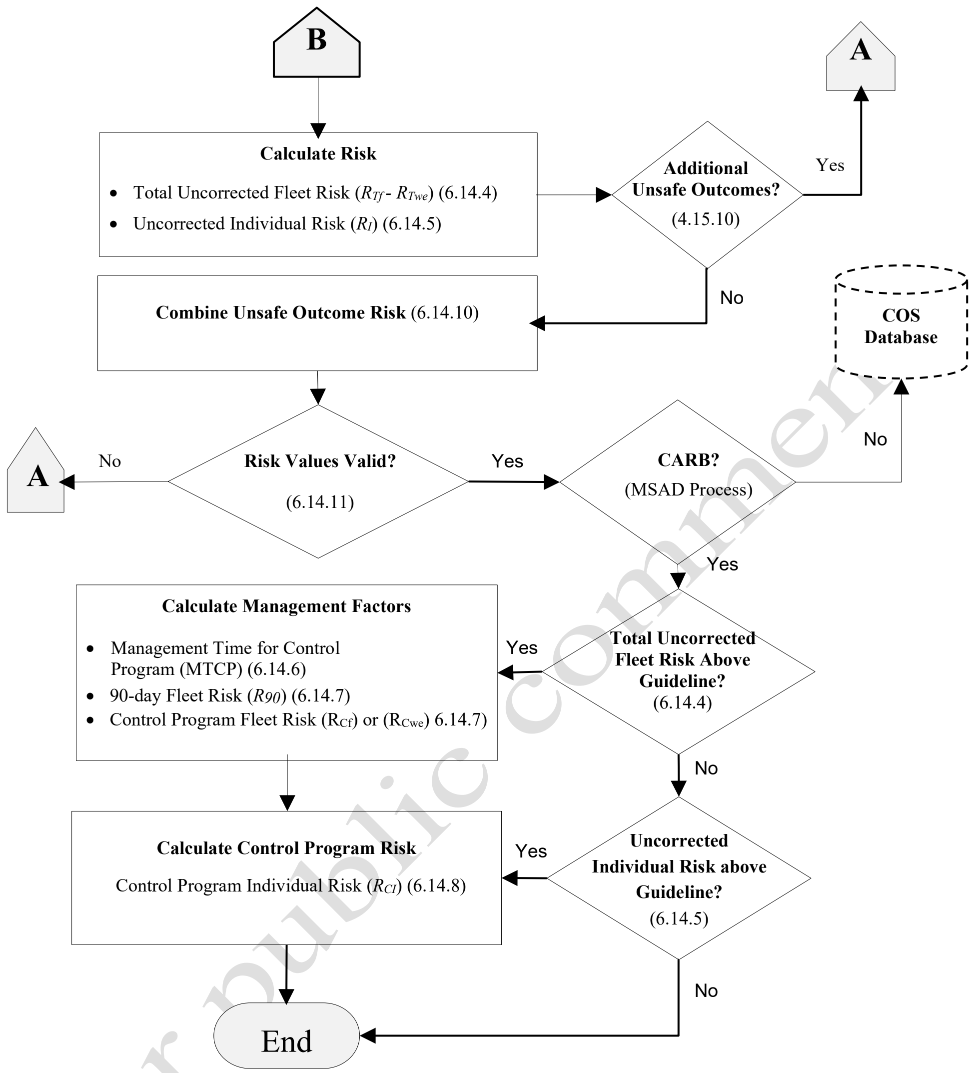

Figure 1. TARAM Process Flowchart (continued)

5.1 TARAM Risk Values

5.1.1 Fleet Risk. The term "Fleet risk," as used in this handbook, consists of the following factors:

- Number of times a Condition Under Study (6.3) is expected to occur within the affected fleet over a specific period of Time (*T*) (6.8), e.g., the statistical expectation of the Number of Occurrences (6.14.2) of the condition. Risk analyses for constant-failure-rate issues use the frequency and exposure variables shown in figure 2 and figure 3. In wear-out analysis, calculate the Number of Occurrences using Weibull or other Failure Distribution Analyses Methodology (paragraph 7).

- Conditional Probability (*CP*) (5.6.5) of a specific airplane-level Unsafe Outcome(s) (6.4), occurring as the result of the Condition Under Study, i.e., the likelihood that the Condition Under Study will result in an outcome of known Severity (*S*) (6.14.3).
- *S* of the Unsafe Outcome, in terms of the fatalities per event, i.e., the product of the Fatal Injury Ratio (*FIR*),(5.6.6) and the estimated number of persons exposed (Exposed Occupants (*EO*)), (5.6.7) per event; or the *FIR* alone. The appropriate *S* definition to use depends on the risk value calculated.

Note: The *FIR* is the Unsafe Outcome probability of fatal injury. Figure 2 illustrates this concept of fleet risk.[1]

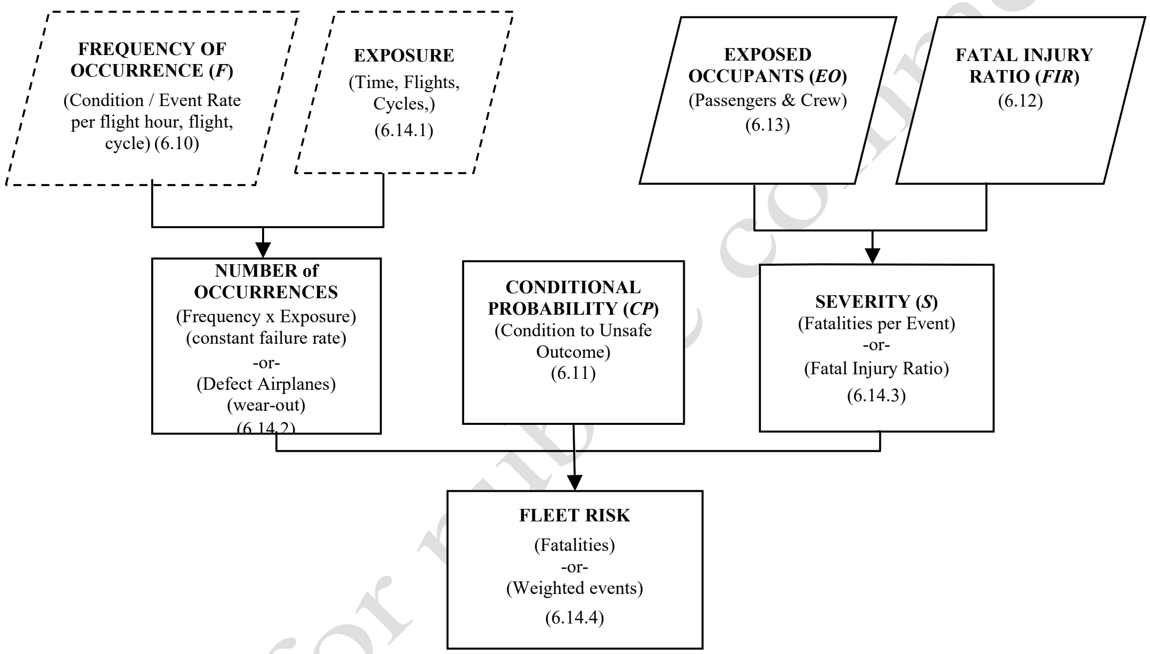

Figure 2. Components of Fleet Risk

5.1.2 Individual Risk. Individual Risk, as used in the TARAM, is the average per flight-hour risk, or in certain circumstances, it is the higher-than-average per flight-hour risk that will occur on a subset of flights during the analysis period. If calculated for the higher-risk flights, use the largest resulting product of the variables below, providing the larger variables are statistically expected to occur together during a reasonable number of actual flights during the analysis period:

- *F* or Hazard Function ($h_{(t)}$) associated with the Condition Under Study. In constant-failure-rate analysis, the *F* is used. Wear-out analyses use the largest $h_{(t)}$ value expected to occur in the analysis period.

[1] In constant failure rate analyses, these components are used to calculate fleet risk as shown. When calculating fleet risk for wear-out or other non-constant failure rate issues, the "Number of Occurrences" is determined using Weibull analyses or other applicable methodologies.

- *CP* that a specific airplane Unsafe Outcome will occur, as the result of the Condition Under Study, i.e., the likelihood that the Condition Under Study will result in an event of known (*S*).
- *FIR* associated with the Unsafe Outcome.

Note: Figure 3 illustrates this concept of Individual Risk.

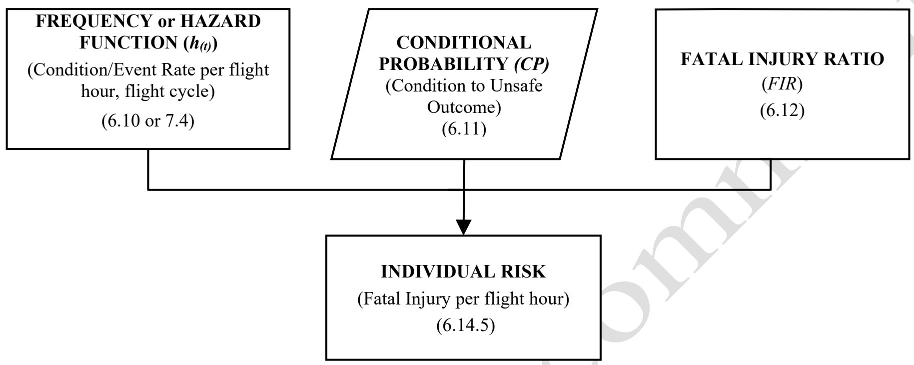

Figure 3. Components of Individual Risk

5.2 Non-Fatal Injuries[2]

5.2.1 A safety issue determination can result from events with an unacceptable rate of occupant injuries that are not fatal.

5.2.2 Although such injuries are not the focus of the TARAM, conditions that would result in routine and/or life-threatening injuries to occupants may be unacceptable. Address such cases by applying the FAA Order 8110.107B process, with the individual risk calculated as described in this handbook and the predicted injury used as the *S* measure.

5.2.3 Applying the process in this way produces data representing 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 widely, it is not possible to establish acceptable risk guidelines for all non-fatal injuries. Each accountable certification branch manager determines, on a case-by-case basis, whether the risk of injury associated with a condition justifies corrective action. AIR-633 is available for consultation on non-fatal injury analyses.

5.3 Incremental Risk

5.3.1 Most risk analyses involve a Condition Under Study (a failure, defect, etc.) that can directly cause an Unsafe Outcome. In some cases, the Condition Under Study may be a secondary factor that does not directly cause an Unsafe Outcome, but, instead, increases

[2] The guidance in paragraph 5.2 applies in cases where no fatal injuries are expected to occur due to the Condition Under Study. If a *FIR* can be determined for the injury-causing event (Unsafe Outcome) the basic guidance contained in this handbook applies.

the *CP* and/or *S* of the event. For example, the failure of an emergency exit to open does not directly cause an Unsafe Outcome where egress is needed, but when an event that requires emergency egress occurs, a faulty emergency exit can result in increased *S* of the Unsafe Outcome.

5.3.2 In cases where the Condition Under Study does not directly cause an Unsafe Outcome but exacerbates it, calculate only the incremental increase in risk due to the Condition Under Study. Exclude the fatalities or weighted events that would occur without the Condition Under Study. In the example of the faulty emergency exit, there will be a likelihood of fatalities from the Unsafe Outcome where egress is needed whether the emergency exit is faulty or not. Those fatalities or the associated weighted events should not be included in the risk due to a faulty emergency exit. Calculate the incremental addition to risk, due to the inability to exit through the emergency exit, by calculating the incremental change in risk variables.

5.4 TARAM Risk Definitions

The TARAM Handbook provides guidance for calculating one time-based risk value (*MTCP*) and five fatality-related risk values as shown in table 1. See table 3 for Risk-Level Guidelines.

Table 1. Risk Definition and Purpose

Risk	Units	Definition and Guidance	Purpose
Total Uncorrected Fleet Risk (Fatalities, R_{Tf})	Fatal Injuries (Fatalities)	6.14.4	FAA managers and ASEs consider this in conjunction with Uncorrected Individual Risk and the associated risk guidelines to determine whether a condition is a safety issue when the associated *EO* value is 150 or more.
Total Uncorrected Fleet Risk (Weighted events, R_{Twe})	Event Fatalities per Exposed Occupant (Weighted events)	6.14.4	FAA managers and ASEs consider this in conjunction with Uncorrected Individual Risk and the associated risk guidelines to determine whether a condition is a safety issue when the associated *EO* value is less than 150.
Uncorrected Individual Risk (R_I)	Fatal Injury per Flight Hour	6.14.5	FAA managers and ASEs consider this in conjunction with Total Uncorrected Fleet Risk to help FAA managers and ASEs determine whether a condition is a safety issue.
90-Day Fleet Risk (R_{90})	Fatalities or Weighted events	6.14.7	FAA managers and ASEs use the 90-day Fleet Risk as a short-term risk forecast for prioritization and resource allocation.
MTCP	Days	6.14.6	FAA managers and ASEs use this to manage corrective action program activities.
Control Program Fleet Risk (fatalities, R_{Cf})	Fatal Injuries (Fatalities)	6.14.7	FAA managers and ASEs consider this along with the associated Control Program-Risk Guideline when evaluating the acceptability of candidate corrective actions when the associated *EO* value is 150 or more.
Control Program Fleet Risk (weighted events, R_{Cwe})	Event Fatalities per Exposed Occupant (Weighted events)	6.14.7	FAA managers and ASEs consider this along with the associated Control Program-Risk guideline when evaluating the acceptability of candidate corrective actions when the associated *EO* value is less than 150.
Control Program Individual Risk (R_{CI})	Fatal Injury per Flight Hour	6.14.8	FAA managers and ASEs consider this when determining the urgency of corrective action due to the risk of fatal injury to persons flying on average or higher than average risk flights during the corrective action period.

5.4.1 Total Uncorrected Fleet Risk (fatalities). Defined as the number of fatalities statistically expected to occur without mandatory corrective action due to a specific condition in affected airplanes during the remaining time the condition exists (the remaining life of the affected fleet if there is no voluntary corrective action).

5.4.2 Total Uncorrected Fleet Risk (weighted events). Defined as the cumulative weighted events expected without mandatory corrective action due to a specific condition in affected airplanes during the remaining time the condition exists (the remaining life of the affected fleet if there is no voluntary corrective action).

5.4.3 Uncorrected Individual Risk. Defined as the likelihood of individual fatal injury per flight-hour, at any time in the remaining life of affected airplanes, if no mandatory corrective action is required.

5.4.4 90-Day Fleet Risk.[3] The number of fatalities or weighted events statistically expected to occur due to a specific condition in affected airplanes in 90 days. The 90-Day Fleet Risk is used in the following formulas to help determine relative priority:

- For fatalities: Priority Rating = $2 * \log_{10} (R_{90f} / 2.552E\text{-}10)$
- For weighted events: Priority Rating = $2 * \log_{10} (R_{90we} / 1.701E\text{-}12)$

Note: Priority Rating = higher calculated value from above equations.

5.4.5 MTCP. The number of days that, when entered into the applicable uncorrected fleet-risk calculation, along with the associated number of affected airplanes and the other varying parameters, results in the associated Control Program Fleet Risk Guideline.

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 for consideration in a single risk analysis. This term can refer to all transport category airplanes or a subset of airplanes of a particular model. Normally, airplane issues and resulting corrective actions focus on one model or a subgroup of one model. Occasionally, the Condition Under Study may affect airplanes that are not similar enough for consideration in a single risk analysis. In those cases, the risk associated with the Condition Under Study is analyzed for each sub-fleet, and (usually) added together to determine the "fleet" risk. Results of each individual sub-fleet analysis can be used, if necessary, to communicate and justify different corrective actions and corrective-action timeframes for each sub-fleet. See paragraph 6.7, Number of Airplanes.

