# Air Force Materiel Command

## *ASIP PANEL SESSION*

# Addressing the NDI Crack Miss Problem in Safety of Flight Structures

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# The Catalyst

- In Spring of 2005, a flight restricted Air Force transport aircraft experienced moderate turbulence, which violated the restrictions.  Aircraft wing structure was re-inspected per engineering direction.
  - Two cracks found at only 24.3 hours after a previous depot inspection.

- Reinspections of several other aircraft identified cracks that should have been detected by a previous inspection.

- Analysis concluded that these cracks were “missed” during the TCTO inspection.

***Not isolated to a single base or depot!***

# Cracks Missed

# Challenging Inspection

- ***Human Factors (Overhead Inspection)***
- ***Technical Data (Complex)***
- ***Surface Condition (Coating Removal Required)***
- ***Restricted Access (Inspection Area Near Fairing)***
- ***Large Area (Many Details)***

Root Cause Investigation Pending

# NDI Tiger Team Findings
# *AF Wide Issue*

**<u>NDI Tiger Team Survey</u>**

- 4 of 43 AF aircraft systems reporting that nondestructive inspections missed cracks at various locations in past ten years.
- 42 individual documented misses in past 2 years
- Misses attributed to multiple factors:
    - Difficult locations to inspect
    - Incomplete inspection procedures
    - Adequacy of oversight
    - Adequacy of training
    - Lack of inspector sensitivity to criticality of task
    - Human Factors
    - Newness of organization to aircraft requirements

# Air Force Audit Agency Findings

**1999 Air Force A[illegible]ort**

- Identified a serie[illegible] inspections
- 10 bases evaluated
  - 7 bases did [illegible] 136 (16%) of 839 inspecti[illegible]s
    - 81 (10%) inspections a[illegible]
    - [illegible] altogether

**Poor POI**

**+**

**Poor POD**

---

**!!Big ProblemS!!**

# *What Are The Root-Causes?*

- Root-Cause Analysis not routinely accomplished unless mishap occurs
  - Fortunately only one Mishap (Class B) in past ten years related to NDI misses in safety of flight structures

- Effective Corrective Actions not implemented

***Have We Been Lucky??***

# *What Makes For an Effective Inspection?*

- Well Trained People
- Empowered People
- Motivated People
- Well Engineered Inspections
  - Clearly Defined Requirements
  - Suitable Equipment (Instruments, probes standards)
  - Human Factors Considered in Inspection Development
  - Clear Guidance and Documentation
  - Capability Meets Requirement
- Strong Organization
  - Employee Feedback
  - Strong Proactive Management
  - Effective Oversight

# Questions to Address

- How do we accurately identify the Root Causes and implement effective corrective action?
- What are the Human Factors driving NDI misses?
- Are the equipment, procedures and calibration methods effective?
- Are current training programs effective?
- Are the current Certification/Qualification programs effective?
- Is the organization effective?
- What can be learned from other services or agencies?

# *Undetected Cracks: Structural Significance and Root Cause Investigations*

*ASIP Conference - Panel Session:*

***"Addressing the NDI Crack-Miss Problem for Safety-of-Flight Structure"***

30 November 2005

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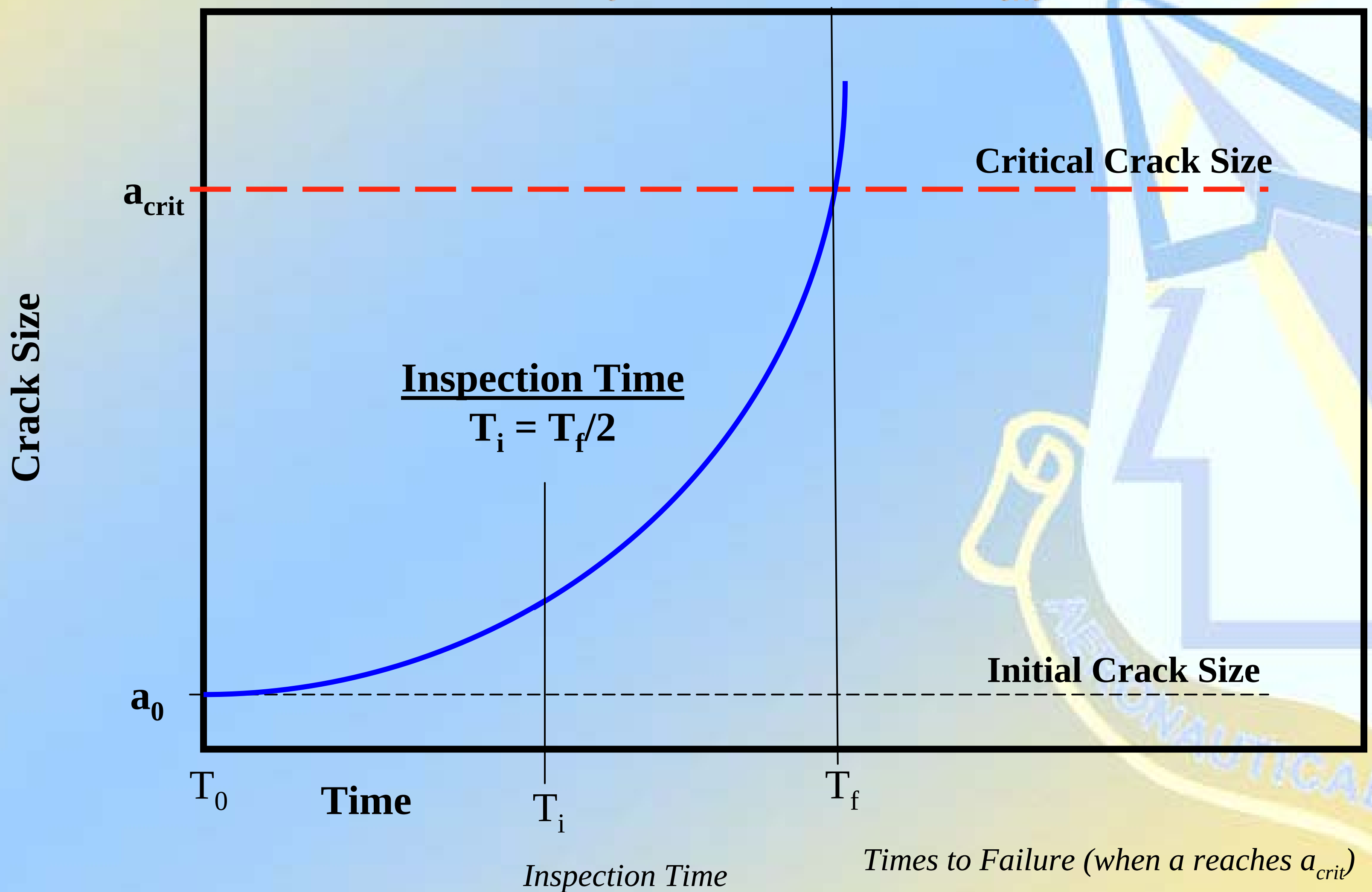
# Traditional Damage Tolerance Inspection Philosophy



