# FAA Monitor Safety Analyze Data Risk Analysis Methodology

Federal Aviation Administration

2011 Aircraft Airworthiness and Sustainment

San Diego, CA

April 18-21, 2011

***Updated for EASA Briefing on March 12, 2014 to Address Systems Aspects***

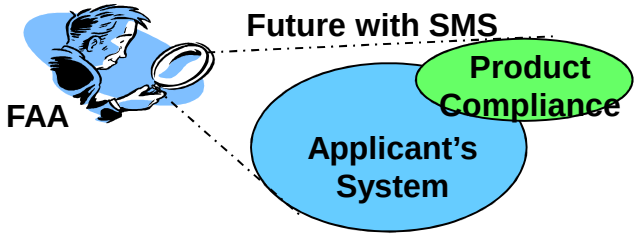
***Dan Withers***

# FAA Monitor Safety Analyze Data Risk Assessment Methodology

## Outline

- Monitor Safety Analyze Data (MSAD)
- Risk Assessment Method used by Small Airplane Directorate for Aging Aircraft and Systems Issues
- Risk Assessment Example

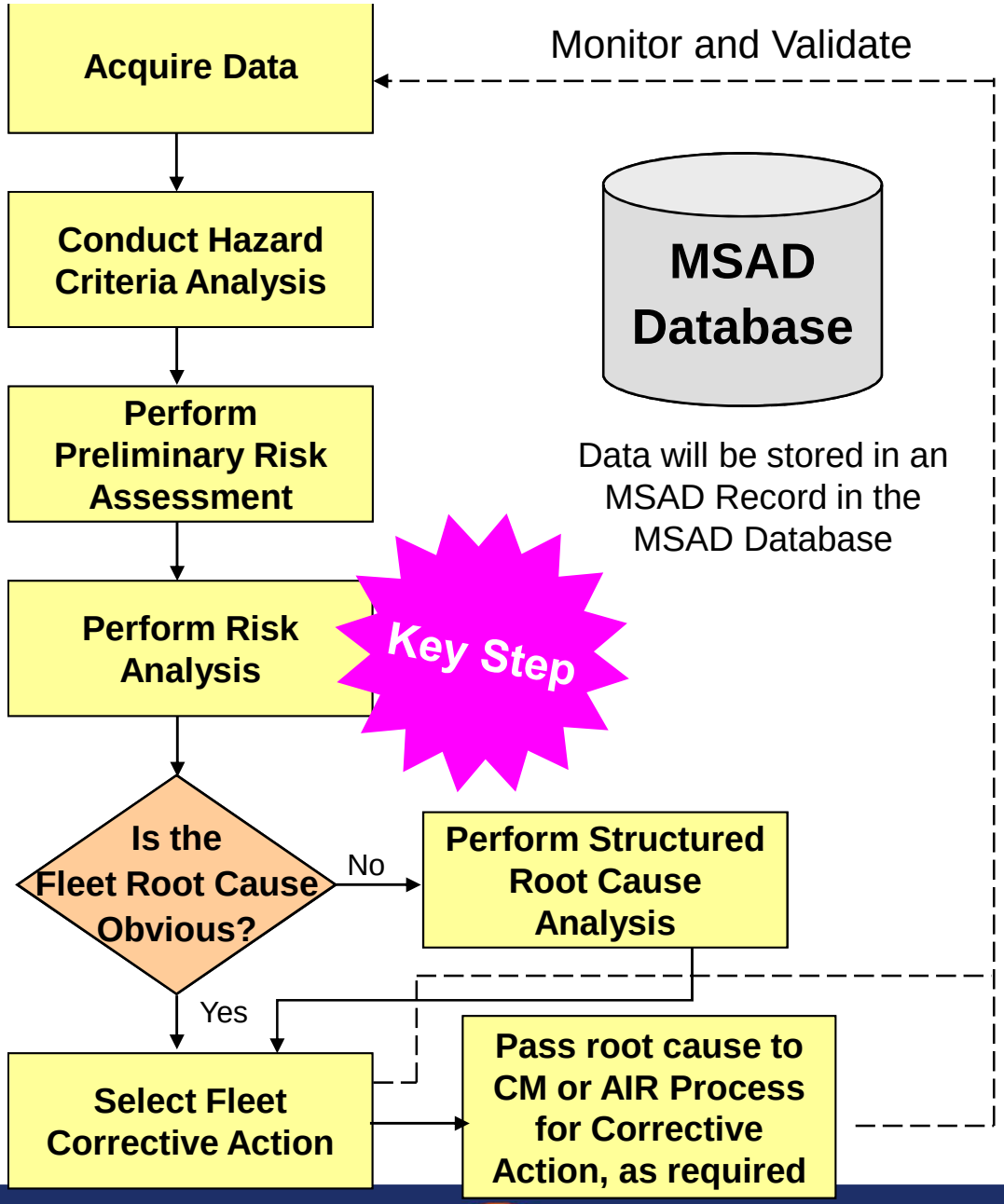
# FAA Safety Management System (SMS)




| Process | Was → | Will Be |
|---|---|---|
| Risk Analysis Specification | Subjective | Corporately baselined |
| Risk-Based Resource Targeting | Personal assessment | Corporate, standardized approach to resource allocation |
| Designee Management | Locally focused | Corporate, risk-based approach to designees |
| Design/Production Approval | Stovepiped | Integrated / standardized |
| Applicant SMS | Non-existent | Applicant system based |
| Oversee Systems Performance | Tactical/specific | Integrated / Strategic / Global |
| Monitor Safety & Analyze Data | Reactive fixes | Reactive/Proactive / systems approach |
| Certificate Management | Production audit system | Design / production system - oversight |
| Staffing and Budget | Subjective | Need identified by system |

# MSAD Process Flow

- Process generally flows from top to bottom
- Industry may take part/perform some activities
- Some activities will be conducted in parallel
- ASE may not go all the way through the process in some cases (i.e. risk determined not actionable)