5.4.6 Control Program Fleet Risk (fatality). The number of fatalities statistically expected to occur due to a specific condition in affected airplanes during the Time (T_c) for Control Program Fleet Risk (6.8.4).

[3] If based on data or initial risk values, corrective action is not necessary, then the MTCP, 90-day Fleet Risk and Control Program Fleet/Individual Risk values are not calculated.

5.4.7 Control Program Fleet Risk (weighted events). The cumulative weighted events expected due to a specific condition in affected airplanes during the Time for Control Program Fleet Risk (6.8.4).

5.4.8 Control Program Individual Risk. The likelihood of individual fatal injury per flight hour occurring at any time within the Time for Control Program Fleet Risk (6.8.4).

5.5 Risk Formulas and Variables

Table 2 provides the basic risk formulas and variables. Definitions associated with both *S* and probability variables immediately follow the table. The wear-out analysis formulas in table 2 use variables associated with failure-forecast analysis, such as Weibull or similar methodologies. Paragraphs 6 and 7 of this handbook provide detailed guidance for determining risk values.

5.5.1 Basic Risk Formulas. Typically, TARAM risk analyses are most efficiently performed using the basic risk formulas provided in table 2. TARAM risk analyses can also be accomplished using other techniques if the resulting risk values conform to the TARAM Risk Definitions (5.4).

5.5.2 Variables. The airplane, engine, and systems manufacturers can assist in determining values for many of the variables. AIR-633 collects and develops *FIR* data. That data and information is available on the MyFAA AIR SMS COS Website: https://my.faa.gov/org/linebusiness/avs/offices/air/cos.

5.5.3 ASPIRE. Additionally, Analyze Safety Performance Insight Results Environment (ASPIRE) is available to FAA employees and provides access to aviation data such as the Service Difficulties Reporting System (SDRS), the National Transportation Safety Board (NTSB) database, and the Accident Incident Database System (AIDS). The ASPIRE platform contains a vast repository of COS data. Once fully implemented, performing, and storing the analysis in ASPIRE will make it possible to search previous analyses for those with certain characteristics, for example, affected airplane model, type of issue being evaluated, or *CP* such as Extended Operations (ETOPS) missions or flight crew response.

5.5.4 Replacement vs. Non-Replacement. There are two methods to calculate the Number of Expected Occurrences of the Condition Under Study, the statistical probability equations for constant failure rate issues, and Weibull equations for wear-out issues.

5.5.4.1 **Replacement**. The statistical probability equations for constant failure rate fleet risk formulas in table 2 are based on an assumption that when a failed part is discovered, the failed part that is removed is replaced with a similar part that will also fail in the same manner at the same rate (e.g. same part number). For constant failure rate issues, the formula in this handbook assumes replacement.

5.5.4.2 **Non-replacement**. The Weibull wear-out equations presented assume that repairs and replacements eliminate the Condition Under Study for the repaired airplane, e.g., the repair of a fatigue crack will prevent reoccurrence of a similar crack in the same location on the repaired airplane. For wear-out issues, the formula in this handbook assumes non-replacement.

5.5.5 Localized Threats. Sometimes a Condition Under Study can result in an Unsafe Outcome that only exposes a subset of the individuals on an airplane to fatal injury. In such cases, two *FIR* values are used when calculating the risk values described in this handbook. When calculating fleet-risk values, the localized threat *FIR* is the probability per Unsafe Outcome that the subset of persons exposed will be fatally injured. For example, if the Unsafe Outcome will always result in fatal injury to those exposed, the localized threat *FIR* for fleet risk would be 1.0, and the *EO* value would only be the subset of individuals exposed to fatal injury, not the entire airplane. When calculating individual risk factors, the localized threat *FIR* is the probability that those aboard the airplane will suffer fatal injury, i.e., the number of persons expected to be fatally injured divided by the average number of passengers and crew aboard the affected airplanes. In the previous example, if one person is expected to be fatally injured per Unsafe Outcome, and the average passenger and crew for the affected airplane model is 100, the localized threat *FIR* for individual risk will be 0.01. The risk-level guidelines in table 3 apply when localized risk values are calculated using two *FIR* values as described.

Table 2. Formulas and Variables

Total Uncorrected Fleet Risk	90-Day Fleet Risk	MTCP	Control Program Fleet Risk	Uncorrected Individual Risk	Control Program Individual Risk
Constant Failure Rate Analyses					
$\boldsymbol{R_{Tf}} = F\ x\ U\ x\ T\ x\ \Sigma\ x\ CP\ x\ FIR\ x\ EO$ $\boldsymbol{R_{Twe}} = F\ x\ U\ x\ T\ x\ \Sigma\ x\ CP\ x\ FIR$ *(5.4.1, 5.4.2, 6.14.4)*	$\boldsymbol{R_{90f}} = F_{90}\ x\ U_{90}\ x\ T_{90}\ x\ \Sigma_{90}\ x\ CP\ x\ FIR\ x\ EO$ $\boldsymbol{R_{90we}} = F_{90}\ x\ U_{90}\ x\ T_{90}\ x\ \Sigma_{90}\ x\ CP\ x\ FIR$*(5.4.4, 6.14.7)*	$3 \approx F\ x\ U\ x\ \sum_{(MTCP)}\ x\ \boldsymbol{MTCP_{(f)}}\ x\ CP\ x\ FIR\ x\ EO$ $0.02 \approx F\ x\ U\ x\ \sum_{(MTCP)}\ x\ \boldsymbol{MTCP_{(fr)}}\ x\ CP\ x\ FIR$ *(5.4.5, 6.14.6)*	$\boldsymbol{R_{Cf}} = F_C\ x\ U_C\ x\ T_C\ x\ \Sigma_c\ x\ CP_c\ x\ FIR\ x\ EO$ $\boldsymbol{R_{Cwe}} = F_C\ x\ U_C\ x\ T_C\ x\ \Sigma_c\ x\ CP_c\ x\ FIR$ *(5.4.6, 5.4.7, 6.14.7)*	$\boldsymbol{R_I} = F_I\ x\ CP_I\ x\ FIR$ *(5.4.3, 6.14.5)*	$\boldsymbol{R_{CI}} = F_{CI}\ x\ CP_{CI}\ x\ FIR$ *(5.4.8, 6.14.8)*
Wear-Out Analyses					
$\boldsymbol{R_{Tf}} = ND\ x\ DA\ x\ CP\ x\ FIR\ x\ EO$ $\boldsymbol{R_{Twe}} = ND\ x\ DA\ x\ CP\ x\ FIR$ *(5.4.1, 5.4.2, 6.14.4)*	$\boldsymbol{R_{90f}} = ND\ x\ DA_{90}\ x\ CP\ x\ FIR\ x\ EO$ $\boldsymbol{R_{90we}} = ND\ x\ DA_{90}\ x\ CP\ x\ FIR$*(5.4.4, 6.14.7)*	$3 \approx ND\ x\ \boldsymbol{DA_{MTCP(f)}}\ x\ CP\ x\ FIR\ x\ EO$ $.02 \approx ND\ x\ \boldsymbol{DA_{MTCP(fr)}}\ x\ CP\ x\ FIR$ *(5.4.5, 6.14.6)*	$\boldsymbol{R_{Cf}} = ND\ x\ DA_C\ x\ CP_C\ x\ FIR\ x\ EO$ $\boldsymbol{R_{Cwe}} = ND\ x\ DA_C\ x\ CP_C\ x\ FIR$ *(5.4.6, 5.4.7, 6.14.7)*	$\boldsymbol{R_I} = ND\ x\ h_I\ x\ CP_I\ x\ FIR$ *(5.4.3, 6.14.5)*	$\boldsymbol{R_{CI}} = ND_{CI}\ x\ h_{CI}\ x\ CP_{CI}\ x\ FIR$ *(5.4.8, 6.14.8)*
Frequency (F) *(5.6.1, 6.10)*	F_{90} *(6.10)*	F *(6.10)*	F_C *(6.10)*	F_I *(6.10.3)*	F_{CI} *(6.10.3)*
Utilization (U) *(5.6.2, 6.6)*	U_{90} *(6.6)*	U *(6.6)*	U_C *(6.6)*	*N/A*	*N/A*
Number of Airplanes (Σ) *(5.6.3, 6.7)*	Σ_{90} *(6.7)*	Σ *(6.7)*	Σ_C, Σ_t *(6.7)*	*N/A*	*N/A*
Time (T) *(5.6.4, 6.8, 6.8.2)*	T_{90} *(6.8.3)*	*MTCP* *(6.8, 6.14.6)*	T_C, *(6.8.4)*	*N/A*	*N/A*
Conditional Probability (CP) *(5.6.5, 6.11, 6.11.2)*	CP_{90} *(6.11.2)*	*CP* *(6.11)*	CP_C *(6.11.2)*	CP_I *(6.11.3)*	CP_{CI} *(6.11.3)*
Fatal Injury Ratio (FIR) *(5.6.6, 6.12)*	*FIR*	*FIR*	*FIR*	*FIR*	*FIR*
Exposed Occupants (EO) *(5.6.7, 6.13)*	*EO*	*EO*	*EO*	*N/A*	*N/A*
Not Detected (ND) *(5.6.8, 7.2)*	*ND*	*ND*	*ND*	*ND*	*ND*
Defect Airplanes (DA) *(5.6.9, 7.3)*	DA_{90}	DA_{MTCP}	DA_C	*Hazard Function* (h_I) *(5.6.10, 7.4)*	h_{CI} *(5.6.10, 7.4)*

5.6 **Variable Definitions**

5.6.1 Frequency of Occurrence (*F*). The expected rate that a Condition Under Study will occur within the affected fleet or sub-fleet per flight hour, cycle, day, etc.[4]

5.6.2 Utilization (*U*). The average affected airplane flight hours or flight cycles per day (or other analysis-consistent units), during *T* in the risk analysis.

5.6.3 Number of Airplanes (Σ). The Number of Airplanes in the affected fleet[4] during the period of *T* risk is calculated.

5.6.4 Time (*T*). The period of time over which risk is calculated.

Note: When calculating T and Σ for constant failure rate issues, only one should be a total value, and the other will be an average value.

5.6.5 Conditional Probability (*CP*). The probability that a particular Condition Under Study will result in an Unsafe Outcome with known *S*. The *CP* is the product or combination of all the individual *CPs* for all the conditions that must occur in conjunction with the Condition Under Study in order for the defined Unsafe Outcome to occur. Although probabilities do not have units, it aids understanding to assign *CP* the implied units of Unsafe Outcomes per Condition Under Study.

5.6.6 Fatal Injury Ratio (*FIR*). The single-event probability of fatal injury to those exposed to a specific Unsafe Outcome. Although probabilities do not have units, it aids understanding to assign *FIR* the implied units of fatalities[5] per *EO*.

5.6.7 Exposed Occupants (*EO*). The expected, average number of occupants (passengers and crew) exposed to fatal injury during an Unsafe Outcome.

5.6.8 Not Detected (*ND*). The likelihood that the occurrence of a defect will go undetected until the defect leads to either a specific Unsafe Outcome, or an obvious major failure that has a likelihood (associated *CP*) of leading to a specific Unsafe Outcome.

5.6.9 Defect Airplanes (*DA*). The expected number of airplanes that would develop the Condition Under Study. *DA* is analogous to the Expected Number of Occurrences.

5.6.10 Hazard Function ($h_{(t)}$).

The instantaneous failure rate of a unit. The $h_{(t)}$ is analogous to the *F*.

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[4] For wear-out failures or failures with unknown failure distributions, Weibull or Log Normal analysis are helpful in determining the distribution of failures over time (6.8).

[5] *FIR* is the fatality probability per occurrence of an Unsafe Outcome not per "fatal" event. Not all Unsafe Outcomes have fatal outcomes, e.g., a runway overrun is an Unsafe Outcome, but many do not result in fatalities.

5.7 Engineering Judgment

An important element of good analysis is ensuring that judgments and estimates arise from empirical data, i.e., data based on observation, test, or experience, when practical.

5.7.1 Determine Best Estimate. When sufficient empirical data is not available, use accepted engineering practices to determine the "best estimate" of the actual quantitative values needed for risk value determination. If you are an ASE making such estimates, document the basis for your estimates on the Risk Analysis Worksheet, part 2. This information aids safety decision-making in response to a potential safety issue.

5.7.2 Sensitivity Study. Used to evaluate the output based on alternative assumptions (varying input values). When engineering judgment is used to determine "best estimates", it is recommended to perform a sensitivity study, particularly when high uncertainty exists, for issues with high *S,* or issues above 2/3 of the risk guideline. Typical variables to consider for sensitivity study are *F*, *CP* (particularly when related to human reliability), *ND*, or η.

5.7.2.1 Estimate Range

Estimate a high value and low value for the input(s) using paragraph 5.7.1, and document those values, assumptions, and rationale on the Risk Analysis Worksheet, part 2.

Note: Do not use intentionally conservative estimates or arbitrarily inflated risk values to account for uncertainty. Conservative estimates, leading to conservative risk values, could create an unjustified appearance of safety risk. Likewise, avoid unrealistically optimistic risk values which may lead to concealing of safety risk. Both approaches might result in the diversion or withholding of limited FAA resources, necessary to implement needed safety risk controls.

5.7.2.2 Calculate Risk Values

After calculating the risk values per paragraph 6.14, repeat the calculation using the high and low input value(s) to calculate the high and low-risk value outputs. The validation process in paragraph 6.14.11 can sometimes be used to assist in determining if the chosen input ranges are reasonable. Sensitivity studies provide meaningful results when limited to varying only one or two inputs. When performing sensitivity studies, if there are multiple parameters that affect the risk, avoid setting all the parameters to the high-risk values simultaneously. Doing so can skew decision-makers outlook towards unrealistic worst-case scenarios instead of looking at actual expected outcomes as is desired when performing risk-based decision-making.

5.8 Documenting the Analysis

Record the basis for the analysis (the Condition Under Study, and associated Unsafe Outcome(s)), along with the results of the analysis on the applicable worksheet in appendix B. An alternate but equivalent document that contains the same information may be used. On part 2 of the Risk Analysis Worksheet (or equivalent form), document the process through which the Condition Under Study and associated Unsafe Outcome(s) were determined, how each risk variable was derived, and information pertinent to the risk calculations. The documented information should include a description of DAH participation in the analysis process, for example, whether the DAH performed the whole analysis or supplied data in support of the process, and DAH confidence in the risk variables and values (if known). Include the following on the Risk Analysis Worksheet, part 2.

5.8.1 Condition Under Study

- Source
- Judgment factors and assumptions made in the selection

5.8.2 Unsafe Outcome(s)

- Judgment factors and assumptions made in the selection
- If applicable, the Failure Condition/Event Modeling methodology used in the Condition-to-Outcome determination

5.8.3 Affected Airplanes

- Data source(s)
- Judgment factors and assumptions made in the selection

5.8.4 Risk Variables

- Data source(s)
- Judgment factors and assumptions made in the determination
- A qualitative statement of confidence in the variable values

5.8.5 Risk Values

- Judgment factors and assumptions made in the determination
- Special circumstances or conditions factored into the individual risk values
- A qualitative statement of confidence in the risk values

6 TARAM GUIDANCE

This handbook has standardized definitions and usage guidance to facilitate consistent risk analysis results and simplify the tasks associated with calculating risk, the *S*, and probability variables. Follow the process illustrated in figure 1 to determine and use the TARAM risk values and variables.