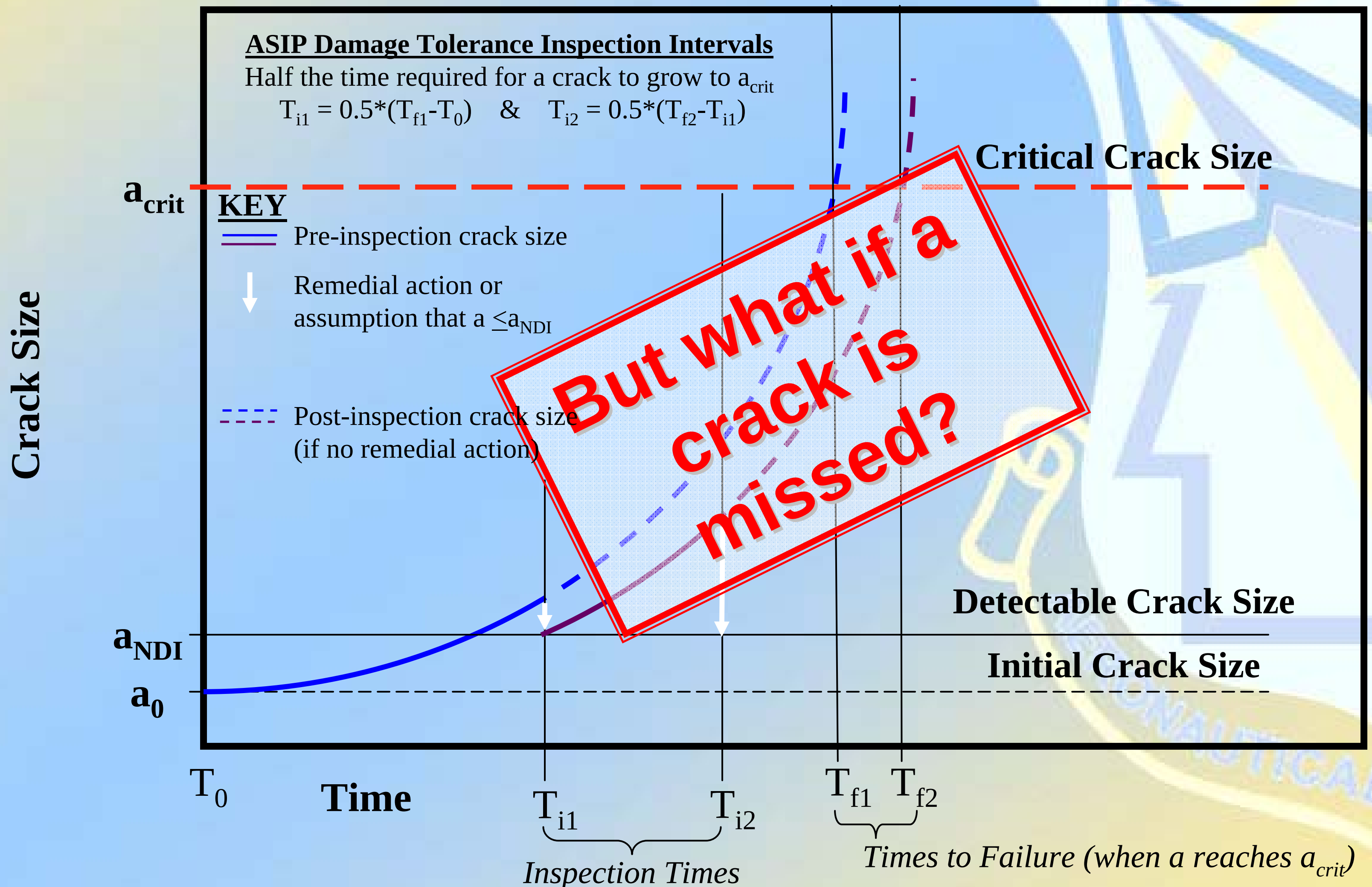
**Inspections are performed at ½ the time it takes for a crack to grow from some initial (assumed) size [$a_0$] to a critical size [$a_{crit}$] (i.e. failure)**



# Traditional Damage Tolerance Inspection Philosophy



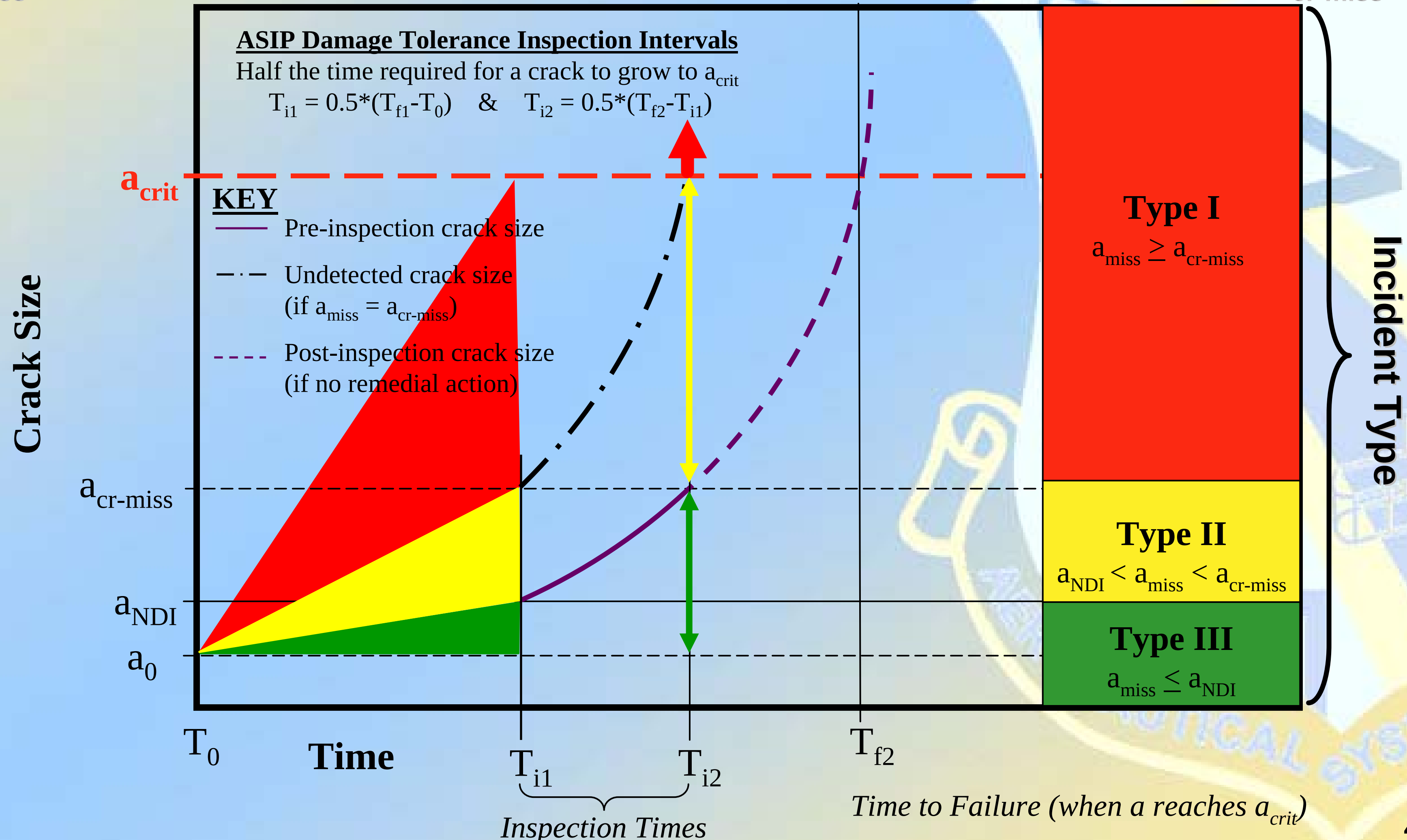
**If a crack exceeds the detectable crack size [$a_{NDI}$] and is found and remedial action is taken, then another inspection time is computed**



# Classifying Undetected Cracks

*Dominant Air Power: Design For Tomorrow…Deliver Today*

**The significance of an "NDI Miss" depends on the lengths of an undetected crack [$a_{miss}$] and of a crack that can grow to failure before the <u>next</u> inspection [$a_{cr\text{-}miss}$]**



# *Classifying Undetected Cracks*



- **Type I Incident** ($a_{miss} \geq a_{cr\text{-}miss}$)
  – Poses a high risk to flight safety or mission capability
  – Consequences:
    - Failure or potential failure of a safety-of-flight structural component before the next scheduled inspection
    - loss of life or aircraft
    - effects that could result in a Class A mishap

- **Type II Incident** ($a_{NDI} < a_{miss} < a_{cr\text{-}miss}$)
  – Poses a moderate risk to flight safety or mission capability
  – Consequences: major readiness or economic impacts