# Small Airplane Risk Assessment (SARA)

# Small Airplane Risk Assessment (SARA)

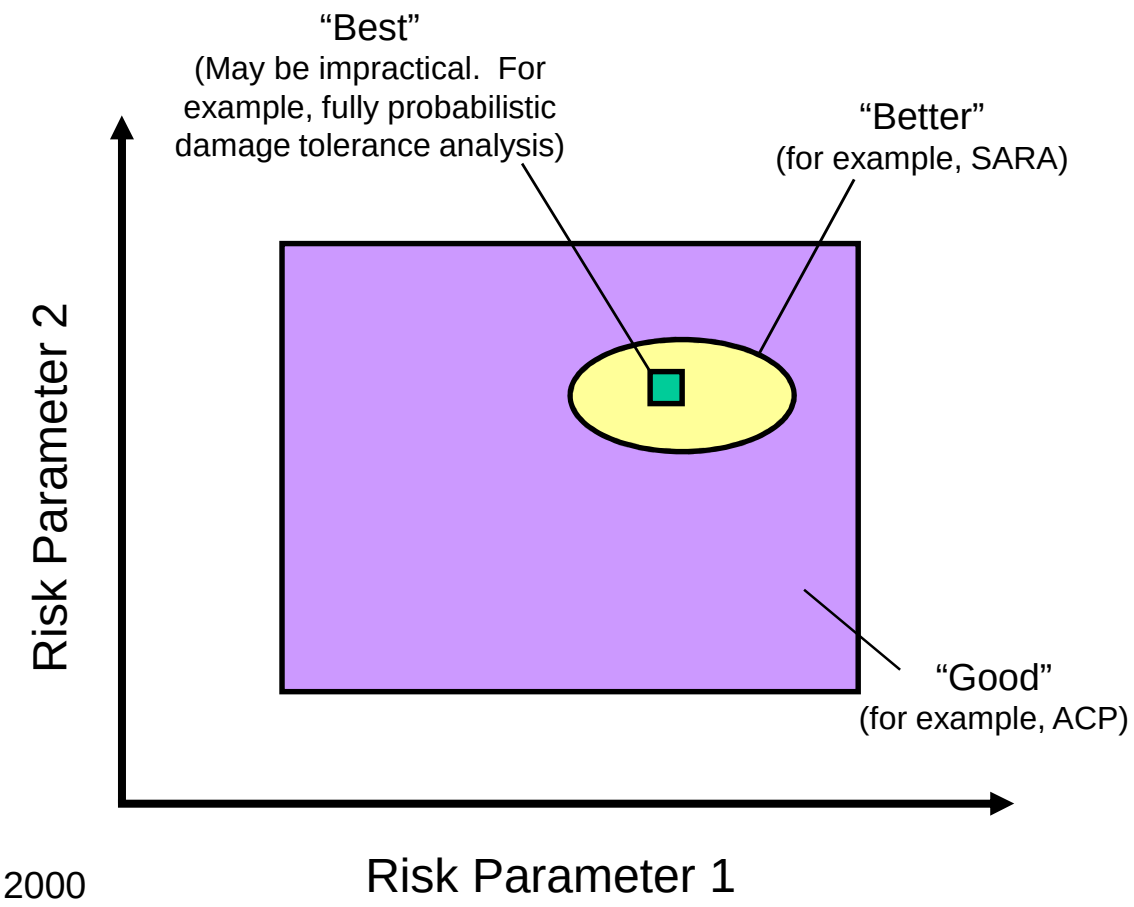
## Purpose and Intent for the tool

- The FAA will use risk analysis as a tool in making continued operational safety (COS) decisions.
- The risk analysis should:
  - be as quantitative as possible
  - define risk in terms of the expected frequency of failures and the probability that those failures will lead to undesired outcomes
  - evaluate candidate control programs by the risk reduction they provide.

# SARA Goals

## Accuracy of Risk Analysis Methods

**Comment on Accuracy**




ACP – Airworthiness Concern Process 2000

# SARA Basics

## Types of Risk Analysis

- **Random (Constant rate) failures**
  - Parts are equally likely to fail regardless of their age
  - Typically used by Mechanical & Electrical Systems, Propulsion
- **Wear-out failures**
  - Failures are increasingly likely as parts age
  - Typically used by Structures/Airframe

# General SARA Process

## Basic idea is to

- Determine:
  - the chances of a failure (or defect) occurring
  - the chances that the failure (or defect) will result in an outcome of a given severity
  - the future exposure of the fleet to the failure condition
  - and the total number of outcomes of a prescribed severity.

- Compare these values to risk thresholds to determine a recommended airworthiness action
  - Airworthiness Directives (AD)
    - Immediate Adopted Rule (IAR)
    - Notice of Proposed Rulemaking (NPRM)
  - Special Airworthiness Information Bulletin (SAIB)

# SARA Process for Airframe

- Gather data
- Determine the severity of the failure(s)
- Perform Life Analysis
  - Statistical distributions
  - Predict future failures
- Compare Life Analysis results to Directorate risk thresholds to determine which airworthiness action (IAR, NPRM, SAIB, No Action) and control program are appropriate.
- Review Issue with Corrective Action Review Board (CARB)

# Example Issue - SARA for Airframe

**Twin Cessna Wing Fatigue**

**Cessna 400 Series (Various Models)**

**AD 2005-12-12**

**AD 2005-12-13**

Unsafe condition:

Fatigue cracks in wing spars that cannot be reliably detected before it reaches critical crack length resulting in a catastrophic event.

# SARA for Airframe

## Step 1 - Gather Data

- Determine Time-In-Service (TIS) for crack findings and negative inspection results (suspensions)
- Reported crack size
- Number of components per airplane
  - Life analysis based on the number of components in the fleet, not the number of airplanes
- Crack growth rate and residual strength if known

# Example Issue – Twin Cessna Wing Fatigue

## Step 1 - Gather Data

| Unit | Flight Hours | Wing Station | Location | Crack Origin | Failure Mode |
|---|---|---|---|---|---|
| 402-0046 | 8373 | 81.50 | Fwd Flg | Fastener Hole | Complete cap failure. **The airplane had an engine fire** that left the cap with 50% of required tension capability after 1830 hours. – Right Wing |
| 402-0295 | 8057 | 74.50 | Aft Flg | Fastener Hole | Complete cap failure – Left Wing |
| 402A-0043 | 13824 | 67.14 | Aft Flg | Fastener Hole | .05” crack detected when evaluating new NDI equipment. |
| 402-0101 | 16000 | 71.90 | Fwd Flg | Fastener Hole | Complete cap failure – Left Wing |
| 402A-0080 | 13773 | 67.65 | Fwd Flg | Fastener Hole | Complete cap failure – Left Wing |
| 402-0216 | 9012 | 67.14 | Fwd Flg | Fastener Hole | Spar cap ligament failure – Left Wing |
| Cyclic Test | 14,000 | 66.70 | Aft Flg | Fastener Hole | Complete cap failure. |

# Example Issue – Twin Cessna Wing Fatigue

## Step 1 - Gather Data

US Registry & Age collected from SAD COS Website:

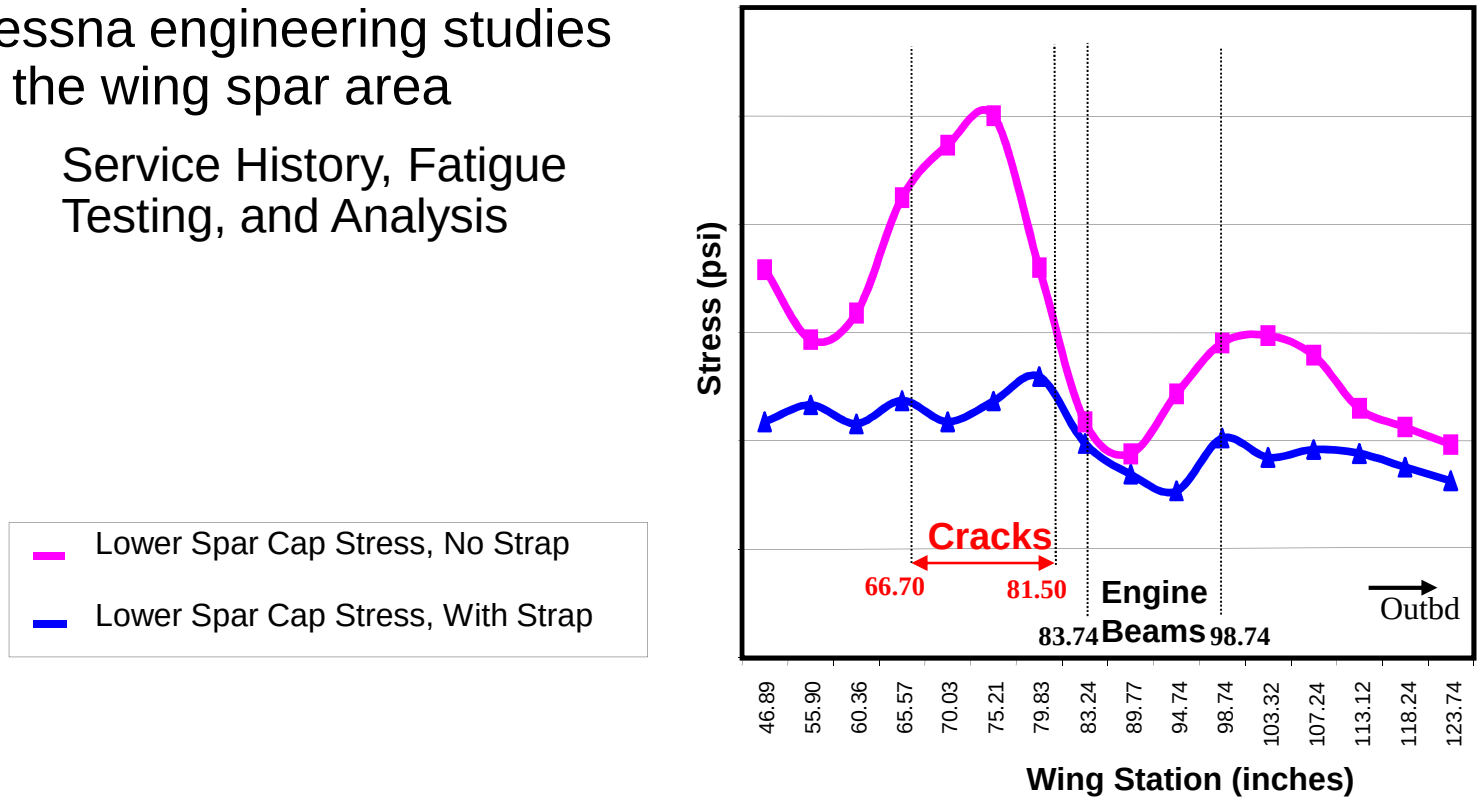
| Model Number | TCDS | Year of Manufacture (Registry) | Number on Registry | Average Flight Hours per Year (Bluebook) | Average Flight Length Hours (GA Survey) | Average Number of Landings per Year (Average Flight Hours / Average Flight Length) |
|---|---|---|---|---|---|---|
| | | | | | | |
| | | | | | | |
| | | | | | | |
| 402 | A7CE | 1966 | 1 | [redacted] | 0.70 | [redacted] |
| 402 | A7CE | 1967 | 21 | | 0.70 | |
| 402 | A7CE | 1968 | 20 | | 0.70 | |
| 402 | A7CE | None Listed | 3 | | 0.70 | |
| | | | | | | |
| | Total Number on Registry | | 45 | | | |

Small Airplane Directorate - SAD

# Example Issue – Twin Cessna Wing Fatigue

## Step 1 - Gather Data

- Cessna engineering studies of the wing spar area
  - Service History, Fatigue Testing, and Analysis