6.1 **TARAM**

6.1.1 Goal. To aid the ASE in determining the best estimate of the risk associated with the Condition Under Study. It is important to understand that there is often more than one way to construct an analysis using the handbook guidance. For example, when an Unsafe Outcome (or a condition closer to an Unsafe Outcome in the causal chain) occurs due to a particular condition, the ASE should assume that the condition will result in the same event at the demonstrated best-estimate rate unless circumstances indicate otherwise. The best estimated rate coupled with the *S* of the associated Unsafe Outcome(s), would be sufficient to determine the TARAM risk values. Another option would be for the analyst to construct a failure model (simulation) of the causal chain (Fault Tree Analysis, etc.), leading from the Condition Under Study to reasonably likely Unsafe Outcomes, and estimate risk based on the frequency of the condition and an estimate of all the associated *CP*s. ASEs should base the model on empirical data to the extent practical and use historical data to support and validate the results of failure modeling (6.14.11). The TARAM analyst may work with the product manufacturer and their pertinent equipment suppliers to gather failure modeling information. Pertinent information used for showings of compliance to 14 CFR 25.1309, if available, may also be evaluated. Care should be taken when evaluating any certification data for causal chain use. The depth of analysis accomplished in the certification data, how the safety data is partitioned, estimates of specific failure mechanisms and rates, and exposure times may vary drastically from the COS study parameters.

6.1.2 Understanding the causal chain(s). It is important that the ASE understand the causal chain(s) associated with the Condition Under Study as described in paragraph 6.2 below. This knowledge is necessary to both validate the results of the analysis, and to evaluate and choose the best corrective action. In some cases, the best corrective action will involve the elimination or reduction of a conditional factor other than the Condition Under Study.

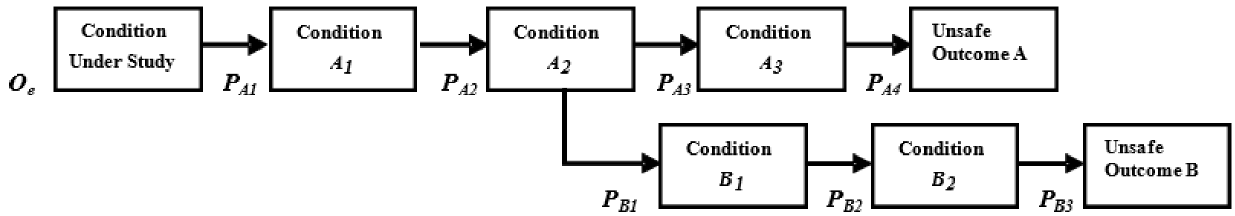
6.2 **Failure Condition/Event Modeling (Causal Chain)**

Figure 4 is an illustrative condition model showing:

- Condition Under Study
- Expected number of occurrences of the Condition Under Study
- Each condition and associated *CP* that led from the Condition Under Study to reasonably possible Unsafe Outcomes of known *S*

The Condition Under Study could be any airplane-related potential safety issue. Figure 4 shows two Unsafe Outcomes: Unsafe Outcome "A" and Unsafe Outcome "B." The expected Number of Occurrences of Unsafe Outcome A occurring, as the result of the Condition Under Study, is the product of the Expected Number of Occurrences (O_e) of the Condition Under Study, and all the Conditional Probabilities ($P_{A(x)}$) leading from the Condition Under Study to Unsafe Outcome A. Similarly, the expected Number of Occurrences of Unsafe Outcome B is the product O_e and the *CPs* leading to Unsafe Outcome B. Usually, the total fleet risk estimate is the sum of the risks associated with each Unsafe Outcome (fleet Risk A + fleet Risk B).[6]

[6] For Individual the risk values are proportionally combined.



O_e = Expected number of occurrences of the Condition Under Study

$P_{A(x)}$ and $P_{B(X)}$ = The conditional probabilities leading to Unsafe Outcomes A & B

$S_{(X)}$ = The Severity of Unsafe Outcomes A & B

Risk = Number of occurrences x Conditional Probability x Severity

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

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

Total Risk = Risk A + Risk B

Figure 4. Failure Condition/Event Modeling (Causal Chain)

6.2.1 When performing a transport-airplane risk analysis of the Condition Under Study, the analyst obtains, to the extent possible, quantitative data to define the *Oe* and all the *CPs* associated with all the conditional factors leading to the Unsafe Outcomes with known *S*. The *CP*s might be determined separately or captured in historical or test data as a combined value.

6.2.2 Often, the quantitative data needed to determine the likelihood and *S* of various Unsafe 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, certification data, and/or expert opinion.

6.2.3 AIR-633 has compiled historical data on the *S* (in terms of fatalities) associated with common transport-airplane Unsafe Outcomes and has determined the historical *FIRs* (5.6.6) associated with those events.

6.2.4 If a causal chain has a known *FIR* for an intervening condition, consider only the *CPs* that lead from the Condition Under Study to the intervening condition. The *FIR* captures the combined conditional probabilities of all subsequent Unsafe Outcomes in the causal chain. If, for example, the Condition Under Study is a landing-gear strut failure, and condition A_1 (A_1 is an Unsafe Outcome) is a landing-gear collapse with a known *FIR*, the analyst would only need to determine the Conditional Probability (P_{A1}) that a strut failure would result in a landing-gear collapse. No knowledge of subsequent Unsafe Outcomes, such as runway overruns, high-speed rejected takeoff, emergency evacuation, fire, etc., would be necessary, because the *FIR* for condition A1 captures all subsequent conditional probabilities and severities.

6.2.5 If more than one Unsafe Outcome is reasonably likely due to the Condition Under Study, we recommend that a TARAM Worksheet be prepared for each Unsafe Outcome. Document the risk values associated with all the Unsafe Outcomes added together (or proportionally combined as appropriate, see paragraph 6.14.10). Separate worksheets are not necessary if there is an event with a known *FIR* in the causal chain leading to all subsequent Unsafe Outcomes.

6.2.6 As an example, if the only *FIRs* known were those associated with Unsafe Outcomes *A* and *B* in figure 4, the analyst would prepare a worksheet for each of those Unsafe Outcomes, then add (or proportionally combine, as appropriate, see paragraph 6.14.10) the results on a summary worksheet to obtain the combined risk. If there was a known *FIR* for Condition A_1, (A_1 is an Unsafe Outcome), the analyst uses only one worksheet with Condition A_1 listed in the Unsafe Outcome description. In other words, the *FIR* for Condition A_1 includes the conditional probabilities and severities associated with subsequent (in the causal chain) Unsafe Outcomes *A* and *B*.

6.3 Condition Under Study

Clearly define the condition, failure, defect, error, or event that is the Condition Under Study for the analysis. The Condition Under Study would normally be a record associated with one of the following:

- Title 14 CFR 21.3 Report
- DAH Notification
- Service Difficulty Report
- Air Traffic Control Event Report
- Condition or conditions identified during the investigation of an accident or incident or during the MSAD process

In the MSAD process, the potential safety issue will often be the Condition Under Study in a TARAM risk analysis. As noted in paragraph 6.2, in some cases, using another condition in the causal chain as the Condition Under Study will simplify or improve the risk analysis. When the potential safety issue is not the focus of the risk analysis, the condition chosen must have a direct analytical relationship to the identified potential safety issue. Record a description of that relationship in the TARAM Worksheet, Part 2. See appendix A for the definition of Condition Under Study.

6.4 Unsafe Outcome(s)

See appendix A for the definition of Unsafe Outcome.

6.4.1 <u>Unsafe Outcome - General Guidance</u>. Use knowledge of the causal chain to identify the reasonably likely airplane-level Unsafe Outcomes with a known (or knowable) *FIR* closest in the causal chain to the Condition Under Study. Identifying the Unsafe Outcomes with a known *FIR* minimizes the analytical complexity and data requirements in the risk analysis and tends to improve the accuracy of the analysis. In cases where the Condition Under Study is a secondary factor that does not directly cause an Unsafe Outcome, but instead increases the *CP* and/or *S* of the event, see paragraph 5.3 for additional guidance.

Note: An Unsafe Outcome is an actual condition or outcome such as an uncontrolled crash, overrun, etc. Do not use abstract hazard categories (catastrophic, hazardous, etc.) or intermediate conditions that “could, may, or might” result in an Unsafe Outcome.

6.4.2 <u>Unsafe Outcome Guidance</u>. For R_{90}, R_{Cf}, R_{Cwe}, R_{CI}, and *MTCP*, consider only those identified Unsafe Outcomes with a potential to occur during the prescribed period. For example, if the event requires a particular operational condition, and the affected fleet will not encounter the condition during the period under consideration, do not consider that Unsafe Outcome.

6.5 Analysis Units of Measure

Choose analysis-exposure units that provide the best correlation to the in-service failure history of the Condition Under Study. For example, flight hours are a common time unit used in risk analyses. Individual Risk guidelines are in units of flight hours, so conversion is necessary if other units are used. Flight cycles are often associated with structural fatigue-related issues. Other conditions, such as corrosion, more directly relate to chronological time (hours, days, years). Use consistent units of measurement and conversion factors throughout the risk analysis.

6.6 Utilization (*U*)

The airplane operation time divided by that time in days (U = Operating Time/Days). Utilization is the exposure rate of a particular airplane, or the average exposure rate of a fleet of airplanes, within a specific period. The units of the U variable are usually flight hours per day or flights (cycles) per day. Airplane manufacturers, operators, and/or airplane-operations-data providers can aid in establishing risk-variable values including U. Significant changes in U that are expected to occur in the affected fleet during the period under study should be reflected in the average U. See paragraph 5.6.2 for the definition of U.

6.7 Number of Airplanes (*Σ*)

In a constant-failure-rate analysis, the Σ used in calculating exposure is either the average or total Number of (existing and future) Airplanes operating over either the total or average T (6.8). When calculating T and Σ for constant failure rate issues, only one should be a total value, and the other will be an average value. In a wear-out analysis, all existing and future airplanes and their respective ages are considered. Usually when analyzing potential safety issues involving United States-manufactured airplanes or airplane equipment, the Σ variable is the worldwide number of all affected transport-category airplanes. When the need arises to analyze the risk associated with foreign-manufactured transport category airplanes or airplane equipment (3.2), use the world fleet of affected airplanes to calculate the risk values used to help determine whether corrective action is necessary and facilitate discussion with the applicable foreign civil airworthiness authority. Affected airplanes could include:

- Airplanes that are substantially similar in design for common design problems (including products altered by STC), and/or
- Airplanes within a certain identifiable serial-number range.

If multiple airplane models have the same safety issue, the affected fleet will include all affected airplane models in the fleet. It may be necessary to separate the affected fleet into sub-fleets. In addition, treat sub-fleets separately if the input variables or underlying risk differs between the sub-fleets. When a manufacturer service bulletin describes the corrective action, the number of airplanes listed in the service bulletin is often the affected fleet size. If no voluntary production change is currently planned or anticipated to correct the Condition Under Study, the affected fleet size includes all future production airplanes. Airplane manufacturers, operators, and/or airplane-operations data providers can aid in establishing risk variable values including Σ. See paragraph 5.6.3 for the definition of Σ.

Note: Reflect voluntary corrective action in the analysis when there is data that it has occurred, and only consider voluntary action that adequately corrects the condition and is not expected to be significantly reintroduced later.

6.8 Time (*T*)

6.8.1 Time – General Guidance. In a constant failure rate analysis, the time used in calculating exposure will be either the total or average time over which either the total or average number of (existing and future) airplanes will operate (6.14.1.2). See paragraph 5.6.4 for the definition of *T*. When calculating *T* and Σ for constant failure rate issues, only one should be a total value, and the other will be an average value.

6.8.2 Time for R_T

6.8.2.1 Time for Total Uncorrected Fleet Risk

When using a total value for *T*, an estimate of the remaining production time (for airplanes continuing to be produced with the Condition Under Study) and the estimated average airplane retirement age are added to obtain the total time value. This can be obtained from affected fleet service information. It is based on the average airplane retirement age on the retirement history of the affected fleet and/or the retirement history of airplanes of similar design, operation, and utilization. When the necessary retirement information is not available, assume a 35-year retirement age unless similar sub-fleets, models, or types of airplanes have a significantly lower or higher average retirement age. Sometimes a condition will only exist over a certain maintenance or inspection interval. In those cases, the Time for Total Uncorrected Fleet Risk is the maintenance or inspection interval.

6.8.2.2 Close to Retirement

For fleets close to retirement, and if more relevant information is not available, estimate the remaining fleet life by subtracting the age of the youngest airplane in the fleet from 35 years. When the airplanes in the fleet are all nearing or past the average retirement age, the Limit of Validity (LOV) can aid in the estimation of remaining fleet life for older fleets. The DAH-defined LOV, in flight cycles or flight hours, along with the average fleet-utilization information, can be used to establish an estimated, mandatory retirement age for those few airplanes that continue in operation past the retirement of the majority of the fleet.

6.8.3 Time (T_{90}). For 90-day Fleet Risk, Time is 90 days, or the equivalent of 90 days in consistent analysis units.

6.8.4 Time (T_C). The period for Control Program Fleet Risk starts when the Corrective Active Review Board (CARB) determines that a safety issue requires mandatory corrective action. Time for Control Program Fleet Risk includes the time needed for the DAH to prepare corrective action instructions if necessary; all AD Worksheet and AD processing time; and any time after AD release needed for the DAH to prepare and distribute corrective action instructions, and manufacture, obtain and distribute any necessary parts. It also includes the time needed by operators to obtain sufficient parts and/or information to accomplish the necessary changes, plus the average incorporation time based on the best estimate of the incorporation rate. If a good estimate of the incorporation rate is not possible, linearly estimate the average incorporation time as one-half of the AD compliance time within which the operators are able to incorporate the required changes.

6.9 Determining the Type of Risk Analysis

For the purposes of this handbook, the three failure categories are:

- Early failures (infant mortality): A failure category where parts are more likely to fail early in their life,[7]
- Constant failure rate: A failure category where parts are equally likely to fail regardless of their age, and
- Wear-out failures: A category in which failure is increasingly likely as the unit ages.

Although the risk-analysis formulas are similar for each failure category, the complexity of determining the frequency of occurrence is significantly different between the constant failure rate and the other failure categories (early and wear-out). Consequently, this handbook treats the failure categories separately.

6.9.1 Early-failure-distribution-related issues are infrequent in transport-airplane COS and are not discussed separately in this handbook. "Batch" problems are a type of early-failure distribution. Batch problems occur when a limited number of parts or assemblies (a batch) are produced with a design or manufacturing defect. As a result, only a limited number of airplanes are exposed to the effects of the "batch" failure rate. Only include the sub-fleet of airplanes known (or estimated) to have the early failure condition in the analysis. Contact AIR-633, if necessary, for additional guidance and/or information regarding early-failure analysis.

6.9.2 If the failure type and the failure distribution of the Condition Under Study is not known, the ASE can perform a Weibull analysis (or use another suitable analytical method) to determine the failure type and, thereby, the associated type of risk analysis necessary. The slope of the Weibull plot, beta (β), indicates the category of failures (distribution). The DAH may be able to provide results of a Weibull or Log Normal analysis performed in the past to aid in the failure-category determination.

- $\beta < 1.0$ - early failure distribution
- $\beta \cong 1.0$ - a constant failure rate (independent of age)
- $\beta > 1.0$ -wear-out failure distribution

Note: See paragraph 7 of this handbook for guidance in assessing the risk associated with wear-out issues. Many commercial, off-the-shelf software packages, like SuperSmith, are available to simplify wear-out (and early failure) analysis.