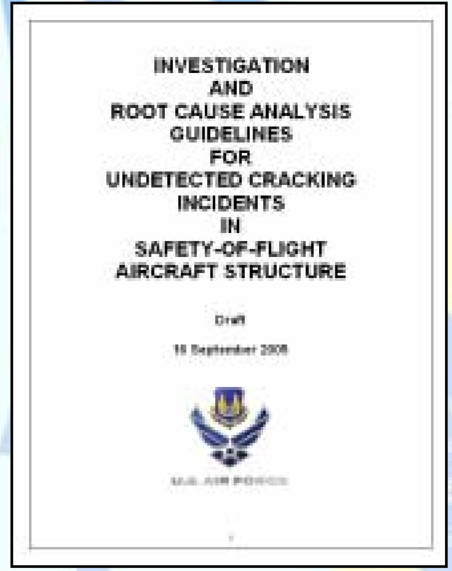
- **Type III Incident** ($a_{miss} \leq a_{NDI}$)
  – Poses a low risk to flight safety or mission capability
  – Consequences: standard repairs to affected structure

# Root Cause Investigation Methods

*Dominant Air Power: Design For Tomorrow…Deliver Today*

## Type I Incident ($a_{miss} \geq a_{cr\text{-}miss}$)

- Sequential Event and Causal Factor Analysis
  - "Walk-Through" analysis with Time-Sequence diagram
- Cause and Effect Analysis
  - "Fishbone" Diagram
- Human Performance Evaluation
  - Evaluation of inspectors and management
- Change Analysis
  - Comparison of expectations with actual events


INVESTIGATION
AND
ROOT CAUSE ANALYSIS
GUIDELINES
FOR
UNDETECTED CRACKING
INCIDENTS
IN
SAFETY-OF-FLIGHT
AIRCRAFT STRUCTURE

Draft

## Type II Incident ($a_{NDI} < a_{miss} < a_{cr\text{-}miss}$)

- Sequential Event and Causal Factor Analysis
- Cause and Effect Analysis
- Human Performance Evaluation
- (optional) Change Analysis

## Type III Incident ($a_{miss} \leq a_{NDI}$)

- Informal data gathering & analysis and reporting

# *Final Thoughts*



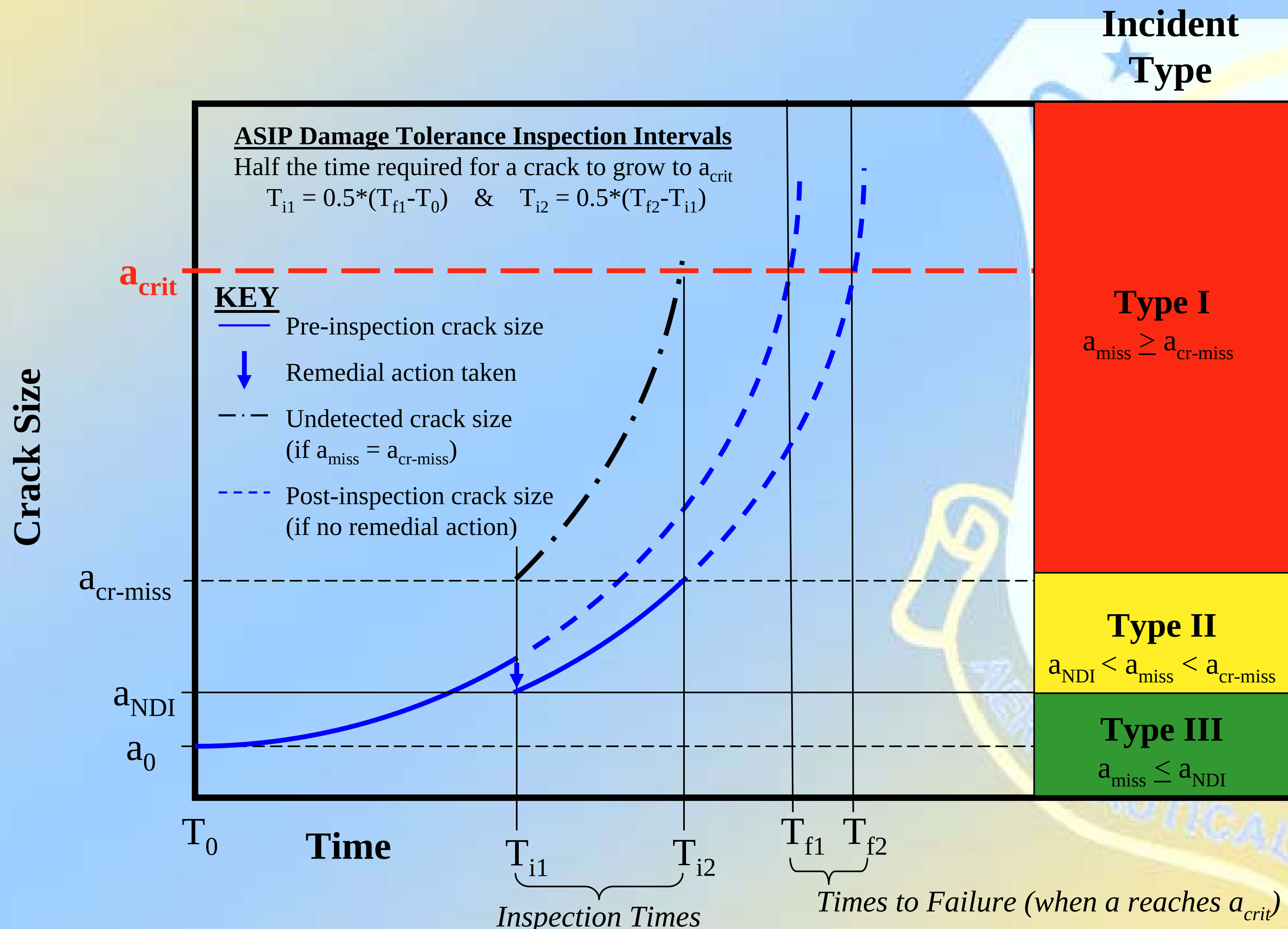
- **The significance of an undetected crack depends on:**
  - **The length of the undetected crack**
  - **The length of a crack that can grow to failure before the next planned inspection**
  - **The planned inspection interval**
  - **The consequences of a failure resulting from the undetected crack**

- **Various root cause analysis techniques can be used to investigate "NDI Miss" incidents**
  - **Guidance has been drafted to assist in root cause analyses**

- **Next steps**
  - **Quantification of $a_{NDI}$**
  - **Linking to risk assessments**

# Classifying Undetected Cracks

*Dominant Air Power: Design For Tomorrow…Deliver Today*



# OKLAHOMA CITY AIR LOGISTICS CENTER

*TEAM TINKER*

# NDI COVERAGE: EDDY CURRENT & ULTRASOUND

**9 NOV 05**

**Karl E. Kraft**

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# OVERVIEW



- **Eddy Current (ET) and Ultrasonic (UT)**
- **Aircraft and Propulsion Depot and Field**
- **Aircraft and Propulsion Field Level Only**

# Manual Inspection

Overview

Manual

Flaw Size

Coverage

Control

Summary

- Propulsion components have much lower fatigue crack tolerance
- Propulsion handheld inspections are typically unplanned implementations
- Propulsion manual inspections often used to mitigate risk between scheduled maintenance intervals
- Propulsion part design change often follows inspection development to eliminate risk mitigating NDI procedures
- Propulsion component design is complex and typically requires one-of-a-kind probe/standard design – no off the shelf probes
- Probe design is restricted by part geometry/access
- Propulsion probes purchased per acceptance test plan and often require matching to standard to ensure uniformity in inspection sensitivity and repeatability
- Sensitivity requirements mandate limiting operator control as much as possible to minimize false calls and ensure coverage
- Inspectors may require special training including successful completion of POD tests
- Methods like eddy current require the probe pass over flaw for detection – ensuring coverage is critical
- Propulsion probes are designed to cover a specific coverage zone often smaller than the probe diameter
- Aircraft inspectors are tasked with covering zones many times larger than probe requiring careful attention to scanning and a methodical approach to ensure coverage