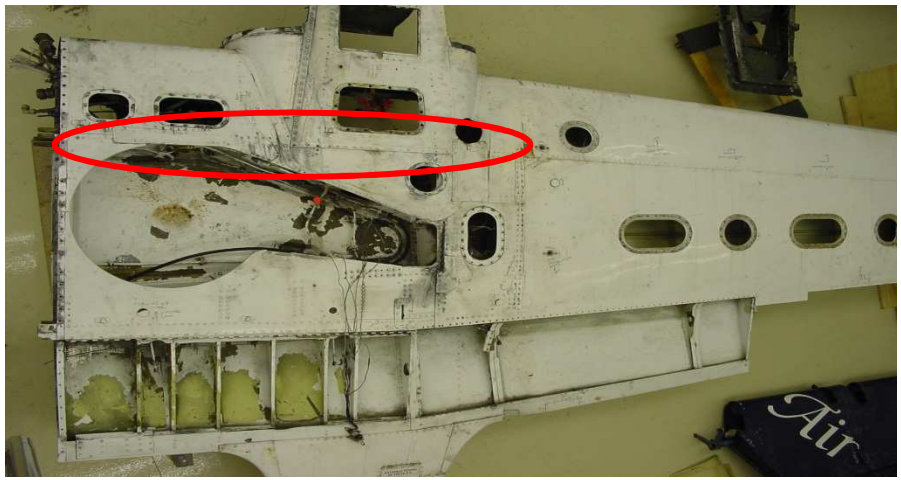


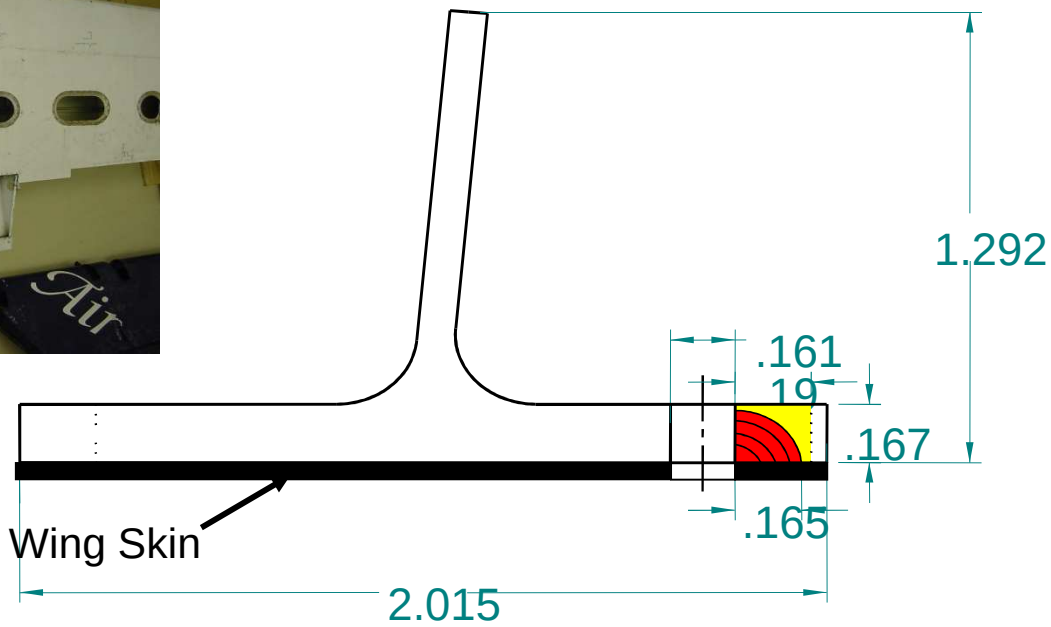
# Example Issue – Twin Cessna Wing Fatigue

## Step 1 - Gather Data

**Critical Crack** (Cap failure if max design limit load is applied)

**Detectable Crack** (Can be found by 95/100 inspectors 90% of time)





# Severity Definitions for Airframe

## Step 2 - Determine the Severity of the failure(s)

| Severity Level | Residual Strength | Residual Stiffness (Flutter Speed) |
|---|---|---|
| Level 5 | ≤ 100% Limit Load | ≤ 1.0 $V_D$ |
| Level 4 | ≤ 130% Limit Load | ≤ 1.1 $V_D$ |
| Level 3 | <150% Limit Load | <1.2 $V_D$ |

Cessna 401, 402

For most small airplanes

- Crack growth rate and residual strength not readily available.
- Similar data for corrosion not available.

# Severity Definitions for Airframe

Qualitative Descriptions in Absence of Residual Strength

| Severity Level | Description of Fatigue Crack |
|---|---|
| Level 5 | Fatigue crack through “X”% or more of the part thickness. |
| Level 4 | Fatigue crack at least “Y” inch in maximum dimension up to “X”% of the part thickness. |
| Level 3 | Fatigue crack less than “Y” inch in maximum dimension. |

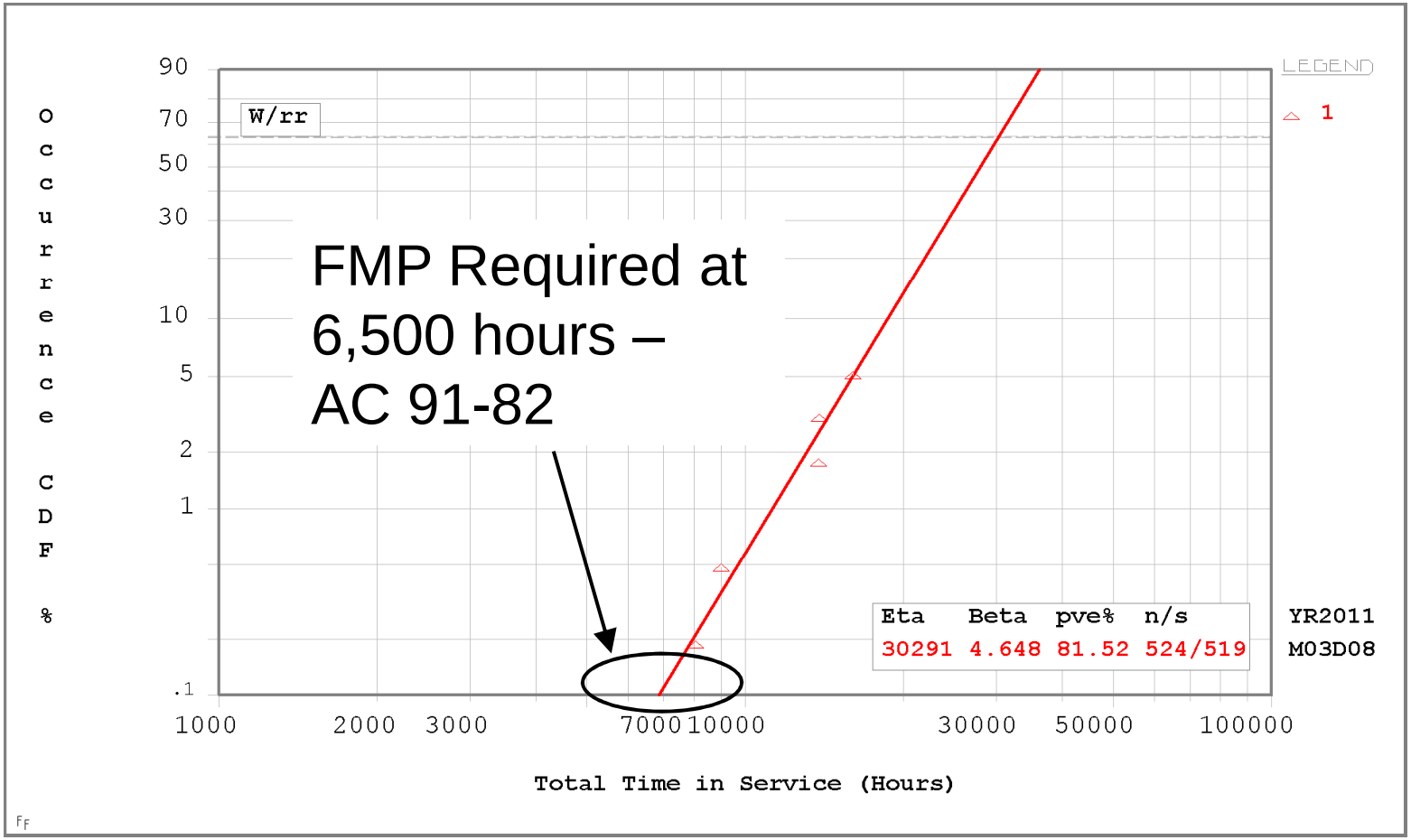
# SARA for Airframe

## Step 3 - Perform Life Analysis

- Use statistical distribution (typically Weibull) to estimate fleet-wide distribution of TIS to the initiation of fatigue cracking