6.10 Frequency of Occurrence (*F*)

6.10.1 <u>Frequency of Occurrence (*F*) – General Guidance</u>. For a constant failure rate, and the associated basic probability equation of $P = \lambda t$, (probability equals failure rate times exposure

[7] In reliability and risk analysis literature the term "infant mortality" is typically used and is synonymous with the term "early failure category" used in this handbook.

time), *F* is the same as the failure rate, i.e., equivalent to λ.[8] If the condition is determined to have a constant failure rate (6.8), one method of estimating the average frequency is to determine the number of times the condition has occurred, in service to-date. The Number of Occurrences divided by the total number of flight hours or flight cycles, accumulated by fleet in which the condition could occur is the frequency. When occurrences of the Condition Under Study are few, you can better estimate *F* using statistical methods. When occurrences of the Condition Under Study are zero, a statistical approach is to use 0.693 divided by the total number of flight hours or flight cycles. 0.693 is the 50% confidence, lower bound on 1 future event if zero have occurred. Only use such methods if the intended result is in the "best estimate" of the actual probability. The effect of operational considerations such as latency, i.e., multiple flights before the discovery of the condition or Minimum Equipment List (MEL) dispatch, should be included in the Frequency of Occurrence estimate (6.10.3). See paragraph 5.6.1 for the definition of *F*.

6.10.2 Always Present Condition. The equations for calculation of the various constant-failure-rate risk values presented in this handbook are structured for cases where the Condition Under Study is a discrete event, e.g., a failure, malfunction, etc. When calculating the risk associated with a condition that is always present, such as a discovered design error that exists throughout the affected fleet, use the frequency of another significant condition in the causal chain that leads to the Unsafe Outcome as the *F*. Be sure that all *CPs* leading from the always-present condition to the envisioned Unsafe Outcome(s) are included in the analysis.

6.10.3 Frequency of Occurrence for Latent Events or MEL Conditions. Sometimes a Condition Under Study can persist for multiple flights after it occurs because it is a latent failure (initially undetected), or correction is delayed for a period based on MEL considerations. In such cases, account for the additional flights with the Condition Under Study remaining in the fleet-risk calculation. One method of doing this is to use an Effective Frequency of Occurrence (F_{eff}).

Note: The use of the (F_{eff}) for latent or MEL dispatch is for the condition under study. Other conditions in the causal chain may be latent or have MEL dispatch provisions. Account for them in the *CP* (6.11).

6.10.3.1 **Latent Events**. For latent failures of the Condition Under Study, the effective frequency of occurrence is given by:

$$F_{eff} = F * [1 + (T_{latent}/2) *(\{1/T_f\} - F)] \sim= F * [1 + \{(T_{latent}/2) / T_f\}]$$

F is the frequency of occurrence for the condition, $T_{latent}/2$ is the average latency time in flight-hours or flights (i.e., one-half the maximum latency time), and T_f is the average flight duration in hours or in flights (i.e., 1 flight).

6.10.3.2 **MEL Conditions**. For MEL dispatch of the Condition Under Study, the effective frequency of occurrence is given by:

[8] The equation shown ($P = \lambda t$) is an approximation/simplification of the actual probability equation which is $P = 1 - \exp^{(-\lambda t)}$. The simplified version is sufficient for illustrative purposes. $P = \lambda t$ is only a useful simplification when λt is a small number. When λt nears or is greater than 1, the simplified equation results in significant error. Use the actual equation in probability calculations when λt is large.

$$F_{eff} = F * [1 + (P_{mel} * T_{MEL}/2) * (\{1/T_f\} - F)] \sim= F * [1 + (P_{mel} * \{T_{MEL}/2\} / T_f)]$$

F is the Frequency of Occurrence for the condition, $T_{MEL}/2$ is the average MEL dispatch time in flight-hours or flights (e.g., typically one-half the maximum MEL time), T_f is the average flight duration in hours or in flights (i.e., 1 flight), and P_{mel} is the probability of being MEL dispatched after a failure.

Note: If the MEL procedure has risk mitigations, the use of an effective frequency of occurrence as defined here is inappropriate; instead, calculate the fleet risk of the failure flight and the MEL flights separately, then add the values to obtain the effective frequency of occurrence.

6.10.4 Frequency of Occurrence for Individual Risk (F_I or F_{CI}). This is often the average value, which is the same value used for Total Uncorrected Fleet Risk. Sometimes "a condition or combinations of conditions" will result in a significantly higher-than-average *F* on a "few" future flights. For guidance on when and how a higher-than-average *F* value is used, see paragraph 6.14.5.1.

6.11 **Conditional Probability (*CP*)**

6.11.1 Conditional Probability – General Guidance. The *CP* includes all the individual conditional probabilities for all the conditions that must necessarily occur for the Condition Under Study to result in a specific airplane-level Unsafe Outcome. Ensure that part or all the *CP* is not mistakenly included in either the *F* or the exposure variables or has probabilities that are also in the *FIR*.

6.11.1.1 Use historical operating data or test data, when available, to determine *CP*. Use certification data, expert opinion, analysis, and/or simulation, if historical data is unavailable. AIR-633 can assist with the development of simulation models. Lacking historical or test data, you can estimate *CP* with related design or certification fault-tree analyses. Although some of the assumptions made at the time of certification, such as conservative estimates, may not be relevant or acceptable for use in a TARAM analysis, such information may be helpful in determining the likely conditional probabilities for contributory conditions. When neither sufficient data nor analytical estimations are available, estimate *CP* based on informed engineering judgment (5.7).

6.11.1.2 *CP* may consist of several *CPs* that are most often multiplied together to obtain a single condition-to-Unsafe Outcome *CP*. The method used to combine *CP*s depends on the extent that they are independent, i.e., their probabilistic relationship. When *CPs* are not independent, consider consulting AIR-633 regarding the best analytical approach.

6.11.1.3 Be aware that *FIRs* associated with a particular Unsafe Outcome capture all subsequent conditional probabilities in the causal chain. Take care that conditional probabilities are not "double counted" in both *CP* and *FIR*. See paragraph 5.6.5 for the definition of *CP*.

6.11.2 Conditional Probability for Fleet Risk (*CP*, CP_{90}, or CP_C). The average *CP* anticipated, over Time for R_T (6.8.2), of the affected fleet (or sub-fleet; 6.8.2), 90 days (6.8.3), and/or the airplanes flying during the T_C (6.8.4). When there are multiple Unsafe Outcomes with known

FIRs, treat each Unsafe Outcome and its associated *CPs* separately, then add the resulting fleet-risk values to obtain the total fleet risk due to all the potential Unsafe Outcomes.

6.11.3 Conditional Probability for Individual Risk (CP_I or CP_{CI}). The *CP* for Individual Risk is often the average value, which is the same value used in Total Uncorrected Fleet Risk or Control Program Fleet Risk calculations. Sometimes "a condition or combinations of conditions" will result in a significantly higher-than-average *CP* on a "few" future flights.

Note: For guidance on when a higher-than-average *CP* value is used, see paragraph 6.14.5.1.

6.11.4 Conditional Probability for Latent Events or MEL Conditions.[9]

6.11.4.1 **Latent Events**. The probability for latent events that are part or all the *CP* (not for the Condition Under Study, but for other events in the causal chain) is given by:

$$CP_{(x)} = \lambda \ x \ T_{latent}/2$$

where λ is the frequency of the condition per flight-hour or per flight times, and $T_{latent}/2$ is the average latency period (i.e., one-half the maximum latency time) in flight hours or flights.

6.11.4.2 **MEL Conditions**. The probability for an MEL condition that is part or all the *CP* (not for the Condition Under Study, but for another event in the causal chain) is given by:

$$CP_{(x)} = \lambda \ x \ [T_f + (P_{mel} \ x \ (T_{MEL}/2)]$$

where λ is the frequency of the condition per flight-hour or per flight times. $T_{MEL}/2$ is the average latency period (i.e., one-half the maximum MEL time) in flight hours or flights. P_{MEL} is the probability of being MEL-dispatched after a failure. T_f is the average flight duration in hours or in flights (i.e., 1 flight).

6.12 **Fatal Injury Ratio (*FIR*)**. AIR-633 derives useful *FIRs* from the historical record of the Unsafe Outcomes. This is accomplished by dividing the total number of fatalities (including people on the ground) in each past event by the total number of occupants exposed (airplane passengers and crew). The *FIR* includes all occurrences of a specific Unsafe Outcome whether the events resulted in fatalities or not. It is not the fatality rate for "fatal accidents" alone. See paragraph 5.6.6 for the definition of *FIR*.

6.13 **Exposed Occupants (*EO*)**

For those Unsafe Outcomes that pose a general threat to all the occupants of the airplane, the *EO* is the average total capacity (passengers and crew) of the airplanes that make up the affected sub-fleet, model or type of airplanes. In general, do not consider load factors when determining *EO*, because the data is often difficult to obtain and changes with time and circumstances. Using average total capacity results in uniform comparative risk-factor values that are not significantly different from those with load factors included. Airplane manufacturers, operators, and/or airplane operations data providers can aid in establishing risk-variable values including *EO*. See paragraph 5.6.7 for the definition of *EO*.

[9] The equation shown (P = λt) is an approximation/simplification of the actual probability equation, which is $P = 1 - \exp^{(-\lambda t)}$. The simplified version is sufficient for illustrative purposes. P = λt is only a useful simplification when λt is a small number. When λt nears or is greater than 1, the simplified equation results in significant error and the actual equation should be used.

Note: The *EO* value will normally be the same for Total Uncorrected and Control Program Fleet Risk. The threat to persons outside the airplane is included in the calculation of TARAM *FIRs* and is not considered when estimating *EO*.

6.14 **Calculating Risk**

Find guidance below on calculating the variables in the risk calculations Exposure, Number of Occurrences, and *S,* as illustrated in figures 1 and 2, along with instructions on determining the appropriate variables to use in each calculation. After the risk values for each Unsafe Outcome are determined, combine them to calculate the total risk values.

6.14.1 Exposure. Exposure, as used in the analysis of constant failure-rate issues, represents the total number of flights or flight hours of the fleet affected by the Condition Under Study during a specific period.

$$\text{Exposure} = (U \times \Sigma \times T)$$

Where:

U = Utilization (5.6.2)

Σ = average number of airplanes that were affected during T (6.7)

T = Time period under study (6.8)

6.14.1.1 **Sub-fleets.** Exposure can usually be determined directly for an entire affected fleet. When U varies significantly among sub-fleets, such as between cargo and passenger versions of the aircraft model, use the following equation:

$$\text{Exposure} = (U1 \times \Sigma 1 \times T1) + (U2 \times \Sigma 2 \times T2)$$

6.14.1.2 **Exposure for R_T.** Use fleet data to estimate the Time for R_T and the Σ expected to be in service during that that period. Use these values to calculate exposure in the total uncorrected risk computation. The resulting $\Sigma \times T$ value is multiplied by U, to calculate the total exposure for determining Total Uncorrected Fleet Risk.

6.14.1.3 **Exposure for R_{90}.** For 90-day Fleet Risk calculations, T is 90 days, the total Σ operating at the time of analysis, and the average U during that period.

6.14.1.4 **Exposure for R_C.** Base control-program exposure on the guidance of paragraphs 6.8.4 and 6.14.1.2 unless the total AD processing time, plus the average corrective-action time, is so short that fleet size changes are not significant. In that case, calculate control-program exposure based on the guidance of paragraphs 6.8.3 and 6.14.1.3.

6.14.2 Number of Occurrences. For constant-failure-rate issues, the predicted number of occurrences equals the product of F and the exposure, i.e., $U \times \Sigma \times T$. The predicted number of occurrences is the expected number of times the Condition Under Study will occur during the analysis period . In wear-out failure distribution analysis, *DA* (5.6.9) is analogous to the number of occurrences. See paragraph 7 for further guidance on wear-out failure distribution analysis.

6.14.2.1 **Frequency of Occurrence Times Time is $\lambda \times$ T.** In this case, this is an exact solution to the cumulative hazard function which yields the total expected number of failures. It is not an approximation of the exponential distribution. These two solutions look identical, i.e., λT, but they are solving for different things. The former is solving for Expected Number of Occurrences. The latter is the estimated probability.

6.14.2.2 **Predicted Number of Occurrences.** The predicted number of occurrences can usually be determined directly for an entire affected fleet. When F is expected to vary significantly among sub-fleets, the exposure of each sub-fleet is determined separately, multiplied by the associated sub-fleet F, and each separate sub-fleet value is added together to obtain the predicted number of occurrences in the fleet. As an example, calculate the predicted number of occurrences of a Condition Under Study, with significantly varying F in three sub-fleets, using the formula(s):

- Predicted Number of Occurrences (constant failure rate) = $(F1 \times U1 \times \Sigma 1 \times T) + (F2 \times U2 \times \Sigma 2 \times T)$
- Predicted Number of Occurrences (wear-out) = $(ND1 \times DA1) + (ND2 \times DA2)$

6.14.3 Severity (S) of a defined Unsafe Outcome. For fleet risk, S is the average number of fatalities per event. For Individual Risk, the S is the Unsafe Outcome associated FIR (the probability of fatal injury per person exposed).

6.14.3.1 For Total Uncorrected Fleet Risk (fatality), Control Program Fleet Risk (fatality), 90-day Fleet Risk (fatality), and MTCP (fatality):

$$S = FIR \times EO$$

6.14.3.2 For Uncorrected Individual Risk, Total Uncorrected Fleet Risk (weighted events) Control Program Individual Risk, Control Program Fleet Risk (weighted events), and MTCP (weighted events):

$$S = FIR$$

Where: FIR = Fatal Injury Ratio and EO = Exposed Occupants

6.14.4 Total Uncorrected Fleet Risk (R_T). See paragraphs 5.4.1 and 5.4.2 for the definition of Total Uncorrected Fleet Risk. See paragraph 7 for additional guidance on wear-out failure distribution analysis.

6.14.4.1 For constant-failure-rate issues:

$R_{Twe} = (F \times U \times \sum \times T) \times CP \times (FIR)$ (weighted events)

$R_{Tf} = (F \times U \times \sum \times T) \times CP \times (FIR \times EO)$ (fatalities)

6.14.4.2 For wear-out issues:

$R_{Twe} = (ND \times DA) \times CP \times (FIR)$ (weighted events)

$R_{Tf} = (ND \times DA) \times CP \times (FIR \times EO)$ (fatalities)

Where:

$F \times U \times \Sigma \times T$ or $ND \times DA$ = Predicted number of occurrences (4.15.2)

CP = Conditional Probability

FIR or $(FIR \times EO)$ = S

6.14.5 Uncorrected Individual Risk (R_I)

6.14.5.1 Often, the Uncorrected Individual Risk calculation is based on average risk variables over the period under study. There may be circumstances where the risk contribution of known special operational conditions and/or combinations of conditions should be included in the individual risk calculation. In some identifiable subsets of the fleet, higher-than-average individual risk may occur. Calculate higher-than-average individual risk when "a condition and/or combinations of conditions" are actual known contributors to risk, such as MEL dispatch, latent failures, airplane loading, environmental conditions, etc.

6.14.5.2 If "combinations of conditions" are used in the individual risk calculation, there must be a reasonable number of actual future flights (10 or more) where all the special operational conditions and the Condition Under Study can be statistically shown to exist together. Do not calculate individual risk based on the "worst case" that can be hypothesized, or using all the conditions that could occur during a flight because it is theoretically possible. All the conditions must be statistically shown to occur together on a reasonable number of actual future flights based on their individual estimated frequency rates. See paragraph 5.4.3 for the definition of Uncorrected Individual Risk (R_I).