# Aircraft Manual ET Surface Scan

- Overview
- **Manual**
- Flaw Size
- Coverage
- Control
- Summary


TWO AXIS SCAN

# Engines Manual ET Scanning



~CRACK SIZE: >60 MILS

SINGLE AXIS SCAN

# Manual UT Scanning



**~CRACK SIZE: >30 MILS**

**SINGLE AXIS & GO/NO-GO SCANS**

# Flaw Size



- ASIP largely uses assumptions
- ENSIP based more upon POD
- ENSIP flaw sizes roughly 10% of ASIPs

# Ensuring Coverage



- **Scan control increases at depot compared to field**
  - **Parts disassembled from aircraft or engine**
  - **Aircraft UT – subsurface (fatigue, corrosion, bonding, etc)**
  - **Propulsion ET – fatigue cracks**
- **Automation increases at depot to ensure coverage**
- **Field inspections**
  - **Aircraft scan control**
    - **Less mechanical control**
    - **Inspections more operator dependent as inspector more often has two axis of freedom to move probe**
  - **Propulsion scan control**
    - **More mechanical control**
    - **Access limitations require special tooling to manipulate probe**
    - **Reduced operator dependence as inspector is restricted to single axis or no axis of freedom to move probe**

# Automated ET



CRACK SIZE: ~5-30 MILS

BORE AND HOLE SCANS

# Automated UT Scanning

Overview

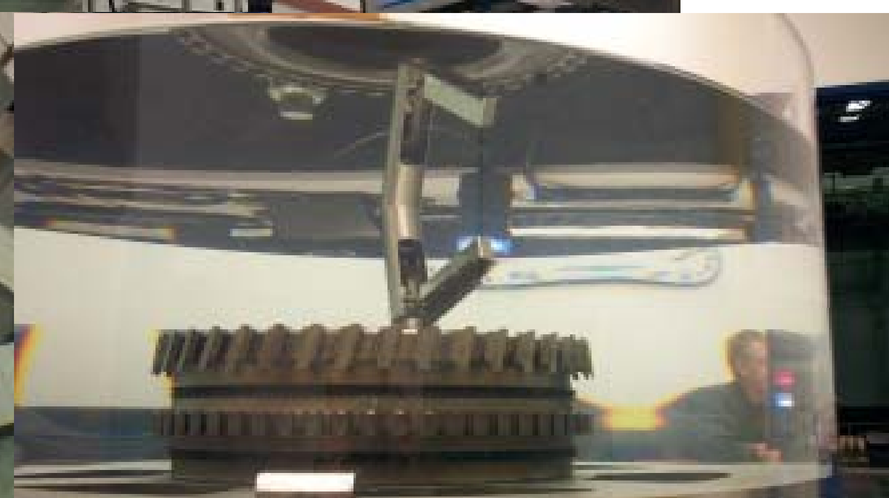
Manual

Flaw Size

Coverage

Control

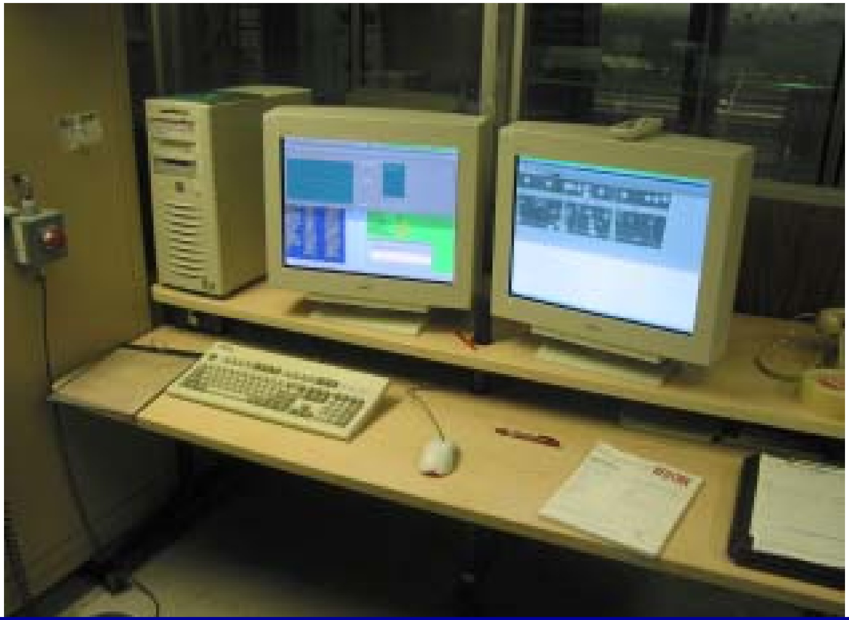
Summary



**MULTI-AXIS SCAN**

# Aircraft Semi-Automated UTScan

- Overview
- Manual
- Flaw Size
- **Coverage**
- Control
- Summary



**Disbonds & Water Entrapment**

# Scanning Categories

Overview

Manual

Flaw Size

Coverage

Control

Summary

- 2 Axis Manual – freehand no restrictions
- 1 Axis Manual – free to move probe in one direction
- 0 Axis Manual – go-no-go
- Bolthole Scanning – scanner controls rotational speed while operator indexes down hole
- Controlled Fixture – rigid test stand where operator centers probe and controls scan start/stop
- Semi-Automated – operator starts/stops and calibrates system, but data acquisition and motion are controlled by machine
- Automated – operator starts system and system runs to completion for operator buyoff

# Scan Control Comparison

Overview

Manual

Flaw Size

Coverage

Control

Summary

| ET | 2 Axis | 1 Axis | Go-No-Go | Bolthole Scanner | Controlled Fixture | Semi-Automatic | Automatic |
|---|---|---|---|---|---|---|---|
| Aircraft | 129 | 17 | 31 | 81 | 0 | 2 | 0 |
| Engines | 0 | 14 | 2 | 3 | 35 | 0 | 368 |

| UT | 2 Axis | 1 Axis | Go-No-Go | Semi-Automatic | Automatic |
|---|---|---|---|---|---|
| Aircraft | 78 | 7 | 1 | 74 | 0 |
| Engines | 2 | 10 | 5 | 6 | 0 |

Propulsion Data for F100-220, F100-229, F101, F108, F110-100/129/400, F118, TF33

Aircraft Data for B-1B, B-52, E-3A, and C-135

# Field Level Comparisons

- Overview
- Manual
- Flaw Size
- Coverage
- Control
- Summary

| ET | 2 Axis | 1 Axis | Go-No-Go | Bolthole Scanner |
|---|---|---|---|---|
| Aircraft | 9 | 4 | 0 | 4 |
| Engines | 0 | 5 | 0 | 0 |

| UT | 2 Axis | 1 Axis | Go-No-Go |
|---|---|---|---|
| Aircraft | 7 | 0 | 1 |
| Engines | 0 | 5 | 5 |

Propulsion Data for F100-220, F100-229, F101, F108, F110-100/129/400, F118, TF33

Aircraft Data for B-1B, B-52, E-3A, and C-135

# Summary



- **Flaw size limits for engines are more stringent**
- **ENSIP utilizes measured reliability**
- **Scan control is key to ensuring inspection coverage, sensitivity, repeatability, and reliability**
- **Automation is employed at depot for aircraft and propulsion while field inspections are manual**
- **Manual propulsion inspections more frequently employ measures to control scanning**
- **Propulsion manual coverage zones are typically smaller than the probe sensing element**
- **Aircraft inspections require organization and attentiveness due to operator dependence and challenge covering large areas with a small diameter probe**

***TEAM TINKER***

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# Human Factors Issues in Aircraft Inspection