# Example Issue – Twin Cessna Wing Fatigue

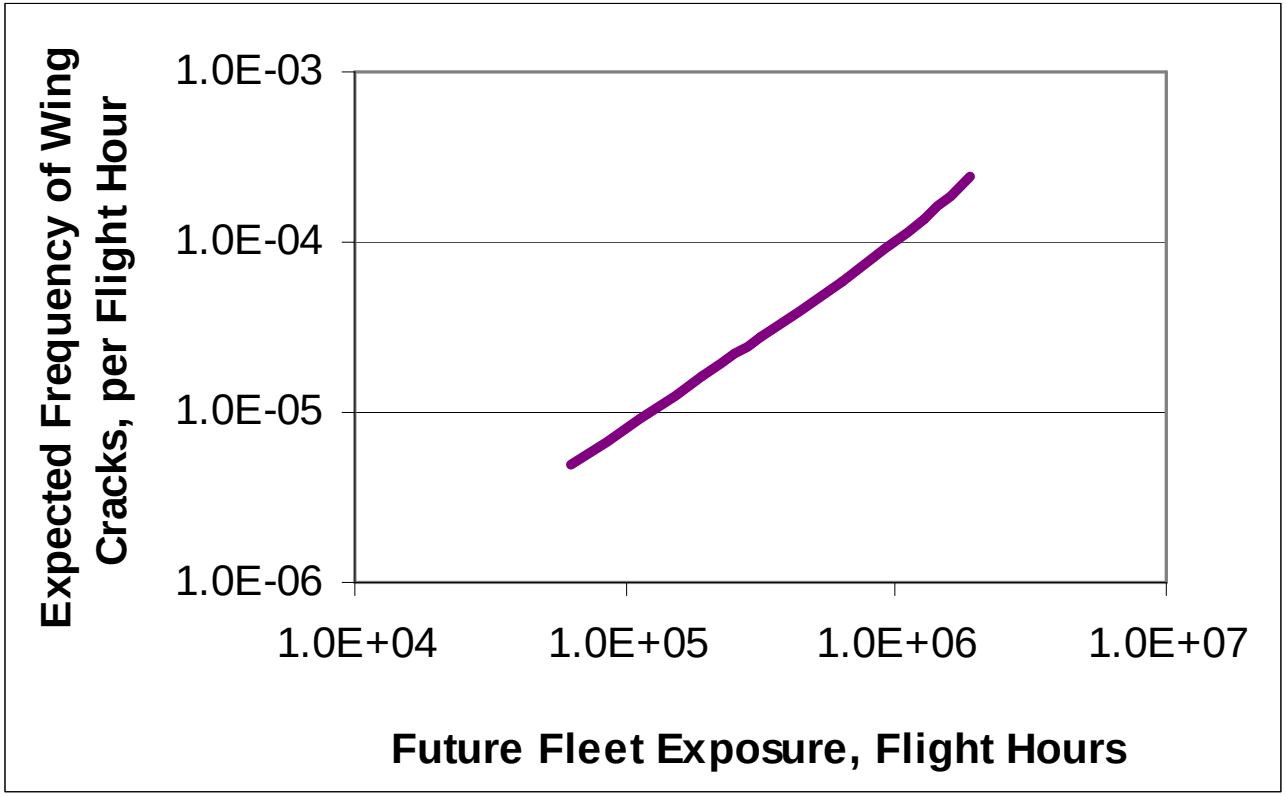
## Step 3 - Perform Life Analysis



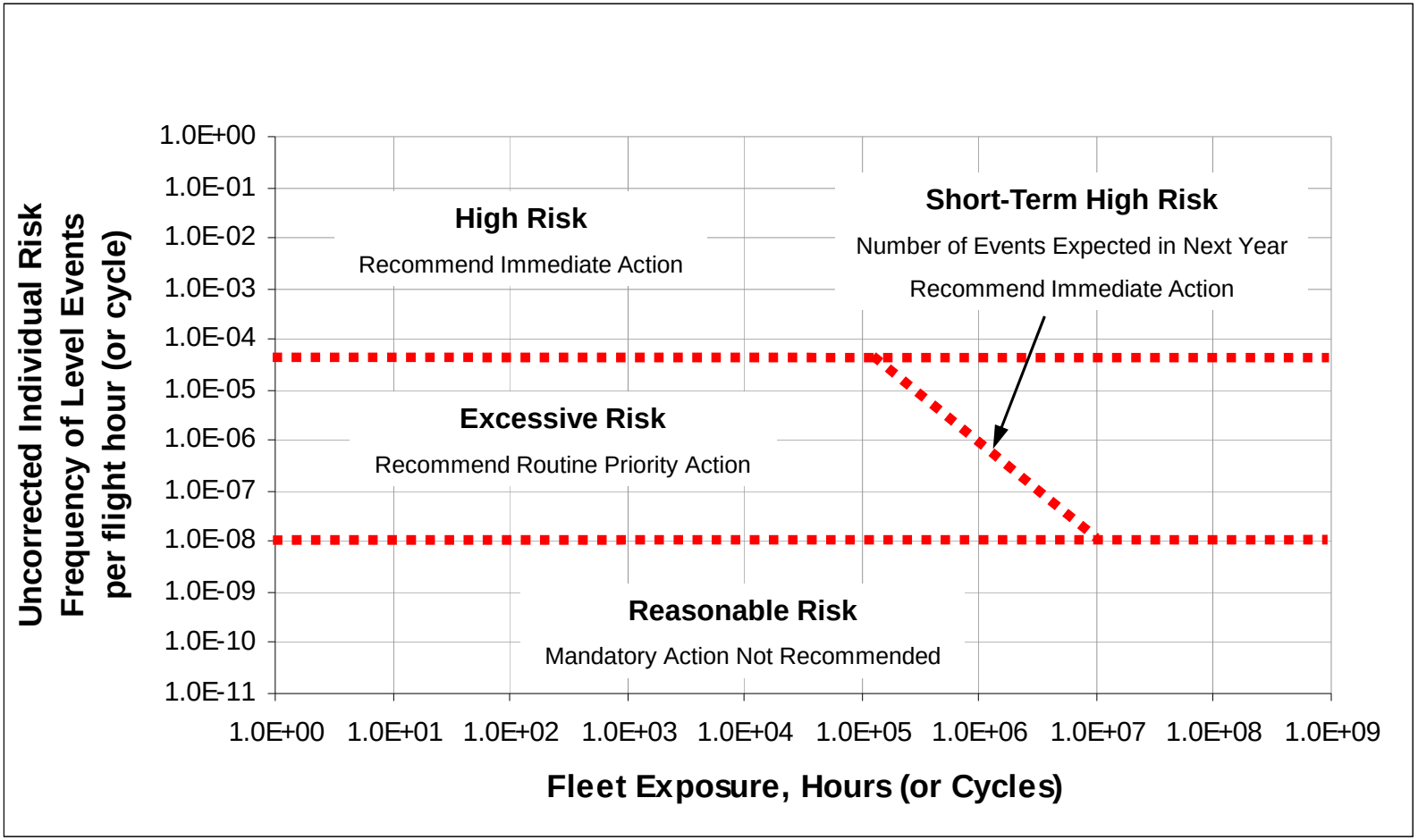
# Example Issue – Twin Cessna Wing Fatigue