- For constant-failure-rate issues:

$$R_I = F_I \; x \; CP_I \; x \; FIR$$

- For wear-out issues:

$$R_I = ND \; x \; h_{I\,x} \, CP_I \; x \; FIR$$

6.14.5.3 **Uncorrected Individual Risk – Special Operational Condition Flights**

6.14.5.3.1 If there is an identifiable sub-fleet where individual risk is higher because of the basic operation or operating environment of the sub-fleet, Uncorrected Individual Risk is the value calculated for the sub-fleet.

6.14.5.3.2 When there are no identifiable individual-risk sub-fleets and there is one identifiable condition that, when present, causes the individual risk to be higher, and that condition will occur on a reasonable number of actual flights (10 or more), individual risk is calculated for the flights when the condition is present.

6.14.5.3.3 When a special operational condition will have a significantly higher frequency or probability of occurring during a reasonable number of actual future flights, use the higher value when calculating individual risk. When a special operational condition will be continuously present during a reasonable number of flights after its initial occurrence due to latency, MEL dispatch, or other considerations, assume the condition is present during those flights in the individual risk calculation, e.g., do not include the condition *F* or *CP*, as applicable in the calculation. The guidance in paragraph 6.10.2 applies in cases where the Condition Under Study is a condition that is assumed to be present in the individual risk calculation. A condition is not assumed to be continuously present merely because it will occur several times based on its *F* or probability.

6.14.5.3.4 If more than one condition is in the causal chain and that can increase individual risk, then individual risk is the largest value associated with a combination of conditions that are statistically shown to occur together on a reasonable number of actual future flights (10 or more). When no combination of conditions is statistically shown to occur together on a reasonable number of actual future flights, calculate individual risk using the single condition that does occur on a reasonable number of actual future flights and results in the largest increase in individual risk.

6.14.5.3.5 To determine whether several independent conditions will occur together on future flights, determine the per-flight frequencies in which the risk-increasing condition will occur, and multiply them by the number of flights in the remaining life of the fleet or control program, as applicable.

$$\text{Increased Individual Risk Flights} = F_{sc1} \ x \ F_{sc2} \ldots\ldots\ldots F_{sc(n)} \ x \ \textit{Future Flights}$$

6.14.5.3.6 If an independent condition can persist after the flight of its occurrence due to it being a latent failure or being on MEL dispatch, the additional flights in that condition increase the likelihood that it will occur together with other conditions. For latent and MEL conditions, use the Effective Frequency of Occurrence (defined in paragraph 6.10.3) in the above formula.

Note: Conditions might be shown to occur together on a few flights in the remaining fleet life, but not during the control-program period. In that case, R_I and R_{CI} will be different values.

6.14.6 Management Time for Control Program (*MTCP*). Calculate *MTCP* when there is a determination that an AD is necessary as part of the MSAD process. However, when the value of Total Uncorrected Fleet Risk is below the guideline, *MTCP* is not relevant and not calculated. In those cases, *MTCP* is the remaining life of the fleet. In addition, when urgent mandatory action is undertaken, *MTCP* is not needed. In those cases, *MTCP* is the statutory rulemaking time associated with the type of AD action chosen (Emergency or Immediately Adopted Rule (IAR)). In most cases, determine *MTCP* for both constant failure rate and wear-out issues by iteration of the fatalities or weighted events fleet-risk equations, as applicable. Calculate *MTCP* using the weighted events formulas in analyses where *EO* values are less than 150. Otherwise, use the fatalities formulas. Calculate *MTCP* based on the assumption that no mandatory corrective action will occur while accounting for any reasonably anticipated voluntary corrective action. High accuracy is not required since the *MTCP* is for planning purposes and is not used directly in safety decision-making. When calculated by these equations, *MTCP* will be in days. See paragraph 5.4.5 for the definition of *MTCP*.

- For either constant failure rate or wear-out issues (fatality-based), a good starting point for iterating on *MTCP* is:

  $MTCP_{(i=1)} = 270/R_{90}$

- For either constant failure rate or wear-out issues (weighted events based with 0.02 guideline), a good starting point for iterating on *MTCP* is:

  $MTCP_{(i=1)} = [(1.8) *(EO)]/R_{90}$

6.14.6.1 ***MTCP* – Constant Failure Rate Analyses.** Because *MTCP* is a total-time value, in constant-failure-rate analysis, use the average number of affected airplanes flying during the *MTCP* period in the iterated equations. When calculating *MTCP* for constant-failure-rate issues, the Σ

variable is usually the only variable that will change during the *MTCP* period. If that is the case, and there is a known function of *Σ* with respect to *T*, it is possible to calculate *MTCP* directly. Otherwise, one method of calculating an iterative solution is to start with the first iteration for *MTCP* using the formula, above. Beginning with that first iteration for *MTCP* and the associated time-related average fleet size, enter refined values for *MTCP* and the corresponding average fleet size into the applicable fleet-risk equation (6.14.4) until the value is approximately equal to the associated Control Program Fleet Risk guideline.

$$3 \approx F \times U \times \Sigma_{f\,(MTCP)} \times MTCP_{(f)} \times CP \times FIR \times EO \text{ (fatalities)}$$

$$0.02 \approx F \times U \times \Sigma_{we\,(MTCP)} \times MTCP_{(we)} \times CP \times FIR \text{ (weighted events)}$$

6.14.6.2 ***MTCP* – Wear-Out Analyses.** For wear-out failure issues, the failure rate increases exponentially with time, and it is not possible to calculate *MTCP* directly. One method of calculating an iterative solution for *MTCP* is to start with a first-iteration guess using the formula above. Iteratively incorporate guesses for *MTCP* into the applicable fleet-risk wear-out equation (6.14.4) until the value is approximately equal to the associated control-program fleet-risk guideline.

$$3 \approx ND \times DA_{f\,(MTCP)} \times CP \times FIR \times EO \text{ (fatalities)}$$

$$0.02 \approx ND \times DA_{we\,(MTCP)} \times CP \times FIR \text{ (weighted events)}$$

6.14.7 Control Program Fleet Risk and 90-Day Fleet Risk (R_{Cf} _ R_{Cwe} _ R_{90})

6.14.7.1 Control Program Fleet Risk and 90-Day Fleet Risk are normally calculated when AD action is determined necessary as part of the MSAD process. However, Control Program Fleet Risk is only relevant when Total Uncorrected Fleet Risk is above the associated guideline and urgent action is not necessary. In cases where urgent action is necessary, control-program timeframes are governed by the statutory rulemaking time associated with the type of AD action chosen (Emergency or IAR).

6.14.7.2 If the Condition Under Study can result in more than one Unsafe Outcome, use the method described in paragraph 6.14.10 to combine the value of each Unsafe Outcome-related Control-Program Fleet-Risk Value to establish the Total Control Program Fleet Risk associated with the Condition Under Study. See paragraph 5.4.6 and 5.4.7 for the definition of Control Program Fleet Risk (R_C), and paragraph 5.4.4 for the definition of 90-Day Fleet Risk (R_{90}).

- For constant failure rate issues:

$$R_{Cf} = (F_C \times U_C \times \textstyle\sum_C \times T_C) \times CP_C \times (FIR \times EO) \text{ (fatalities)}$$

$$R_{Cwe} = (F_C \times U_C \times \textstyle\sum_C \times T_C) \times CP_C \times (FIR) \text{ (weighted events)}$$

$$R_{90f} = (F_{90} \times U_{90} \times \textstyle\sum_{90} \times T_{90}) \times CP \times (FIR \times EO) \text{ (fatalities)}$$

$$R_{90we} = (F_{90} \times U_{90} \times \textstyle\sum_{90} \times T_{90}) \times CP \times (FIR) \text{ (weighted events)}$$

- For wear-out issues:

$$R_{Cf} = ND \times DA_C \times CP_C \times (FIR \times EO) \text{ (fatalities)}$$

$$R_{Cwe} = ND \times DA_C \times CP_C \times (FIR) \text{ (weighted events)}$$

$$R_{90f} = ND \times DA_{90} \times CP_{90} \times (FIR \times EO) \text{ (fatalities)}$$

$$R_{90we} = ND \times DA_{90} \times CP_{90} \times (FIR) \text{ (weighted events)}$$

6.14.8 Control Program Individual Risk (R_{CI})

6.14.8.1 Control Program Individual Risk is calculated when there is a determination that AD action is necessary as part of the MSAD process. Furthermore, Control Program Individual Risk is only relevant when Uncorrected Individual Risk is above the associated guideline. See paragraph 5.4.8 for the definition of Control Program Individual Risk (R_{CI}).

- For constant-failure-rate issues:

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

- For control wear-out issues:

$$R_{CI} = ND_{CI} \times h_{CI} \times CP_{CI} \times FIR$$

6.14.8.2 Control Program Individual Risk calculation is almost always based on average risk variables over Time for Control Program Fleet Risk. There may be circumstances where the risk contribution of known conditions and/or combinations of conditions should be included in the Control Program Individual Risk calculation. There may also be identifiable subsets of the fleet where higher-than-average individual risk will occur. Calculate higher-than-average individual risk only when there are "conditions and/or combinations of conditions" that are actual known contributors to risk, such as MEL dispatch, latent failures, airplane loading, environmental conditions, etc.

6.14.8.3 If "combinations of conditions" are used in the individual-risk calculation, there must be a reasonable number of actual future flights (10 or more) where all the conditions and the Condition Under Study can be statistically shown to exist together. Do not calculate individual risk based on the "worst case" that can be hypothesized, or by using all the conditions that could occur during a flight because it is theoretically possible. All the conditions must be shown statistically to occur together on a reasonable number of actual future flights based on their individual estimated frequency rates.

6.14.9 Residual Risk

6.14.9.1 Most safety issue control programs are selected with the intention of controlling risk to an acceptable level associated with a particular condition. It is generally assumed that a quantitative analysis of the control program would show that the residual (fleet) risk, i.e., the risk remaining after the control program is implemented, is negligible, and further analysis to determine the residual risk is not needed.

6.14.9.2 There are cases where, due to unique circumstances, the control program selected only reduces the risk associated with a particular condition. In this case, calculate a value for "corrected" fleet-risk (and individual-risk value, if different) to illustrate to the CARB where the residual risk stands with respect to the risk guidelines. The CARB may determine that additional action is necessary to correct the condition. In other cases, there is an interim control program mandated to reduce the risk while a control program that fully corrects the condition is selected and implemented. In this second case, calculate the "corrected" residual fleet-risk value after the interim action (and individual-risk value, if different), along with the associated MTCP value so follow-on corrective action can be planned. For cases of planned interim action, the MTCP should be calculated for the final action and should include the risk reduction due to the interim action. This MTCP will reflect both the time needed for the planned interim action as well as the additional time left over to select and implement the final corrective action.

6.14.10 Multiple Unsafe Outcomes

6.14.10.1 If calculating risk for sub-fleet(s), or if more than one Unsafe Outcome is associated with the Condition Under Study, the fleet-risk values 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.

6.14.10.2 Individual risk from multiple Unsafe Outcomes is also combined, but not directly added; instead, add the individual risks from each Unsafe Outcome weighted by the probability of their occurrence. For example, if Unsafe Outcome A happens 10% of the time, and Unsafe Outcome B happens 25% of the time, and the remaining 65% of the time there is no Unsafe Outcome, then the overall individual risk is:

$$[(0.1)\ (R_{IA}) + (0.25)\ (R_{IB})]\ /\ [0.1 + 0.25]$$

Note: Do not combine sub-fleet individual risk. The individual risk is the highest individual-risk value that occurs in any one of the sub-fleets.

6.14.11 Validation

Ensure that the risk analysis process results in risk values that represent a best-effort estimate of actual risk. Always compare the risk values produced by an analysis against the historical record associated with the Condition Under Study and its effects, to validate the analysis. In some cases, the historical record of conditions that result in similar effects can be used to help determine whether the calculated values appear reasonable. If the risk-factor values are considerably higher or lower than expected based on engineering judgment and knowledge of the historical impact of the issue, review the data, estimates, and the associated technical assumptions used, and correct them as necessary to the best estimate of the actual risk. All considerations need proper assessment. Do not introduce overly conservative or overly optimistic assumptions. It may be necessary in some cases to apply the data, estimates, and associated technical assumptions in the analysis to predict past events, and then compare the result to the actual historical record to validate (or invalidate) the analysis. For example, if a Condition Under Study has resulted in two Unsafe Outcomes in the past, the estimated *F* and *CP* can be validated by multiplying them by the affected fleet exposure (6.14.1) over the total past exposure period up to the present, and comparing the result to past occurrences (two events in this example):

$$F \times \underbrace{[U \times \Sigma \times T]}_{\textit{Past Exposure}} \times CP = (\textit{Predicted Past Number of Unsafe Outcomes}) \approx 2$$

Past Exposure

$$\underbrace{ND \times DA}_{\textit{Past Exposure}} \times CP = (\textit{Predicted Past Number of Unsafe Outcomes}) \approx 2$$

Note: Do 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. Neither this handbook nor FAA Order 8110.107B precludes recommendations for corrective action based on engineering judgment when the associated risk-factor values are marginally below the risk guidelines. However, the CARB needs a best-effort estimate of the actual risk in all cases to make knowledgeable safety and corrective action decisions.

7 TARAM GUIDANCE – WEAR-OUT

This paragraph provides additional guidance for those safety issues (Conditions Under Study) related to wear-out. It provides guidance for deriving the risk variables that are unique to wear-out issues. Table 1 contains definitions, purposes, and associated handbook references for the TARAM risk values. Table 2 provides the risk formulas for all TARAM variables with handbook references.

7.1 Distribution Analyses

7.1.1 For wear-out problems such as structural fatigue, use Weibull or similar analyses methodology. Weibull analysis is often used because structural fatigue failures usually fit well to a two or three-parameter Weibull distribution. Use other distributions only if they can accurately model the behavior of the population and allow calculation of the Cumulative Distribution Function (*F(t))* and the hazard function.

7.1.2 The ASE can use a Weibull analysis to determine the shape parameter(β), the characteristic life (η), and the shift parameter (γ). This handbook does not provide information on how to conduct a Weibull analysis. An ASE undertaking a wear-out failure analysis should be fully trained in the use of Weibull analysis and understand the various parameters. Many commercial, off-the-shelf software packages like SuperSmith, are available to aid in performing a Weibull analysis. The DAH may also be able to perform a Weibull or Log Normal analysis and provide the results for ASE review.

7.1.3 Base the choice of time units for the Weibull analysis on the physics of the problem. If it is not clear which time units to use, a comparison of a flight cycle-based Weibull analysis to a flight hour-based Weibull analysis can help determine the time units that provide the best correlation to the data. The time unit used in analyzing structural fatigue problems is typically flight cycles, but there are exceptions. Other problems correlate more directly to chronological time, and in those cases, the units of time are days or years. Once a unit of time is chosen, use it consistently throughout the risk analysis.

7.1.4 When doing a Weibull analysis, there are two parts. In the first part, the analyst analyzes the population data to determine the value of the characteristic life (η). In the second part of the Weibull analysis, the analyst uses the defined parameter of the failure distribution to calculate estimates of the risk over various future time periods, i.e., over the control program or over the life of the fleet.

7.1.5 When doing a Weibull or Weibayes analysis of an airplane structural fatigue issue, in the first part of the Weibull analysis, determining the value of η, there is a fundamental problem due to a lack of knowledge of the failure status of the fleet, i.e., does an airplane have a crack or not? Since most airplanes may be uninspected, the answer would be “I don’t know.” If you don’t know the status of an item in a test population, you cannot include it as a suspense when doing the analysis of the population’s items (airplanes).