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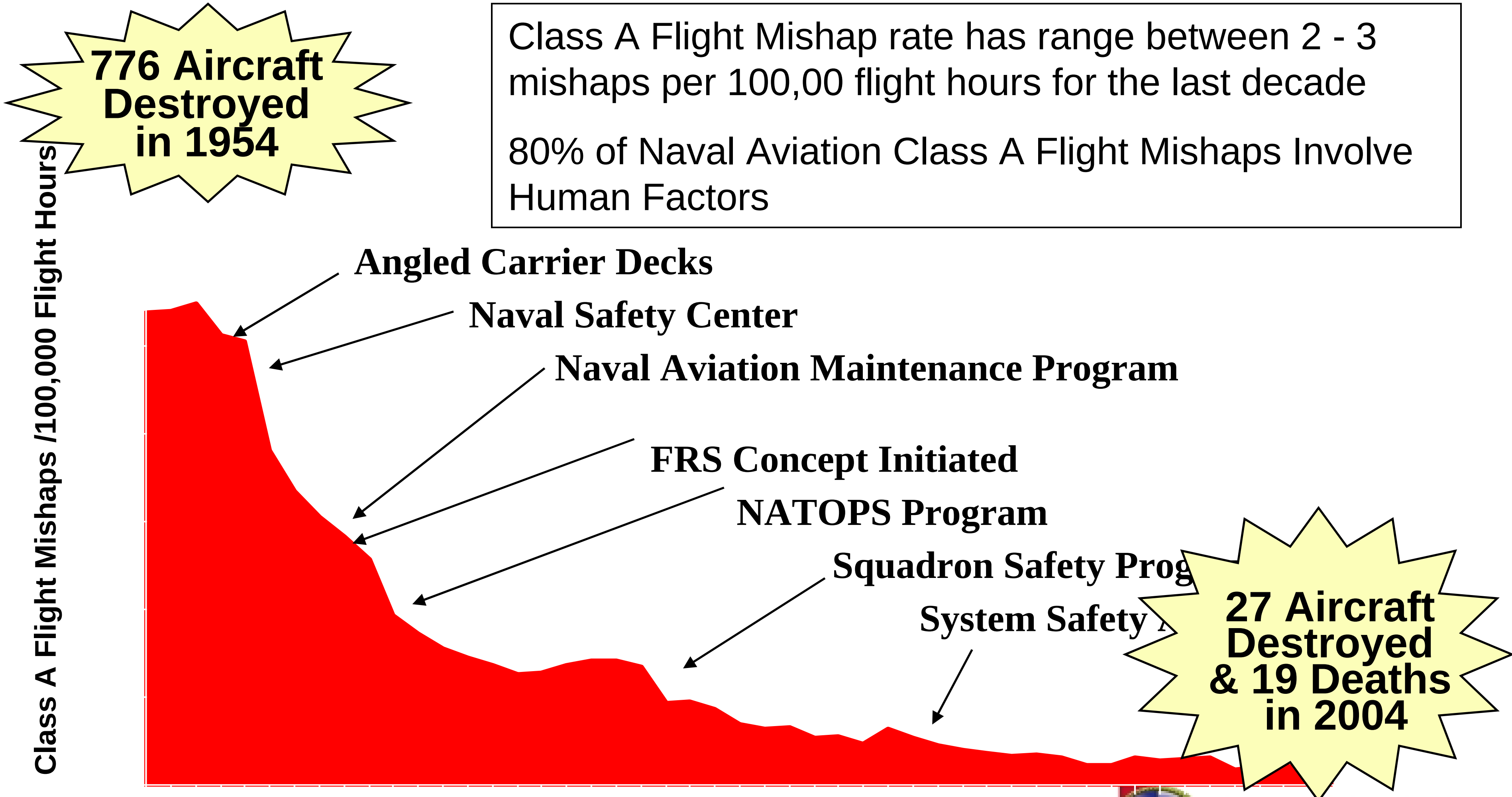
# Naval Aviation Class A Flight Mishaps FY50-04

Class A Flight Mishap rate has range between 2 - 3 mishaps per 100,00 flight hours for the last decade

80% of Naval Aviation Class A Flight Mishaps Involve Human Factors




Engineering & Administrative Controls

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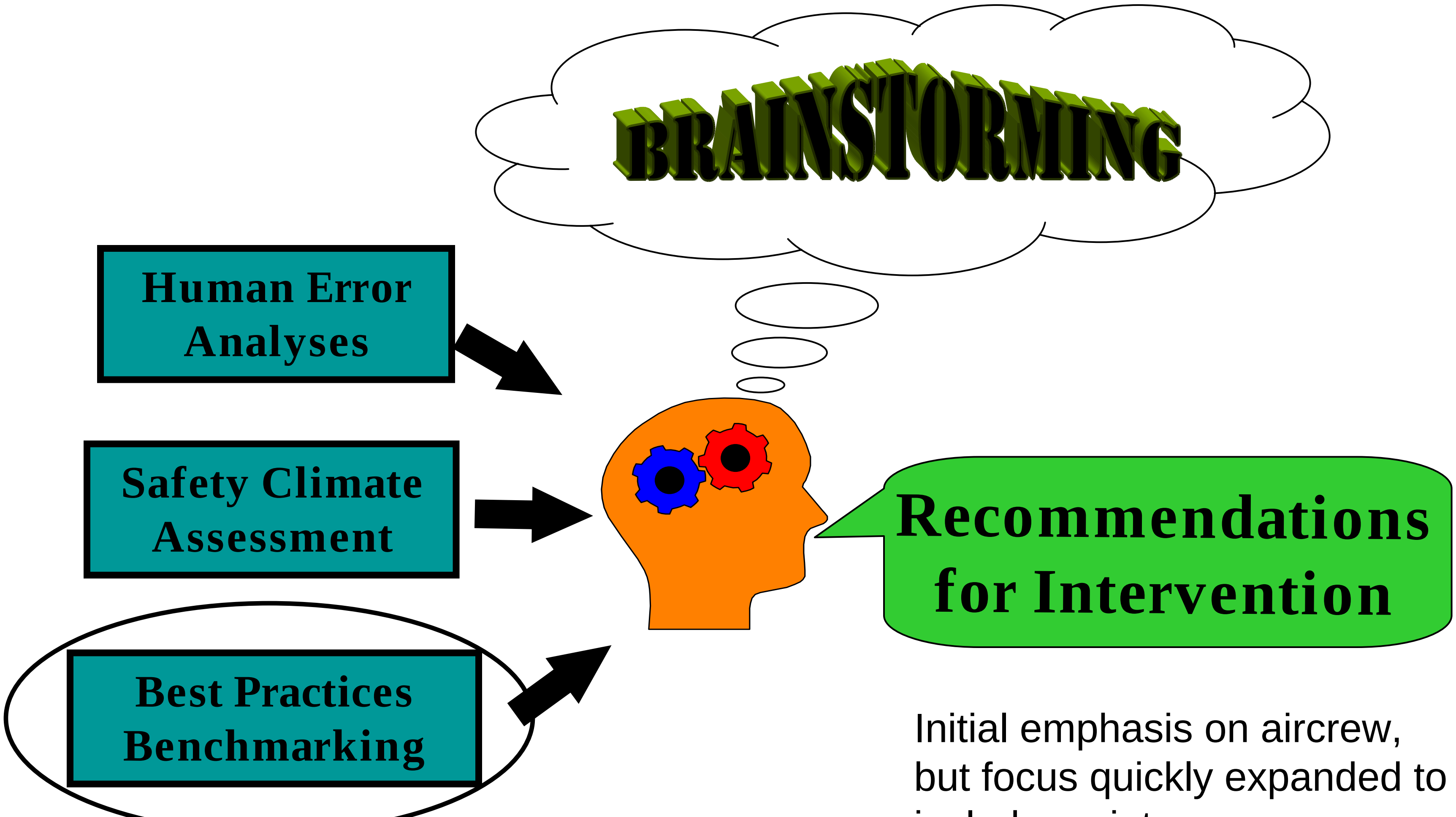
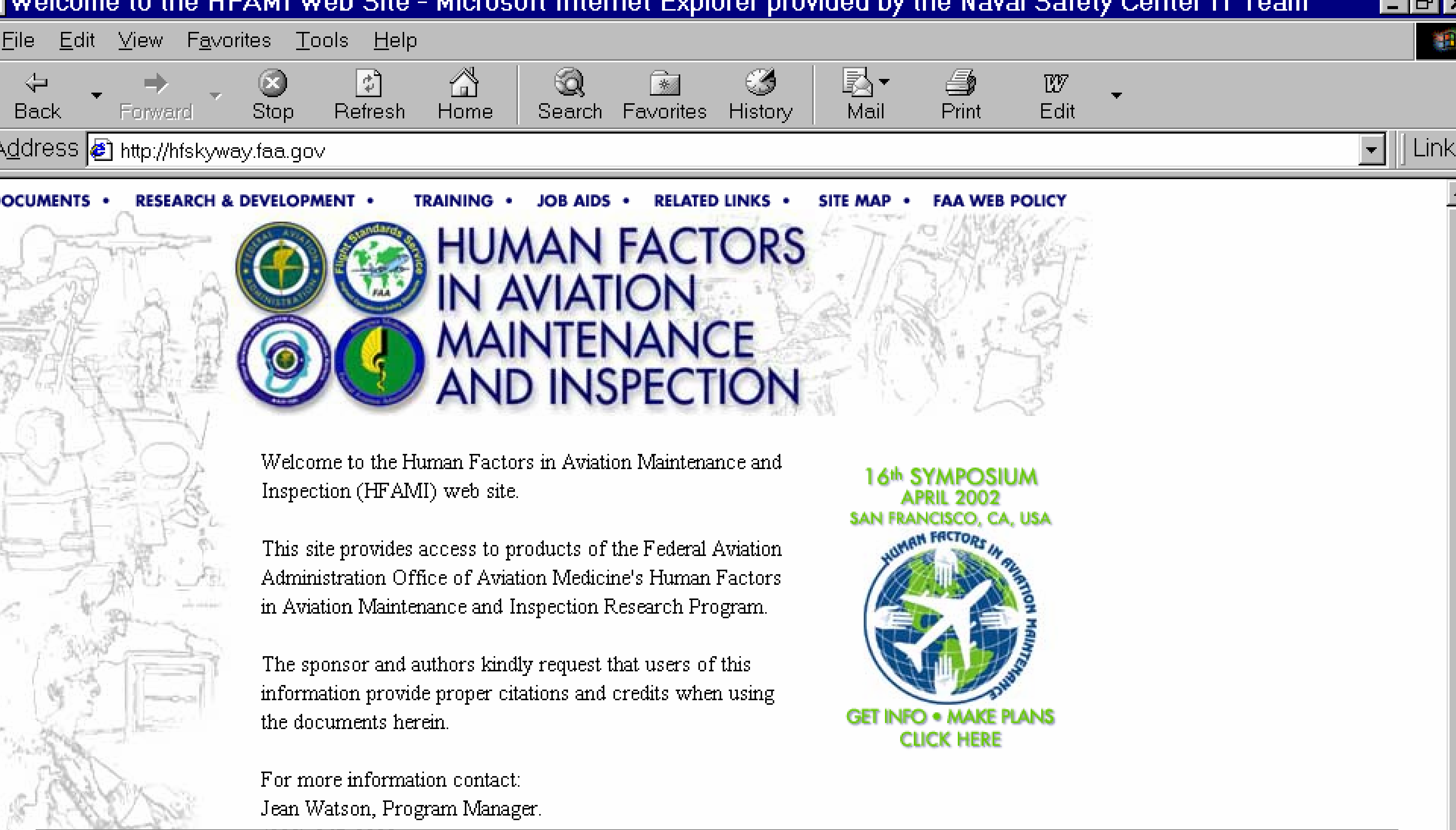
# *Naval Aviation*
# *Human Factors Quality Management Board*