## Step 3 - Perform Life Analysis

Estimate frequency (and number) of cracks at any point in the future

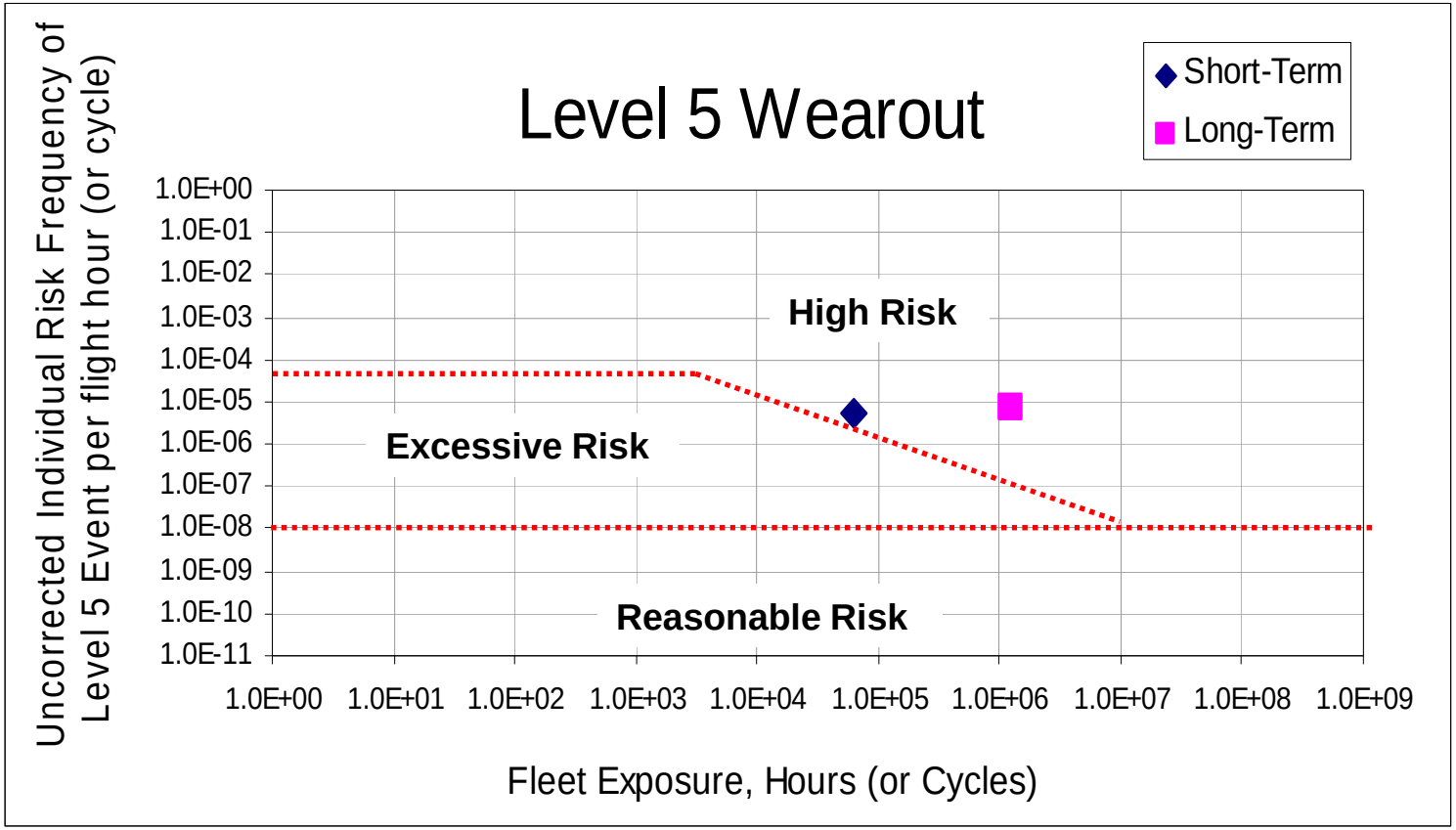


# SAD Risk Threshold – Trapezoid Method



# Example Issue – Twin Cessna Wing Fatigue

## Step 4 – Compare Results to SAD Risk Threshold & Develop Appropriate Airworthiness Action



# Example Issue – Twin Cessna Wing Fatigue

Conclusions:

- The FAA originally issued an AD to correct this unsafe condition in 2005 (AD 2005-12-12 and 2005-12-13)
- In this example that uses the SARA method for Airframe, the risk analysis results support the actions taken by the FAA in 2005
  - Per the trapezoidal graph, immediate action was required (using the SARA method)

# Lessons Learned

- Common Issues in Small Airplane Fatigue and Wearout Assessments
  - Most airplanes do not have mandatory damage tolerance based inspection programs
  - Do not know whether other airplanes in fleet are cracked or are ‘suspensions’
  - Do not know time-in-service of other airplanes