7.1.6 This problem can be overcome with a judicious definition of "failure" when calculating η. Instead of defining failure as some arbitrary length or small defined length crack, define failure as accident size damage, then the entire fleet of uninspected airplanes can legitimately be included as suspenses, since we are certainly aware if there has been an accident or not. Accident size damage is the critical crack length for the load condition expected to result in an accident, typically a routine operational load.

7.1.7 When defining failure as accident-size damage, the fleet data must be normalized to accident-size damage. The fleet data normalization technique is the same whether performing a two or three-parameter Weibull. There are three cases:

- If a crack was found on the airplane, add to the airplane's age the time to grow the crack from its discovered size to accident-size damage. Consider this to be a failure.
- If the airplane was inspected and found to be crack-free, add to the airplane's age the time to grow from a detectable crack to accident-size damage. Consider this to be a suspense.
- If an airplane was not inspected and you do not know if it has a crack, use the airplane's age "as-is" (no adjustment). Consider this to be a suspense.

At this point, the fleet data has been normalized to accident-sized damage and can be used in a Weibayes or Weibull analysis.

7.1.8 <u>Weibayes Analysis</u>

7.1.8.1 At times, there will be insufficient failure data to calculate both parameters (*η* and *β*) used in defining the failure distribution in a two-parameter Weibull analysis. If the failure mode is well understood, it is often possible to assume a value for the shape parameter (*β*) and perform a meaningful analysis. This is known as a Weibayes analysis and is defined in failure-distribution-related literature (The New Weibull Handbook).

7.1.8.2 If the failure mode is fatigue crack in metal structure, well-accepted shape parameters are available for use in a Weibayes analysis: For aluminum structure, use a $\beta = 4$; for low-strength steel (Ftu <= 240 ksi) and titanium, use a $\beta = 3$; and for high-strength steel (Ftu > 240 ksi), use a $\beta = 2.2$.

- For a 2-parameter Weibull the formula is: $\eta = \Sigma\,(t_i^{\beta} / r)^{1/\beta}$
- For a three-parameter Weibull the formula is: $\eta = \Sigma\,((t_i - \gamma_i)^{\beta} / r)^{1/\beta}$

Where the summation is only over those units where $t_i - \gamma_i >=$ zero, and the shift parameter (γ) is the time to for a crack to grow from detectable to accident size damage.

Note: If the fleet is sufficiently old that you don't have to exclude too many airplanes when calculating η, the three-parameter Weibull is the best practice as it accounts for the differing physics of crack initiation and initial growth (fatigue), and continued crack growth to failure.

7.2 Not Detected (*ND*)

7.2.1 For wear-out issues, use *ND* in the calculation of each of the risk values. *ND* is a *CP*, but because it is such an important factor in the risk analysis of structural-fatigue cracking issues, and because it is conceptually different than the other *CPs*, *ND* is a separate factor in the risk calculation for emphasis and visibility. See paragraph 5.6.8 for the definition of *ND*.

7.2.2 Often, for structural fatigue cracking, a damage-tolerance analysis associated with the Condition Under Study can aid in the determination of *ND*.

7.2.3 *ND* is a factor in any issue where the failure or defect is detectable during future inspection, maintenance, or operational activities. *ND* is not limited to directed inspections or inspections associated with approved maintenance activities. Include the likelihood of incidental discoveries when determining *ND*. 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 1.0 if empirical evidence, observation, or expert judgment would indicate that its value is lower. Historical experience indicates that *ND*, for structural cracking issues, is generally a very small number.

7.3 Defect Airplanes (*DA*)

Use *DA* when calculating the Total Uncorrected Fleet Risk, the 90-day Fleet Risk, and the Control Program Fleet Risk (table 2). *DA* is analogous to the Number of Occurrences (6.14.2). To predict the Number of Airplanes anticipated with the wear-out failure, the analyst first determines the *Σ* and the value of the *F(t)*, for each airplane at various points in time. Find guidance for determining the *F(t)* below.

Note: The *F(t)* provides the portion of a population that will fail before *(*T*)*. Remember: it is not possible to predict whether a given individual part will fail, but it is possible to predict the expected number of failures within a given population. See paragraph 5.6.9 for the definition of *DA*

7.3.1 <u>Using the Weibull Distribution Failure Forecast Formula</u>

7.3.1.1 The calculation of the *F(t)* uses the characteristic life (*η*) and the shape parameter (*β*) from the two-parameter Weibull distribution.

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

Figure 5 is a graph of a two-parameter Weibull Cumulative Distribution Function using the following formula:

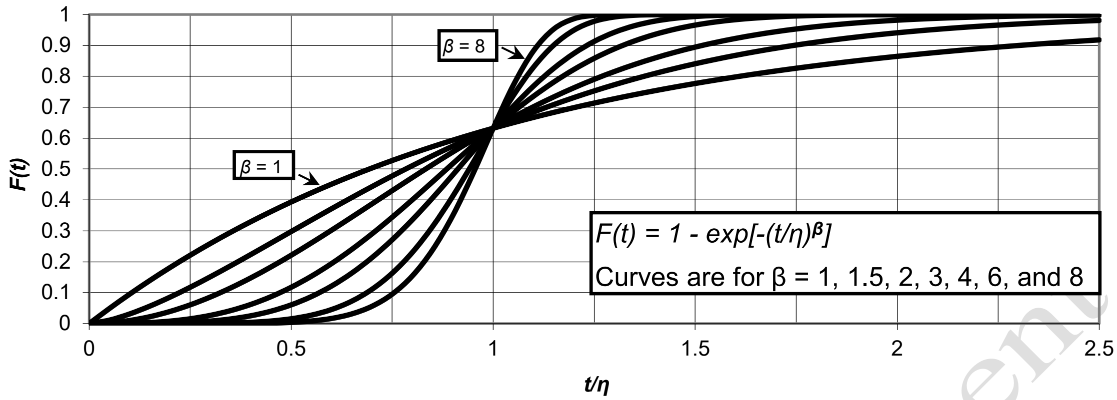


Figure 5. Weibull Cumulative Distribution Function F(t)

7.3.1.2 In a Weibull analysis, the estimated expected number of failures over a future period calculation uses the *F(t)*. Obtain the number of forecast failures by summing the function over the fleet of affected airplanes that have not yet failed:

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

7.3.1.3 The variable *(t)* is the current airplane's age (in the analysis time units), and the Time Being Analyzed (*Δt)* is the amount of time that will elapse for that airplane over the failure forecast period.

Note: *Δt* will vary from airplane to airplane. The value of *Δt* will also vary for the same airplane for Total Uncorrected Fleet Risk, the 90-day Fleet Risk, and the Control Program Fleet Risk calculations, as the *Δt* is different for each of these three risk calculations. For example, when calculating Total Uncorrected Fleet Risk, *Δt* is the amount of time, in analysis consistent units, from now until the airplane retires. *Δt* is a function of the airplane's current age, and typically its utilization as well.

7.3.1.4 When calculating *Δt* for the Control Program Fleet 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 (typically half the compliance time) is used for airplanes above the threshold. The time entered on the TARAM worksheet under T_C represents the Average Control-Program Compliance Time.

7.3.1.5 Using Reliability Software to Directly Forecast *DA*.

Many reliability-analysis programs can directly forecast the number of parts that will fail during a future period. Obtain the resulting failure forecast for use in the risk calculations by entering data for the entire affected fleet into such a program.

7.4 Hazard Function $h_{(t)}$

7.4.1 Use the hazard function, *h(t)*, when calculating uncorrected and Control Program Individual Risk for wear-out issues. The hazard function is analogous to the *F* used in the analysis of constant-failure-rate issues. See paragraph 5.6.10 for the definition of the Hazard Function variable.

7.4.2 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). Figure 6 is a graph of hazard functions for a two-parameter Weibull distribution 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*.

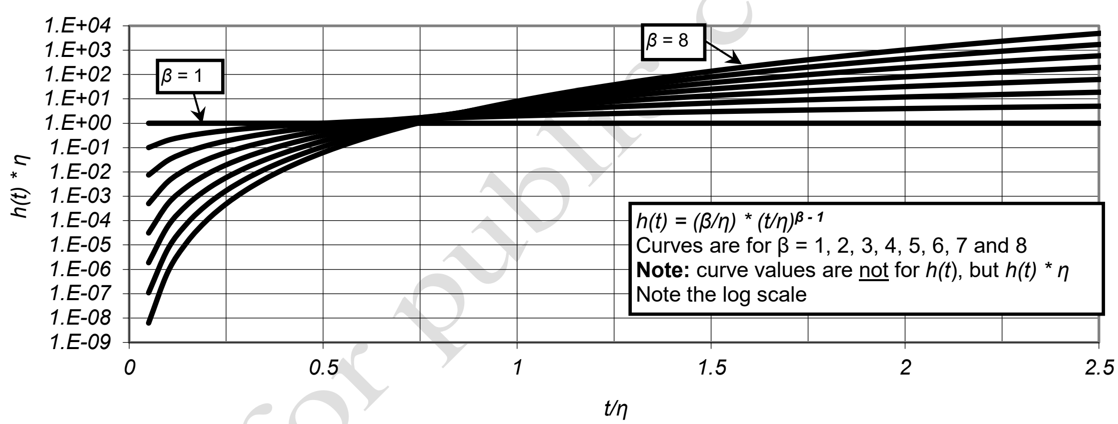


Figure 4. Hazard Function

8 RISK MANAGEMENT

This paragraph provides guidance for applying the risk analysis results to risk-management decision-making as part of the MSAD process.

8.1 Risk Guidelines

8.1.1 Table 3 provides risk-level guidance for corrective action decision-making. These values are guidance for the range of risks that may require corrective action. The risk guidelines in table 3 are not risk thresholds that limit or compel safety action. Confidence in the analytically derived values can vary widely, and the CARB considers that confidence when making risk-management decisions. Further, per FAA Order 8110.107B, factors other than risk may be considered by a CARB during safety decision-making. Although the table 3 guidelines do not limit the scope or weight of those other considerations, the intent of FAA Order 8110.107B is that risk should be the primary consideration in safety decision-making: "In rare situations, the ASE or FAA management may make recommendations not consistent with risk guideline for ADs or other mandatory corrective actions."

8.1.2 Although many of the TARAM fleet-risk factors and associated risk-level guidance are in terms of fatalities or weighted events, they are not deterministically predictive values. The risk values are a statistical expectation. The TARAM risk values and risk-level guidance represent a "level" or "range" of the risk involved.

8.1.3 Use Control-Program Fleet-Risk-Level Guidance in conjunction with a general philosophy to "correct unacceptable risk as soon as reasonably practical." When assessing "reasonably practical," consider factors such as regular maintenance intervals appropriate to the proposed action, parts availability, and other operational factors.

8.1.4 The 90-day Fleet Risk is a good indicator of relative urgency. From a statistical standpoint, for constant-failure-rate issues, the mere passage of time due to a program-schedule problem does not make an issue more urgent. This is not the case for wear-out issues but, in the near term, the change in urgency (90-day Fleet Risk) may be minimal. Per FAA Order 8110.107B, the CARB should be aware of, and concur with the decision to reduce, the planned compliance time or allow the control program to exceed the Control-Program Fleet-Risk-Level Guideline.

Table 3. Risk-Level Guidelines

Safety Decision Making		Priority/Management		Risk Control Decision Making	
Total Uncorrected Fleet Risk	Uncorrected Individual Risk	MTCP and 90-Day Fleet Risk	Control Program Fleet Risk	Control Program Individual Risk,	Control Program Individual Risk,
3 (fatalities)[1]	10^{-7}/flight hour	N/A	3 (fatalities)[1, 2] or, 1 (fatality)[2, 3]	10^{-6}/flight hour	10^{-5}/flight hour
0.02 (weighted events)[1]			0.02 (weighted events)[1, 2] or, 0.0067 (weighted events) [2, 3]		
Guidance: Use this factor in conjunction with Uncorrected Individual Risk to determine whether a condition is a safety issue.	Guidance: Use this factor in conjunction with Total Uncorrected Fleet Risk to whether a condition is a safety issue.	Guidance: Use *MTCP* when applicable as a guide for the available time to accomplish all FAA, DAH, and operator actions. Use the 90-day Fleet Risk as a relative priority measure.	Guidance: Use Control Program Fleet Risk level guidance to ensure that the risk during any selected control program timeframe is acceptable.	Guidance: Consider urgent action. Minimize, to the extent practical, commercial passenger service operations at individual risk levels above this level.	Guidance: Transport airplanes should not operate in commercial passenger service above this individual risk level for any period.

Notes:

1. Use the fatalities guideline when the *EO* value is 150 or above. Use weighted events guidelines when the *EO* value is less than 150.
2. Accomplish corrective action as soon as reasonably practical within the time associated with the appropriate Control Program-Fleet Risk guideline. The risk level guidance represents the maximum acceptable risk level, not a target value.
3. If the control program is to prevent a second catastrophic accident on a passenger airline flight, use 1 fatality or 0.0067 for the initial response control programs

8.2 Risk Guidelines Development

The risk guidelines in this handbook address the requirements of FAA Order 8110.107B. The guideline values reflect the FAA's risk-management policies to the extent possible.

9 SUGGESTIONS FOR IMPROVEMENT

It is important that users of this handbook make recommendations for improving the risk analysis methodology and risk level guidelines contained in it, especially in situations that are difficult to analyze using this guidance. Send user comments, suggestions, and other feedback to AIR-633 at AIR-633-FED@faa.gov.

Appendix A. – Definitions and Acronyms[10]

AIDS - Accident Incident Database System, an aviation database available to all FAA employees through ASIAS or ASPIRE.

Ascend - A trademarked aviation database program available through ASIAS. Formerly known as Airclaims™.

ASE - Aviation Safety Engineer.

ASIAS - Aviation Safety Information Analysis and Sharing, an aviation database repository providing access to a variety of aviation databases, including AIDS, Ascend, SDRS, and the NTSB database.

ASPIRE - Analyze Safety Performance Insight Results Environment

CARB - Corrective Action Review Board. As defined and chartered in FAA Order 8110.107B, this Board makes safety and corrective action decisions.

Certification Branch - References to the "certification branch" include branches and paragraphs responsible for performing operational safety, continued operation safety (COS), certification, or validation branches in the Integrated Certificate Management Division (AIR-500) or Compliance and Airworthiness Division (AIR-700).

Control Program - The actions and schedule required to correct or mitigate the risk of an unsafe condition. The control program typically consists of three segments: Corrective Action Development (CAD), Rulemaking Time (RT), and Compliance Time (CT).

COS - Continued Operational Safety. The means and methods the FAA uses to assure that type-certified airplanes remain safe while in service. FAA Order 8110.107B defines and requires a standardized COS process for use throughout the FAA Aircraft Certification Service.

Condition Under Study - The base (initiating) condition in a risk analysis.

Error - An omission or incorrect action by a flightcrew member or maintenance personnel, or a development error (for example, 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 - In this handbook, the term exposure normally refers to airplane fleet exposure to a condition, usually expressed in either flight hours or flight cycles. It can also refer to the exposure of the occupants of individual airplanes and/or persons on the ground to the effects of an Unsafe Outcome.

Failure[11] - An occurrence which affects the operation of a component, part, or element such that it can no longer function as intended. This includes both malfunction and loss of function.

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[10] See section 5.4 for risk variable definitions.

[11] Errors and events may cause failures or influence their effects, but they are not, themselves considered failures.

Fatal Injury Ratio - Determined from historical data, the single-event probability that persons exposed to an Unsafe Outcome will suffer fatal injury.