Initial emphasis on aircrew, but focus quickly expanded to include maintenance

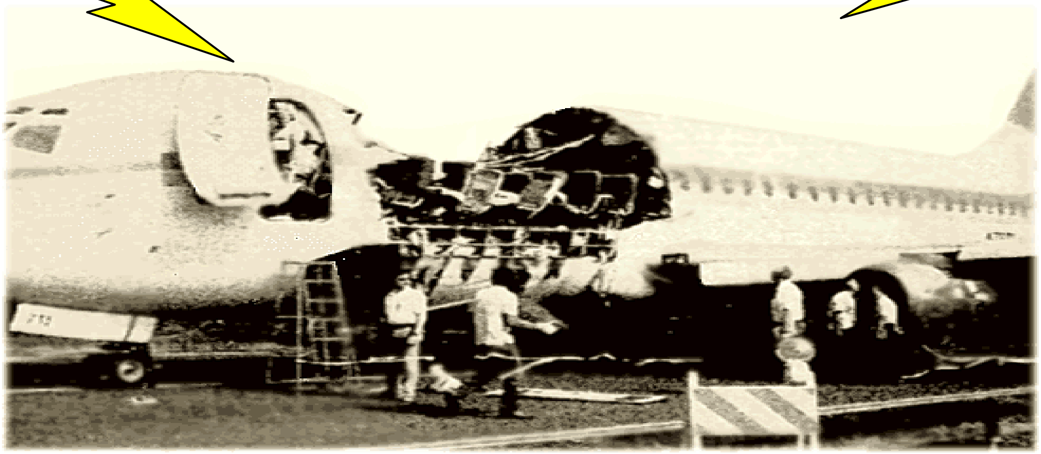


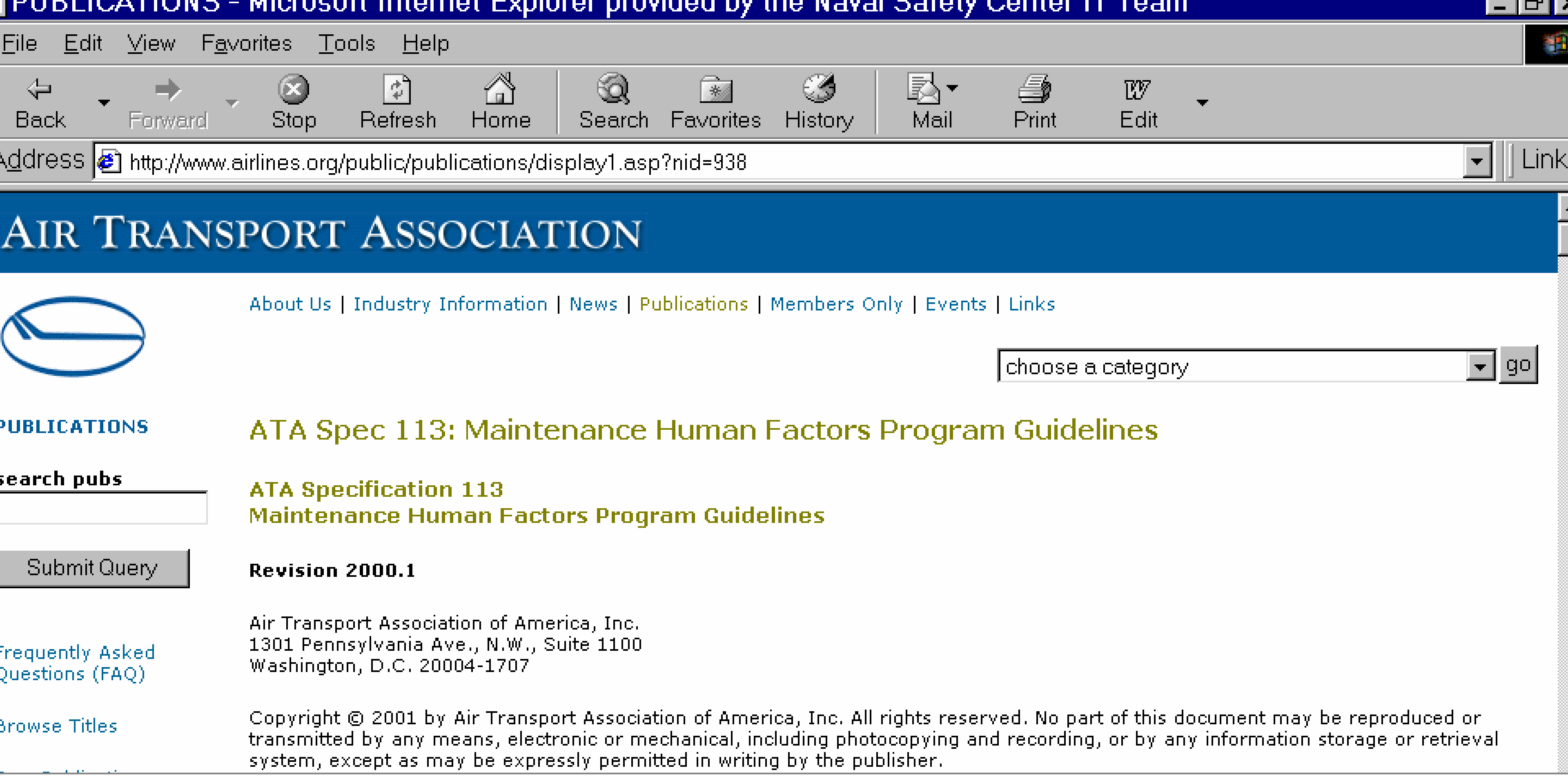

http://hfskyway.faa.gov-

FAA Human Factors in Aviation Maintenance and Inspection website provides access to research products, training materials, etc.