# SARA - Systems and Equipment

- Electrical power and wiring
- Avionics/Navigation/Autopilot
- Fluid/Pneumatic systems
- Flight controls
- Ice protection
- Cabin environment and safety
- Landing gear, wheels, tires, and brakes
- Electrical/Mechanical equipment

# Powerplant, Propeller, and APU

- **Engine, Propeller, APU Installations**
  - Engine, Propeller and APU controls
  - Engine and propeller ice protection
  - Fuel systems
  - Engine oil, bleed, and gear boxes
  - Engine and APU fire protection

# The SARA Process - Systems

- Same basic steps as previously outlined for Airframe
- Collect data
- Calculate risk
- Compare risk parameters to risk guidelines
  - Recommend what kind of airworthiness action should be taken
- Identify corrective actions (ACO CARB)
- Implement corrective actions
- Evaluate effectiveness of corrective actions

# Collect Data

- Number of failures/defects in the fleet
  - Search MSAD, ASIAS (SDR, AIDS, NTSB)
- Number of airplanes in fleet
  - FAA Registry, Manufacturer's records, FAA demographic information
- Average flight hours/cycles per year per airplane
  - General aviation activity survey, FAA demographic information, Aircraft Bluebook
- Long-term Exposure
  - Assume 20 years for risk calculations
- Short-term Exposure
  - Assume 1 year for risk calculations

# Hazard Severity Levels

- Level 5 failures/defects are conditions expected to result in
  - Fatal injury to the pilot and/or passengers/hull loss
  - Aligns with AC 23.1309-1D Catastrophic
- Level 4 failure
  - Serious injuries
  - A large reduction in safety margins or functional capabilities of the crew
  - Aligns with AC 23.1309-1D Hazardous
- Level 3 failure
  - Substantial damage to the aircraft and/or minor injuries
  - Reduction in safety margins or increase in crew workload
  - Aligns with AC 23.1309-1D Major

# Calculate Risk Parameters

- **Frequency of Failure or Defect (per hour or per flight cycle)**
  - Total Number of Defects or Failures / Affected Fleet Hours or Flight Cycles
- **Hazard Ratios**
  - Fraction of defects or failures resulting in Level 3, 4, and 5 events (Note: Level 3 events include Level 4 and Level 5 events. Similarly Level 4 events include Level 5 events.)
- **Uncorrected Individual Risk**
  - Frequency of Defect or Failure x Level 3, 4, and 5 Hazard Ratios
- **Long-Term Exposure**
  - Number of Airplanes x Average Flight Hours (Cycles) per year per airplane x Remaining Service Life of Fleet (20 years default)
- **Short-Term Exposure**
  - Number of Airplanes x Average Flight Hours (Cycles) per year per airplane x 1 year
- **Uncorrected Fleet Risk, Short-Term**
  - Frequency of Level 3, 4, and 5 Events x Short Term Exposure
- **Uncorrected Fleet Risk, Long-Term**
  - Frequency of Level 3, 4, and 5 Events x Long- Term Exposure

# Hazard Ratios

- **Determine hazard ratios from service history if adequate service history is available**
  - In situations where insufficient service history is available use the recommended hazard ratios in SARA Handbook Table 4 and adjust these hazard ratios based on specifics of a particular installation and on engineering judgment.
  - Calculated hazard ratios can be compared against the recommended values in SARA Handbook Table 4 as a check

# Compare Risk Parameters

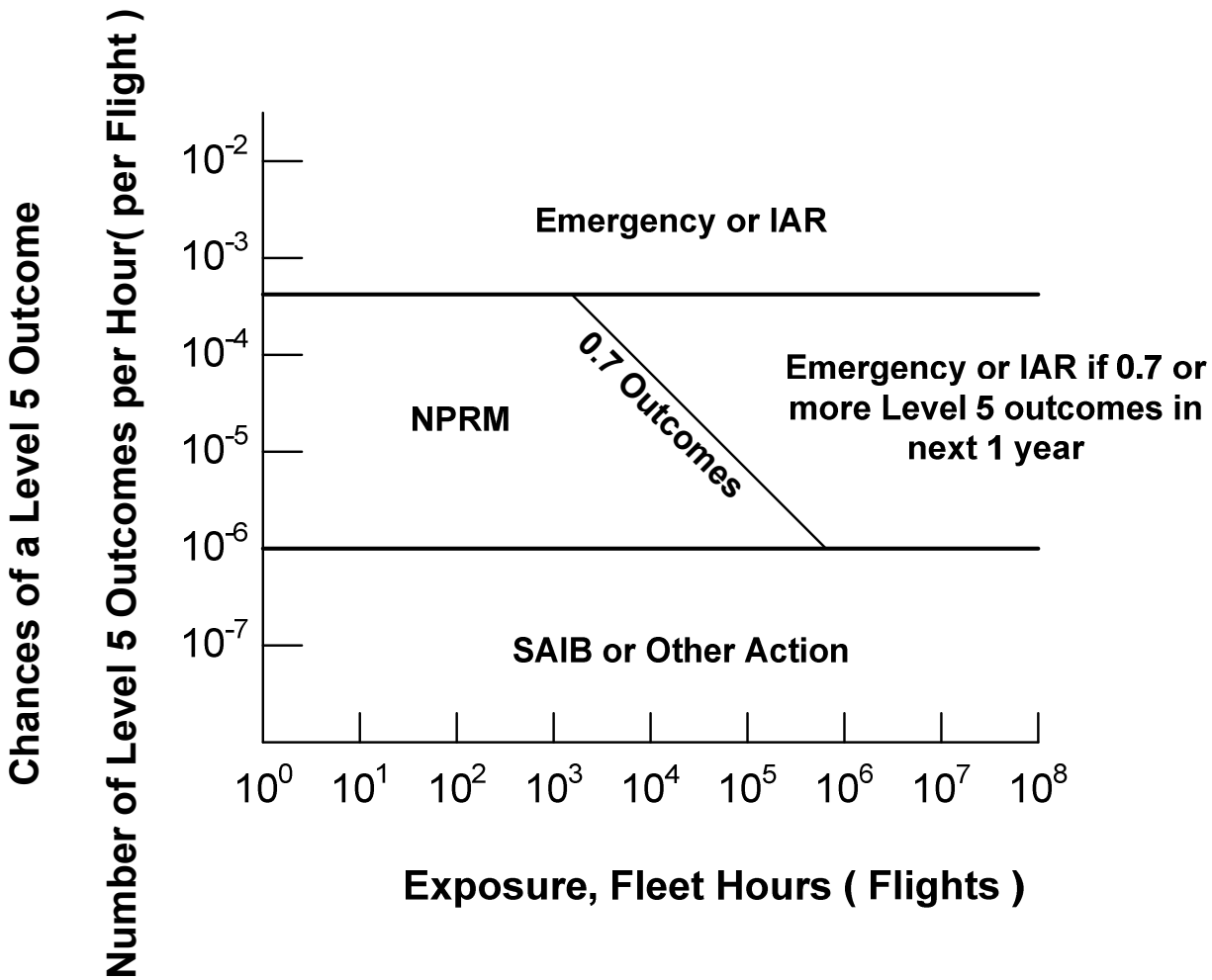
- **Once the risk parameters are determined compare the risk parameters against the recommended risk guidelines to make recommendations on airworthiness actions**
  - risk guidelines are provided for levels 5, 4, & 3 hazards and the four classes of general aviation aircraft
  - airworthiness action should be considered if any if the risk values exceed the risk guidelines