Fleet - As used in this handbook, 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 for consideration together in a risk analysis. The term can refer to all transport-category airplanes or a subset of airplanes of a particular model.

IAR - Immediately Adopted Rule.

ICAO - International Civil Aviation Organization.

Latent - A failure that is not detected or annunciated when it occurs.

LOV - Limit of Validity. As defined by 14 CFR 26.21: the period of time, stated as a number of total accumulated flight cycles or flight hours or both, during which it is demonstrated that widespread fatigue damage will not occur in the airplane. Operation past the limit of validity is not permitted.

Residual Risk - The risk, associated with a condition that remains after a control program is implemented.

Risk - A generic expression that combines the probability and *S* of a given outcome.

Risk Value - The result of the risk analysis for a particular risk level addressing Total Uncorrected Fleet Risk, Uncorrected Individual Risk, Control Program Fleet Risk, Control Program Individual Risk, and time until the Control Program Risk Guideline is reached.

Safety -The absence of unacceptable risk of harm.

Safety Issue - Cause(s), contributing factor(s), or finding(s) that led to, or could lead to, an Unsafe Outcome.

Severity - As used in this handbook, the effect of a condition or outcome on the occupants of an airplane and persons on the ground.

SMS - Safety Management System.

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

Unsafe Outcome - A condition or outcome that has a known or knowable probability of resulting in fatality(s), i.e., for which a *FIR* is known or can reasonably be estimated.

Weibull - A failure-distribution-analysis methodology used in calculating the number of occurrences in wear-out analyses.

Weibayes - A means by which to assume a value for the shape parameter (β), used in performing a meaningful analysis in the event insufficient failure data is available to calculate η and β parameters used in defining the failure distribution in a two-parameter Weibull.

Appendix B. – TARAM Worksheets

The following pages contain worksheets to guide and document the TARAM risk analysis. They break down each major step used in determining the risk values —Total Uncorrected Feet Risk, Total Uncorrected Individual Risk, 90-day Fleet Risk, MTCP, Control Program Fleet Risk, and Control Program Individual Risk.

Use TARAM Worksheet part 2 to document and communicate the source and/or derivation of the data used, the assumptions and engineering judgments involved, and resulting analytical decisions. Each subject line on TARAM Worksheet part 2 can (and if necessary, should) be expanded to document clearly the engineering thought process used in each step. The documentation should be sufficient for knowledgeable engineer to understand the analysis. Attach additional pages as needed.

Example B.1: Risk Analysis Constant Failure Rate Worksheet – Part 1

Risk Analysis Constant Failure Rate Worksheet Part 1

CONDITION DESCRIPTION	PROBABILITY					SEVERITY	
	FREQUENCY OF OCCURRENCE					FATAL INJURY RATIO	EXPOSED OCCUPANTS
	F	F_I	F_{90}	F_C	F_{CI}	*FIR*	*EO*
	UTILIZATION					UNSAFE OUTCOME DESCRIPTION	
	U	U_{90}	U_C				
	NUMBER OF AIRPLANES						
	Σ	Σ_{90}	Σ_C				
AFFECTED AIRPLANES (models)	TIME						
	T	T_{90}	T_C				
	CONDITIONAL PROBABILITY (*CP*)						
	CP	CP_I	CP_{90}	CP_C	CP_{CI}		

RISK ANALYSIS CONSTANT FAILURE RATE WORKSHEET

RISK VALUES	*R = Probability x Conditional Probability x Severity*	VALUE	GUIDELINE	NOTES
Total Uncorrected Fleet Risk (fatalities or weighted events)	$R_{Tf} = [F \times U \times \Sigma \times T] \times [CP] \times [FIR \times EO]$ $R_{Twe} = [F \times U \times \Sigma \times T] \times [CP] \times [FIR]$		3 .02	
Uncorrected Individual Risk (fatal injury per flight hour)	$R_I = [F_I] \times [CP_I] \times [FIR]$		1E-7	
90-Day Fleet Risk (fatalities or weighted events)	$R_{90} = [F_{90} \times U_{90} \times \Sigma_{90} \times T_{90}] \times [CP_{90}] \times [FIR \times EO]$			
Management Time for Control Program (days)	Iterative Solution (See paragraph 6.14.6)			
Control Program Fleet Risk (fatalities or weighted events)	$R_{Cf} = [F_C \times U_C \times \Sigma_C \times T_C] \times [CP_C] \times [FIR \times EO]$ $R_{Cwe} = [F_C \times U_C \times \Sigma_C \times T_C] \times [CP_C] \times [FIR]$		See table 3	
Control Program Individual Risk (fatal injury per flight hour)	$R_{CI} = [F_{CI}] \times [CP_{CI}] \times [FIR]$		See table 3	

Example B.2: Risk Analysis Constant Failure Rate Worksheet – Part 2

Risk Analysis Constant Failure Rate Worksheet Part 2		
RISK VARIABLE	**SOURCE(S)**	**DESCRIPTION, ASSUMPTIONS, and/or CONSIDERATIONS**
Condition Under Study		
Unsafe Outcome/Fatal Injury Ratio (*FIR)*		
Affected Airplanes		
Frequency (*F*)		
Utilization (*U*)		
Number of Airplanes (Σ)		
Time (*T*)		
Conditional Probability (*CP*)		
Exposed Occupants (*EO*)		
Total Uncorrected Fleet Risk (R_t)		
Uncorrected Individual Risk (R_I)		
MTCP		
Control Program Fleet Risk (R_C)		
Control Program Individual Risk (R_{CI})		

Example B.3: Wear-Out Failure Worksheet – Part 1

Wear-Out Failure Worksheet Part 1

CONDITION DESCRIPTION	PROBABILITY						SEVERITY	
	Not Detected	Defect Airplanes	Defect Airplanes 90-Day	Defect Airplanes Control Program	Hazard Function	Control Program Hazard Function	FATAL INJURY RATIO	EXPOSED OCCUPANTS
	ND	*DA*	DA_{90}	DA_C	h_I	h_C	*FIR*	*EO*

CONDITION DESCRIPTION (cont.)	(UTILIZATION (*U*))			UNSAFE OUTCOME DESCRIPTION
	U	U_{90}	U_C	
	(NUMBER OF AIRPLANES (Σ))			
	Σ	Σ_{90}	Σ_C	
AFFECTED AIRPLANES (models)	(TIME (*T*))			
	T	T_{90}	T_C	

AFFECTED AIRPLANES (cont.)	CONDITIONAL PROBABILITY (*CP*)					UNSAFE OUTCOME DESCRIPTION (cont.)
	CP	CP_I	CP_{90}	CP_C	CP_{CI}	

WEAR-OUT WORKSHEET

RISK VALUES	*R = Probability x Conditional Probability x Severity*	VALUE	GUIDELINE	NOTES
Total Uncorrected Fleet Risk (fatalities or weighted events)	R_{Tf} = [ND x DA] x [CP] x [FIR x EO] R_{Twe} = [ND x DA] x [CP] x [FIR]		3 0.02	
Uncorrected Individual Risk (fatal injury per flight hour)	R_I = [ND x h_I] x [CP_I] x [FIR]		1E-7	
90-Day Fleet Risk (fatalities or weighted events)	R_{90} = [ND x DA_{90}] x [CP_{90}] x [FIR x EO]			
Management Time for Control Program (days)	Iterative Solution (See paragraph 6.14.6)			
Control Program Fleet Risk (fatalities or weighted events)	R_{Cf} = [ND x DA_C] x [CP_c] x [FIR x EO] R_{Cwe} = [ND x DA_C] x [CP_c] x [FIR]		See table 3	
Control Program Individual Risk (fatal injury per flight hour)	R_{CI} = [ND x h_{CI}] x [CP_{CI}] x [FIR]		See table 3	

Example B.4: Wear-Out Failure Worksheet – Part 2

Wear-Out Failure Worksheet Part 2		
Risk Variable	Source(s)	Description/Assumptions/ Individual Risk Considerations
Utilization (*U*), Number of Airplanes (Σ), Time (*T*)		
Conditional Probability (*CP*)		
Exposed Occupants (*EO*)		
Total Uncorrected Fleet Risk (R_{Tf} or R_{Tfr})		
Uncorrected Individual Risk (R_I)		
Management Time for Control Program (MTCP)		
Control Program Fleet Risk (R_{Cf} or R_{Cfr})		
Control Program Individual Risk (R_{CI})		

Appendix C. – Examples

C.1 CONSTANT FAILURE RATE EXAMPLE

C.1.1 MSAD Potential Safety Issue

C.1.1.1 A certification branch received a 14 CFR 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 determined to be a capacitor that short-circuited in the control box. The PECU design was determined to be the cause of the short circuit during the investigation.

C.1.1.2 As part of the MSAD process, the report was determined to be a potential safety issue and was assigned to an 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 this one case burned through the container, potentially igniting adjacent flammable materials.

C.1.1.3 Due to the observations, the preliminary risk assessment revealed a significant likelihood of a capacitor failure resulting in an uncontrolled fire in-flight, and potentially an uncontrolled crash, and that the investigation should continue through the MSAD process risk-analysis step.

C.1.2 Condition Under Study and Unsafe Outcome Description

The ASE entered "PECU capacitor short-circuited" in the worksheet's Condition Description field, and "Uncontrolled Crash" in the Unsafe Outcome description field.

C.1.3 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 (date of the ninth PECU capacitor short-circuit). ACME determined that the fleet had approximately 8,640,000 flight hours to date. The ASE then determined *F* of PECU capacitor short-circuits to be:

> 9 PECU capacitor short-circuits per 8,640,000 flight hours = 1.04E-6 PECU short-circuits per flight hour

Because there was no known failure, operational, or maintenance issue that would elevate the risk associated with the capacitor failures on specific flights, 1.04E-6 PECU capacitor short-circuits per flight hour is also entered on the worksheet for the individual-risk frequencies.

C.1.4 Time (*T*), Number of Airplanes (Σ), and Utilization (*U*)

C.1.4.1 ACME also provided the ASE with Model 10P airplane data. ACME expects the 10P to be in production for another 3 years and the 10P has an average retirement age of 30 years. The model will fly another 33 years (3 production years + 30 retirement years for the last airplanes produced), which equals 12053 days, the value listed in the worksheet's *T* field.

C.1.4.2 ACME has designed and ordered kits containing replacement circuit boards and is preparing engineering instructions. Both are scheduled to be available to correct the problem within one year. They have also 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 all occur 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) (the average incorporation time) = 2 years = 730.5 days, the value that is entered in the worksheet's Time (T_C) field.

C.1.4.3 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 335 airplanes; this is the value entered in the worksheet's Number of Airplanes (Σ) field. They also note, at the time of analysis, that the 10P fleet has 562 airplanes. Those values were entered in the worksheet Number of Airplanes (Σ_{90}) and (Σ_C) fields.

C.1.4.4 To determine some of the values necessary for the analysis, the ASE used ASPIRE. From ASPIRE, the ASE determined that the average utilization of the ACME 10P is 2.1 hours per day and entered that value in the worksheet *U* field.

C.1.5 Management Time for Control Program (*MTCP*)

Sales have slowed for the 10P model, and the expected production rate will equal the retirement rate at least until the end of production (3 years). Accordingly, the first iteration in the calculation of *MTCP* used 562 airplanes as the fleet size. Because the time calculated for *MTCP* was fewer than 3 years, no further iterations were necessary. If the time calculated using 704 airplanes had been greater than 3 years, further iterations would have been necessary because the fleet size will decline with time after that period.

C.1.6 Conditional Probability (*CP*), Fatal Injury Ratio (*FIR*), and Exposed Occupants (*EO*)

C.1.6.1 The Condition Under Study chosen was PECU capacitor short-circuited with its associated *F*. The *CP* must include all conditions and their probabilities in the causal chain from the Condition Under Study resulting in the Unsafe Outcome (Uncontrolled Crash). The probability of a PECU capacitor short-circuit burning through the case is 1 out of 9, or 0.11. Using engineering judgment and discussion with senior ASEs, the estimation of *CP* for PECU-case burn-through resulted in an uncontrolled in-flight fire of 0.05 (1 fire (assumed) per 20 case burn-throughs). The ASE also determined that accumulated dust and other potentially flammable materials are often found in the area where the PECUs are mounted in the Model 10P airplane and that the units are not readily accessible to the cabin crew in the event of a fire. Because of this, the ASE determined an uncontrolled in-flight fire would lead to an uncontrolled crash with a *CP* of 0.9. These *CPs* multiplied together are recorded as the *CP* = 0.005 in the worksheet.

C.1.6.2 The ASE used the Injury Ratio Document to determine that the FIR for an Uncontrolled Crash is 0.68 and entered that value in the worksheet's *FIR* field.

C.1.6.3 The ASE used ASPIRE, as previously noted, to find the average seat configuration for the ACME 10P. The average seat count is 74, with provision for a 4-person flight crew, so the average carriage is 78; the number entered in the worksheet's *EO* field.

C.1.6.4 All the data and determinations described above were documented on the ACME Model 10P PECU-depicted in Example C.1. Constant Failure Rate Worksheet.

Example C.1: Constant Failure Rate Worksheet

Constant Failure Rate Worksheet

CONDITION DESCRIPTION	PROBABILITY	SEVERITY
PECU capacitor short-circuited in the control box. Causal chain info: PECU capacitor short-circuit, then case burn-through (1 out of 9), then a non-fightable, in-flight fire (1 out of 4), then uncontrolled crash (9 out of 10)	See probability tables below	See severity table below

FREQUENCY OF OCCURRENCE (F)

F	F_I	F_{90}	F_C	F_{CI}
1.04E-6	1.04E-6	1.04E-6	1.04E-6	1.04E-6

UTILIZATION (U)

U	U_{90}	U_C
2.1	2.1	2.1

NUMBER OF AIRPLANES (Σ)

Σ	Σ_{90}	Σ_C
335	562	562

TIME (T)

T	T_{90}	T_C
12053	90	730.5

CONDITIONAL PROBABILITY (CP)

CP	CP_I	CP_{90}	CP_C	CP_{CI}
0.005	0.005	0.005	0.005	0.005

SEVERITY

FATAL INJURY RATIO	EXPOSED OCCUPANTS
IR	EO
.68	78

UNSAFE OUTCOME
Uncontrolled Crash

AFFECTED AIRPLANES (Models)
ACME Airplane Company, Inc. Model 10P

Constant Failure Rate Worksheet

RISK VALUES	*R = Probability x Conditional Probability x Severity*	VALUE	GUIDELINE	NOTES
Total Uncorrected Fleet Risk (fatalities or weighted events)	$R_{Tf} = [F \times U \times \Sigma \times T] \times [CP] \times [FIR \times EO]$ $R_{Twe} = [F \times U \times \Sigma \times T] \times [CP] \times [FIR]$	R_{Twe} =0.03	3 0.02	Total Uncorrected Fleet Risk exceeds the fleet risk guideline of 0.02
Uncorrected Individual Risk (fatal injury per flight hour)	$R_I = [F_I] \times [CP_I] \times [FIR]$	3.5E-9	1E-7	Uncorrected Individual Risk is below the guideline of 1E-7
90-Day Fleet Risk (fatalities)	$R_{90} = [F_{90} \times U_{90} \times \Sigma_{90} \times T_{90}] \times [CP_{90}] \times [IR \times EO]$	0.029	N/A	Used as an urgency and priority measure by the transport standards staff.
Management Time for Control Program (days)	*Iterative Solution (See paragraph 6.14.6)*	400 Days	N/A	This value helps manage end-to-end issue resolution.
Control Program Fleet Risk (fatalities or weighted events)	$R_{Cf} = [F \times U_C \times \Sigma_C \times T_C] \times [CP_C] \times [FIR \times EO]$ $R_{Cwe} = [F \times U_C \times \Sigma_C \times T_C] \times [CP_C] \times [FIR]$	0.003	See table 3	Weighted events-based Control Program Fleet Risk is very close to the guideline of 0.02.
Control Program Individual Risk (fatal injury per flight hour)	$R_{CI} = [F_{CI}] \times [CP_{CI}] \times [FIR]$	3.5E-9	See table 3	Uncorrected Individual Risk is below the guideline of 1E-7

C.1.7 Risk Level Considerations. Based on the facts associated with the PECU-capacitor-failure potential safety issue and the associated TARAM risk analysis, the value of the Total Uncorrected Fleet Risk, it appears that the condition is a safety issue. Since the risk is not significantly above the guideline, other mitigating considerations could reduce the risk to an acceptable level and affect the ASE/certification branch's corrective action recommendation to the CARB. Because there are no such considerations, the issue appears to warrant corrective action mandated by AD following a Notice of Proposed Rulemaking.