Aloha Airlines 243 28 APR 88

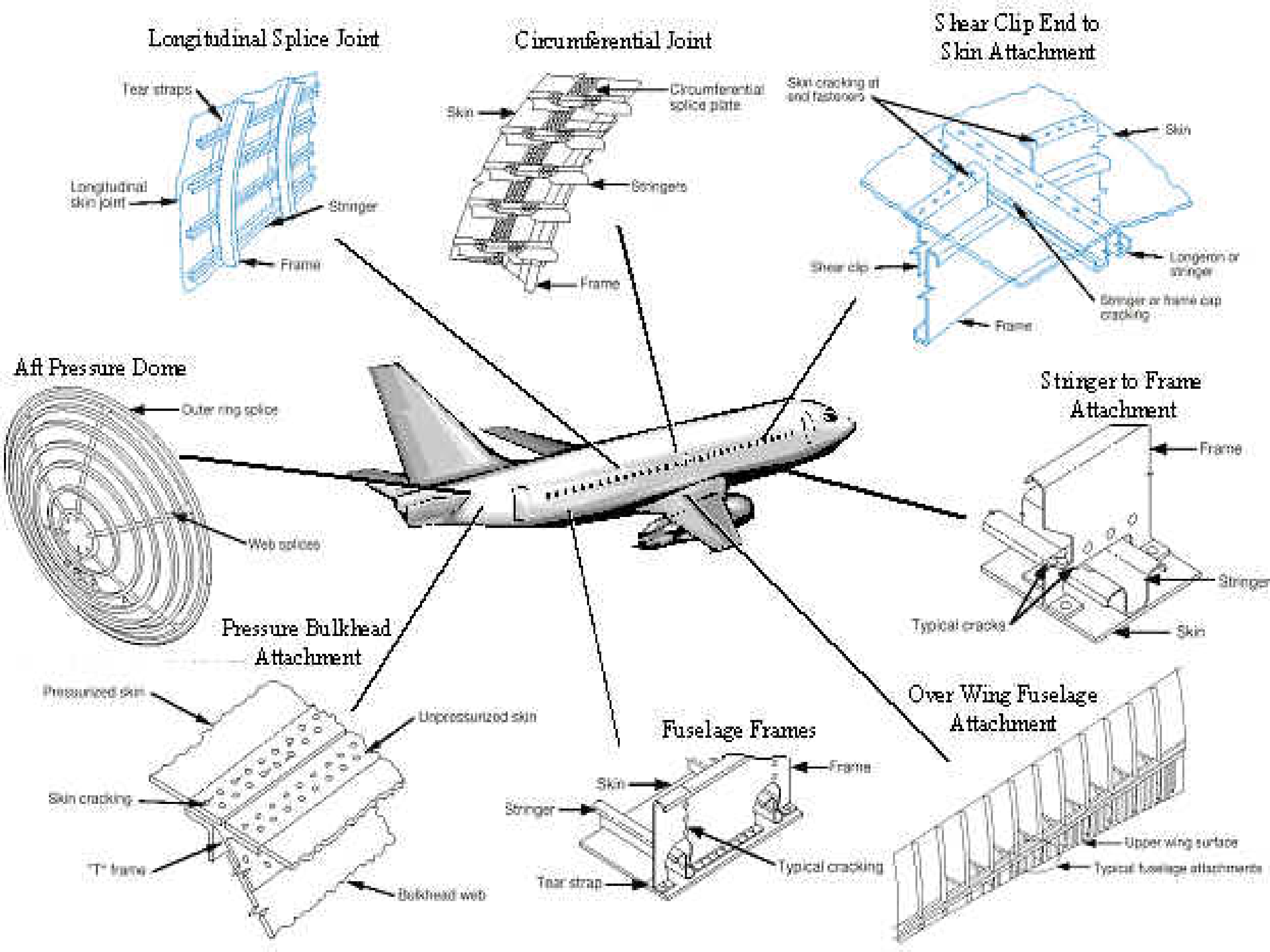
# Watershed Event






**http://www.airlines.org- ATA provides free access to ATA SPEC 113: Maintenance Human Factors Program Guidelines which outlines the essential elements for combating maintainer error:**

- **Error Investigation & Intervention**
- **Ergonomic Audits & Task Redesign**
- **Tailored Human Factors Training**



Longitudinal Splice Joint
Tear straps
Longitudinal skin joint
Stringer
Frame
Circumferential Joint
Skin
Circumferential splice plate
Stringers
Frame
Shear Clip End to Skin Attachment
Skin cracking at end fasteners
Skin
Shear clip
Longeron or stringer
Stringer or frame clip cracking
Frame
Aft Pressure Dome
Outer ring splice
Web splices
Stringer to Frame Attachment
Frame
Stringer
Typical cracks
Skin
Pressure Bulkhead Attachment
Pressurized skin
Unpressurized skin
Skin cracking
"T" frame
Bulkhead web
Fuselage Frames
Frame
Skin
Stringer
Typical cracking
Tear strap
Over Wing Fuselage Attachment
Upper wing surface
Typical fuselage attachments

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# HFAMI Inspection Reports*

- The Maintenance Technician in Inspection
- Human Reliability in Aircraft Inspection
- Correlates of Individual Differences in NDI Performance
- Training for Visual Inspection of Aircraft Structures
- Evaluating the Visual Environment in Inspection
- Design of the Aircraft Inspection Information Environment
- HF Good Practices in Borescope Inspection
- HF Good Practices in Fluorescent Penetrant Inspection

*Primarily the work products of Dr. Colin Drury SUNY Buffalo

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# Generic Inspection Task Descriptions

| Step | Visual Example | NDI Example |
|---|---|---|
| Initiate* | Get and read job card & understand covered Area | Get and read job card, understand covered area, & calibrate |
| Access | Locate area on A/C; get into correct position | Locate area on A/C; get self and equipment into correct position |
| Search** | Move eyes across systematically, stop if any indication | Move probe over each rivet head, stop if any indication |
| Decision*** | Compare indication against standard in memory (e.g., corrosion) | Reprobe while closely watching eddy current trace |
| Respond | Mark defect and write-up repair sheet, if no defect return to search | Mark defect and write-up repair sheet, if no defect return to search |
| Repair | Drill out and replace rivet | Drill out rivet, inspect rivet hole, drill out for oversized rivet |
| Reinspect | Visually inspect marked areas | Visually inspect marked areas |

(Adapted from Drury *The Maintenance Technician in Inspection*)

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# Potential Strategies for Improving Inspection

| Step | Changing Inspector | Changing System |
|---|---|---|
| Initiate* | Training in NDI calibration (Procedures) | -Redesign job/work cards<br>-Calibration of NDI equipment<br>-Feed forward of expected flaws |
| Access | Training in area location (Knowledge & recognition) | -Better support stands<br>-Better area location system<br>-Better Location of NDI equipment |
| Search** | Training in visual search (Cueing & spatial orientation) | -Improved lighting<br>-Optical aids<br>-Improved NDI templates |
| Decision*** | Decision training (Feedback & standards) | -Maintain Inspection Standards<br>-Pattern recognition job aids<br>-Improved feedback to inspector |
| Respond | Train writing skills | -Improved fault marking<br>-Hands free fault recording |

(Adapted from Drury *The Maintenance Technician in Inspection*)

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# Human Factors in Aircraft Inspection

- Example Considerations:
  - Ergonomic
    - Lighting, Access, Obstructions, Etc.
  - Training
    - Initial (Formal vs. OJT), Certification, & Recurrent
  - Supervision
    - Engineering support, Span of control, QA interaction, etc.
  - Reliability
    - Stress, Fatigue, IDs, Expectations, & Speed/Accuracy Trade-off
  - Work Aids
    - PUBs, Work Cards, Equipment, Etc.