- **High Risk**
  - If the risk parameters fall within an area of the guidelines labeled 'High Risk' consider taking immediate action (Immediately Adopted Rule or Emergency AD).

- **Excessive Risk**
  - If the risk parameters fall within an area of the guidelines labeled 'Excessive Risk' consider developing a routine NPRM action

- **Reasonable Risk**
  - Mandatory airworthiness action is not generally indicated if the risk parameters fall into an area of the guidelines labeled 'Reasonable Risk'. In these cases consider voluntary actions including SAIBs and service information
  - All safety issues with a risk above two-thirds of the risk guidelines for AD or mandatory corrective action should be reviewed by the ACO CARB.

# Compare Risk Parameters



# SARA Tips

- **Be cautious when there are few events related to a safety cause where we have taken actions in the past to mitigate (e.g. SAIB recommending use of a service bulletin or inspection)**
  - Effective mitigation will result in a low frequency of historical events and may bias the decision process towards a non-conservative corrective action to address future events.
- **If adequate actual historical data is available use this information to calculate a hazard ratio for the specific case being evaluated. use library hazard ratios when insufficient historical data is available, or to compare a calculated ratio to previously recorded trends.**
- **It is advisable to consider a historical time period less than 20 years when determining event frequency if the majority of events have occurred in a shorter time frame.**
  - For example a failure has 10 events in the past 5 years and 11 events if 20 years is considered. In this case the frequency should be determined using 10 events over 5 years. If a wear out failure is suspected engineers may consider using statistical methods, such as Weibull Analysis, to more precisely account for wear out effects.

# SARA Tips

- **Expect significant under-reporting of (SDR) failures and defects in most situations. This under-reporting may have a direct impact on the risk calculations by reducing the frequency of the failure or defect and by altering the hazard ratios**
  - we expect that most Level 4 and Level 5 outcomes will be reported, however, outcomes with Level 3 and lower severity may be under-reported.
- **In developing hazard ratios based on service history, ASEs should assume that the next failure or defect will result in the next highest level of severity with no reported outcomes.**
  - For example, an airworthiness concern has resulted in 10 Level 3 outcomes and no Level 4 or Level 5 outcomes. In computing the hazard ratios, ASEs should assume that the next event will result in a Level 4 outcome. In this case, an ASE would calculate the hazard ratios based on 11 Level 3 events, 1 Level 4 event, and no Level 5 events. This approach will result in a reasonably conservative interpretation of service history.

# CESSNA AC MOTOR AD EXAMPLE IN EXCEL SPREADSHEET

# Identify Corrective Actions

- **Consult with others with expertise in area of concern**
- **Review risk analysis results with CARB (resources from multiple disciplines)**
- **Identify and reach consensus on corrective actions**
  - May require working with the manufacturer to develop required service information

# Implement Corrective Actions

- **Considering :**
  - Long Term risk
  - Short term risk
  - Control program risk
  - Number of potential fatal accidents if uncorrected

# Evaluate Effectiveness of Corrective Actions

- **Review/analyze individual and fleet risk with corrective actions in place**

- **Continue to monitor and make adjustments to maintain an acceptable level of safety**

# Hazard Level Examples (Systems and Powerplant)

- **Potential Level 5 failures**
  - Complete loss of control in one primary axis
  - In-flight cabin fire
  - Total loss of all flight instruments
- **Potential Level 4 failures**
  - Engine failure resulting in total loss of power
  - Propeller blade/hub failure
  - Autopilot hard-over in more than one axis
  - Unsafe levels of carbon monoxide in cabin
  - Failure of pilots seat
  - Loss of altitude or airspeed information
- **Potential Level 3 failures**
  - Loss of navigation information
  - Total loss of braking
  - Loss of one engine in a multiengine aircraft

# Summary

**SARA Benefits**

- **Provides measurement of effectiveness of candidate control programs**
- **Risk analysis based on accepted risk methods (AC 39-8)**
- **Risk thresholds based on the expected frequency of limit and ultimate loads (airframe)**
- **Risk based on actual number of events**
- **Severity estimate based more on actual outcomes rather than worst case scenarios**
- **Method gives industry and public more transparency into our risk assessment methods and decision making process**

# List of Acronyms

AC – Alternating Current
ACP – Airworthiness Concern Process
AD – Airworthiness Directive
AIDS – Accident/Incident Database System
AIR – FAA Aircraft Certification Service
AFS – FAA Flight Standards Organization
APU – Auxiliary Power Unit
ASE – Aviation Safety Engineer
ASIAS – Aviation Safety Information Analysis and Sharing
CARB – Corrective Action Review Board
CM – Certificate Management
COS – Continued Operational Safety
DAH – Design Approval Holder
FAA – Federal Aviation Administration
FMP – Fatigue Management Program
GA – General Aviation
IAR – Immediately Adopted Rule
LE – Leading Edge
LOV – Limit of Validity
MSAD – Monitor Safety/Analyze Data
NPRM – Notice of Proposed Rulemaking
NTSB – National Transportation Safety Board
PMA – Parts Manufacturer Approval
PI – FAA Principal Inspector
RAS – Risk Assessment Specification
R&D – Research and Development
SAD – Small Airplane Directorate
SAIB – Service Alert Information Bulletin
SARA – Small Airplane Risk Assessment
SID – Supplemental Inspection Document
SDR – Service Difficulty Report
SMS – Safety Management System
SR – Safety Recommendation
TARAM – Transport Airplane Directorate Analysis Methodology
TIS – Time In Service
TSO – Technical Standard Order
Vd– Dive Speed