C.2 WEAR-OUT EXAMPLE

C.2.1 MSAD Potential Safety Issue

C.2.1.1 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.

C.2.1.2 Two additional MSAD reports were received later regarding cracks in two additional airplanes. They, too, were found by evidence of a fuel leak.

C.2.1.3 The ASE assigned to these records believes that it is a potential safety issue and is performing a TARAM risk analysis.

C.2.2 Condition Under Study and Unsafe Outcome(s)

C.2.2.1 The analyst described the Condition Under Study 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 event are descriptions entered on the TARAM worksheet.

C.2.2.2 The Unsafe Outcome, as described by the analyst, was associated with 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 caused by structural failure from fatigue cracking attest to this.

C.2.2.3 The risk that TARAM is estimating relates to a specific airplane's Unsafe Outcome with known *FIR*. Do not end the analysis at an intermediate condition prior to reaching an Unsafe Outcome for which an *FIR* is known or estimated. TARAM risk values should be the best estimate of the actual risk, not conservatively overestimated.

C.2.2.4 The causal chain for this potential safety issue is shown below. The expected number of occurrences of the Condition Under Study, and the various *CPs* between the Condition Under Study and the Unsafe Outcome, would not be known when first constructing the causal chain (whether formally or just in your head), but those statistical values are shown here for a complete illustration.

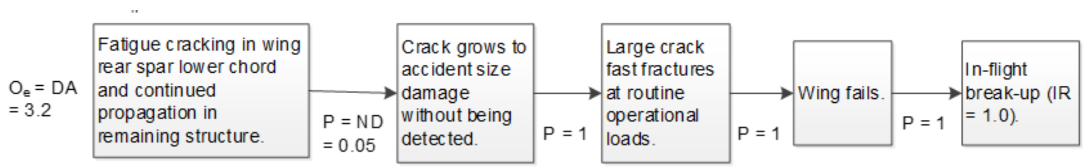

Figure 7. Causal Chain for Potential Safety Issue

C.2.3 Determine Exposure Factors

C.2.3.1 The Number of Airplanes, their age, and their utilization were obtained from ASPIRE. Similar information was also received from the Aves Airplane Company. Either source can be used in the analysis.

C.2.3.2 For wear-out problems, T is not used directly in determining risk as is done in constant-failure-rate problems. This is due to the risk of failure being a function of T in wear-out problems, so using exposure multiplied by a constant failure rate is inappropriate. For wear-out, the risk forecast is performed accounting for each airplane's age, and the length of time (Δt) between the airplane's current age and the end of the analysis period being analyzed (retirement of the airplane, 90 days, or the average control-program implementation time).

C.2.3.3 Average utilizations of 2.4 flights per day and 6.4 flight-hours per day were obtained from ASPIRE, but these averages were not used in the risk calculation. When analyzing a wear-out issue, the analyst could use each airplane's utilization, rather than the fleet average utilization, when performing the failure forecast to determine Δt for that airplane. This can also be done using the various Weibull computer applications that are available, along with the appropriate data entry.

C.2.4 Determine Failure Mode, Select TARAM Worksheet

C.2.4.1 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.

C.2.4.2 When performing the risk analysis, a consistent 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 analysis both ways, selecting the time unit that yields the best correlation to the observed failures. If a fleet is extremely sensitive to utilization, the fleet could be analyzed in groups of similar utilization, and the risk values summed to obtain the total fleet risk, although this typically will not be necessary.

C.2.4.3 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 per day and flight-hours per 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.2.5 Determine Distribution Factors (*ND*, *DA,* and Hazard Function (h_T))

C.2.5.1 *ND* is one of the parameters used in the TARAM analysis of airplane structural fatigue issues. *ND* is the probability that a defect (fatigue crack) will not be detected before the defect leads to an airplane-level Unsafe Outcome, or an obvious major structural or component failure (5.6.8). *ND* is just another *CP* but is defined separately because of its importance in structural-fatigue wear-out issues.

C.2.5.2 Analysts may tend to be conservative in their estimates of *ND*. Historically, almost all fatigue cracks are discovered before they lead to an accident. This is indicative that *ND* typically is a very small fraction, much less than 1.0. 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 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 the cracks were found by ramp personnel seeing evidence of a fuel leak (seepage, or wet or dry stains).

C.2.5.3 In some cases, ND will be close to 1.0. For example, if the crack-growth time from a detectable crack to critical crack length is short, and a directed inspection is needed to find the crack, but the directed inspection is not currently being performed, ND would be close to 1.0.

C.2.5.4 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?

C.2.5.5 If we suspect that the estimated value of ND is overly conservative, which is a typical mistake, a validation of service history should be performed (see paragraph 6.14.11). In this test, the same assumptions and parameters that are used in the risk analysis are used (same eta, beta, CP, and FIR), but instead of predicting future risk, the analysis is performed to see if it can accurately predict history, e.g., from the delivery of the first affected airplane until today. If there have been no accidents, and the predicted expectation using the historical validation analysis is for greater than 0.50 accidents, it is likely that the analysis is conservative. It is certainly conservative if the test predicts multiple accidents when none has occurred. If the test shows that the analysis is conservative, review ND and the other analysis parameters and assumptions, and remove any conservatism or mistakes found.

C.2.5.6 For this issue, all three cases were found by the discovery of evidence of a fuel leak. As a result, 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), 1 in 50 (0.02), etc.

C.2.5.7 For the analysis of this issue, ND is the same for all three risk-factor calculations (life of the fleet, 90 days, and control program). This is typical. ND would only differ between the different analysis periods if the existing maintenance program was changing in a significant way with time. Because Control Program Fleet Risk is the risk that accumulates among the uncorrected airplanes while the control program is phased in, the control program ND is not different from the other NDs. The phase-in effect is accounted for in DA.

C.2.5.8 <u>Defect Airplanes (DA)</u>

C.2.5.8.1 *DA* is the predicted number of airplanes that would have the subject failure, if left undetected, during the time being analyzed. For the uncorrected fleet risk, *DA* uses 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 would typically be less than *DA*.

C.2.5.8.2 To obtain *DA*, the fleet information is entered into a risk-analysis program such as an Excel worksheet. To calculate the predicted number of failures over a time interval Δt, for a two-parameter

- Weibull the failure forecast formula used to calculate *DA* is:

  $DA = \Sigma\, [F\,(t_i+\Delta t) - F\,(t_i)] \,/\, [1-F\,(t_i)]$

- For a three-parameter Weibull the formula is:

  $DA = \Sigma\, [F\,(t_i+\Delta t - \gamma) - F\,(t_i - \gamma)] \,/\, [1-F\,(t_i - \gamma)]$

C.2.5.8.3 Where the summation is over the airplanes are still subject to the failure that have survived (no failure) to time t_i. In the case of the three-parameter Weibull, the summation is only over those airplanes where it is greater than γ. In other words, the probability they will fail during the time interval, given that they have not failed yet. With only three failures, a Weibayes analysis was performed using a beta of 4 (the spar chord is aluminum).

C.2.5.8.4 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 using either the two or three-parameter Weibull failure forecast formula. A similar calculation is performed for the 90-day Fleet Risk (DA_{90}), and the Control Program Fleet Risk (DA_C), using the Δt for those risk values (90 days for DA_{90} and the control-program time for DA_C).

C.2.5.8.5 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: The analysis of this issue is not very sensitive to this estimate. If the time that the cracks were discovered was 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 were entered as the failure times, the characteristic life would be calculated to be 64,180 flights.

C.2.5.8.6 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.

C.2.5.8.7 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 normalizes the analysis to an accident, instead of to an intermediate state, for example, a 3-inch spar-chord crack. Second, it allows the use of additional suspension data. If the analysis was performed based on the discovered 3-inch crack lengths, and because the remaining fleet has not been inspected, it is unknown if they have any cracks or not. However, because the Weibull analysis is normalized to accident-critical damage size, it is a known fact that the remaining fleet has not been involved in accidents, so the remaining uninspected aircraft in the fleet can likewise be entered into the Weibull analysis program as suspensions at their current age. If some of the aircraft had been inspected and found crack-free, they could have been entered as suspensions by adding to the airplane's current age, the time to grow from a detectable crack to an accident-critical length crack.

C.2.5.9 <u>Hazard Function</u>

Use the hazard function when calculating both Uncorrected Individual Risk and Control Program Individual Risk. Because the individual risk increases with airplane age, the hazard function is largest for the oldest airplane at the end of the applicable period (at airplane retirement for Uncorrected Individual Risk, and at the end of the control program for Control Program Individual Risk). You can calculate the hazard function from the formula:

- For a two-parameter Weibull: $h(t) = (\beta / \eta)\,(t / \eta)^{\beta-1}$ or
- For a three-parameter Weibull: $h(t) = (\beta / \eta)\,((t - \gamma) / \eta)^{\beta-1}$

If you are not using a two-parameter Weibull for the failure distribution, use the appropriate formula for the hazard function. All statistical distributions such as Weibull, lognormal, extreme value, etc., that are regularly used in risk analysis have a defined hazard function that can be calculated in any statistical application (or programmed in Excel). If necessary, the hazard function can be calculated numerically using the formula:

$$h(t) = \lim (\Delta t \rightarrow 0)\ \{[F(t_i+\Delta t) - F(t_i)] / [1-F(t_i)]\} / \Delta t$$

C.2.6 Determine Unsafe Outcome Factors

Our "Condition Under Study" fatigue cracking in the wing leads directly (if undetected) to the Unsafe Outcome (in-flight breakup), so the *CP* = 1.0. This example looked at the condition of massive structural failure leading to an in-flight breakup. If other Unsafe Outcomes were envisioned, e.g., fire/uncontrolled crash, fuel exhaustion/controlled crash, then *CP*s could be estimated based on the percentage of the time that Unsafe Outcome would be expected. Additional *CPs* can be included as needed. This cargo airplane has a crew of two but often supernumeraries are aboard. On average, the *EO* is estimated to be four (4).

C.2.7 Calculate MTCP

The calculation of MTCP is non-linear, and an iterative trial-and-error type of solution method is recommended. In this example, it is non-linear from two separate influences. First, the fleet size is shrinking due to retirements in a non-linear fashion (with respect to time), and second, the hazard function increases non-linearly with time. The affected fleet was entered into a spreadsheet tool and the MTCP was iterated until the weighted events-based control-program risk guideline was reached. The resulting MTCP is 782 days. To start the iterative process, a first guess of (*EO**0.04*90)/(R90) = 848 days was used. That resulted in exceeding the control-program risk guideline, so the first guess was reduced for the next iteration. The solution quickly converged to 782 days.

C.2.8 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 Total Uncorrected Fleet Risk (0.17) and Uncorrected Individual risk (2.2E-6) are above the guidelines (0.04 and 1E-7, respectively), indicating that this is a safety issue from both perspectives.

C.2.9 Risk Level Considerations

The Control Program Fleet Risk (0.037) is below the guideline (0.040), indicating that it is an acceptable control program from a fleet risk perspective. The Control Program Individual Risk (1.9E-6) is above the urgent-action guideline (1E-6) for airplanes operated primarily in passenger service, in which case an IAR should be considered. Because this is a freighter model, there is no control-program individual-risk guideline. However, the Control Program Individual Risk is above 1E-6, and because almost one airplane (DAC = 0.70) is expected to develop significant-sized damage (if not detected) during the proposed control program, an IAR for inspection should be considered. This example illustrates how individual risk and fleet risk are separate measures that both need to be calculated and the guidelines considered during safety decision-making. Although the MTCP is 782 days, if this was a fleet used in commercial passenger service, the MTCP would be overshadowed by the high individual risk and the corresponding guidance for urgent action, e.g., an IAR.

Example C.2: Wear-Out Worksheet

Wear-Out Worksheet

CONDITION DESCRIPTION		
Fatigue cracking in the wing rear spar lower chord and continued propagation in the remaining structure.		
AFFECTED AIRPLANES (Models)		

PROBABILITY

Not Detected	Defect Airplanes	Defect Airplanes 90-Day	Defect Airplanes Control Program	Hazard Function	Control Program Hazard Function
ND	*DA*	DA_{90}	DA_C	*h*	h_C
0.05	**3.2**	**0.08**	**0.70**	**4.2E-5**	**3.5E-5**

SEVERITY

FATAL INJURY RATIO	EXPOSED OCCUPANTS
FIR	*EO*
1.0	**4**

UTILIZATION

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

NUMBER OF AIRPLANES

Σ	Σ_{90}	Σ_C
53	**53**	**53**

TIME

T	T_{90}	T_C
15,705 (43yr life)	**90**	**726**

CONDITIONAL PROBABILITY

CP	CP_I	CP_{90}	CP_C	CP_{CI}
1	**1**	**1**	**1**	**1**

UNSAFE OUTCOME DESCRIPTION

In-Flight Breakup due to fatigue cracking in the wing rear spar lower chord and continued propagation in the remaining structure resulting in the inability of the wing structure to react to routine flight loads.

WEAR-OUT WORKSHEET

RISK VALUES	*R = Probability x Conditional Probability x Severity*	VALUE	GUIDELINE	NOTES
Total Uncorrected Fleet Risk (fatalities or weighted events)	R_{Tf} = [ND x DA] x [CP] x [FIR x EO] R_{Twe} = [ND x DA] x [CP] x [FIR]	R_{Twe} = **0.16**	3 0.02	Above the fleet risk guideline of 0.02 indicating a safety issue
Uncorrected Individual Risk (fatal injury per flight hour)	R_I = [ND x h_I] x [CP_I] x [FIR]	**2.1E-6**	1E-7	Above the individual risk guideline of 1E-7/hour indicating a safety issue
90-Day Fleet Risk (fatalities)	R_{90} = [ND x DA_{90}] x [CP_{90}] x [FIR x EO]	**0.017**	N/A	
Management Time for Control Program (days)	Iterative Solution (See paragraph 6.14.6)	**782**	N/A	Because EO is less than 150, MTCP was based on the weighted events based uncorrected fleet risk calculation
Control Program Fleet Risk (fatalities or weighted events)	R_{Cf} = [ND x DA_C] x [CP_c] x [FIR x EO]- R_{Cwe} = [ND x DA_C] x [CP_c] x [FIR]	**0.035**	See table 3	The guideline is 0.040 so the control program is acceptable.
Control Program Individual Risk (fatal injury per flight hour)	R_{CI} = [ND x h_C] x [CP_{CI}] x [FIR]	**1.8E-6**	See table 3	Above the individual risk guideline of 1E-7/hour indicating a safety issue and slightly above the level indicating that urgent action might be necessary.