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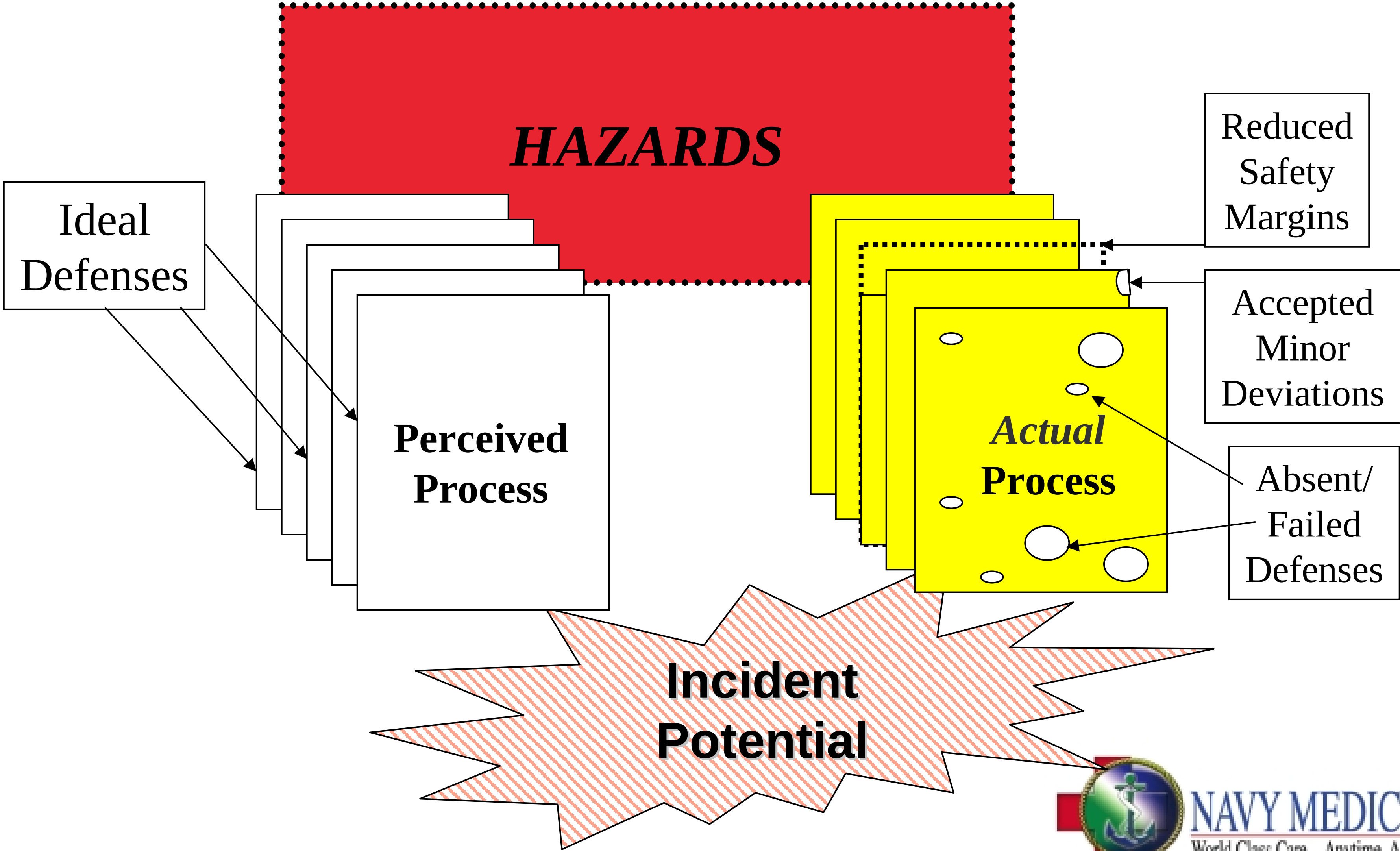
# Potential for Defense Breaches



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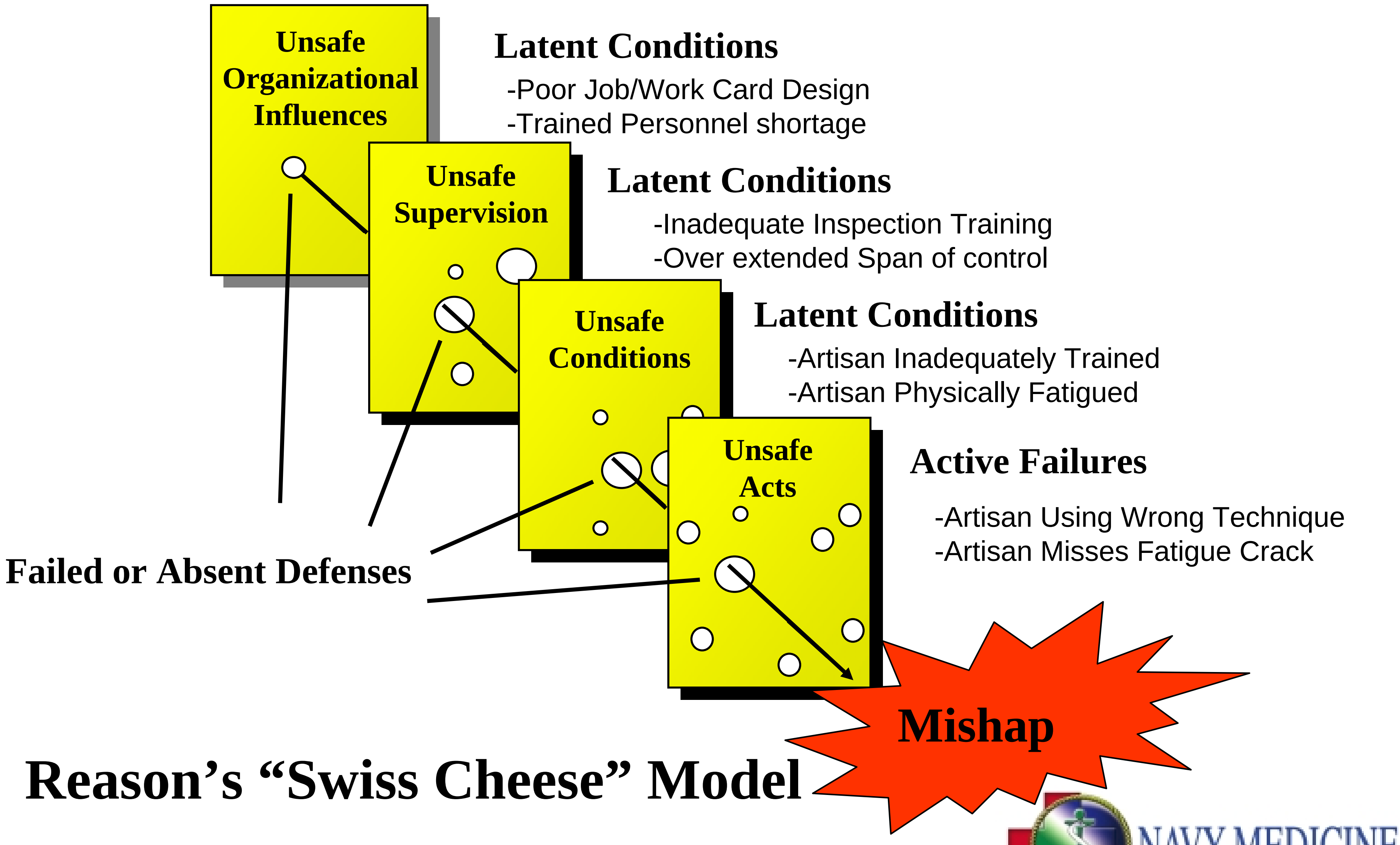


# Reason's "Swiss Cheese" Model

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