Damage Prognosis in Commercial Aircraft Riveted Lap Joints

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Presentation Outline

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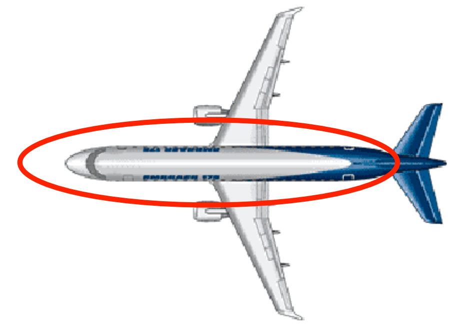
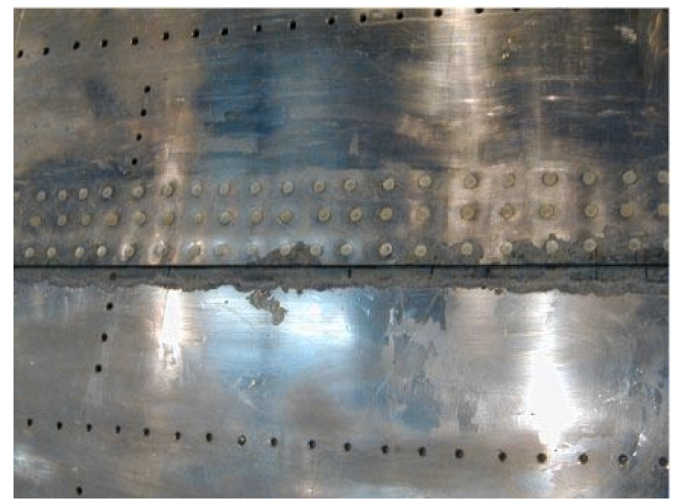
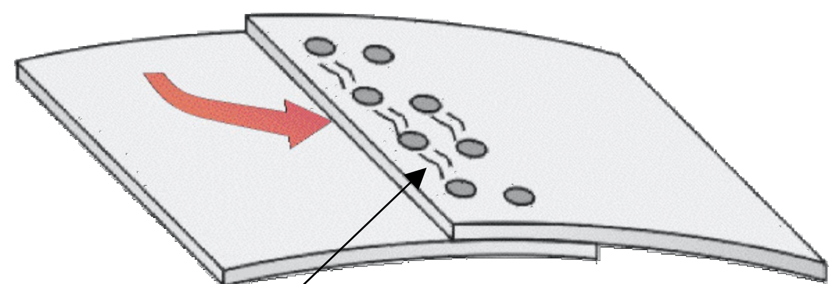
Introduction



- Aircraft riveted lap joints are critical areas on the aircraft
- These areas are susceptible to stress-corrosion fatigue cracks
- 93% of cracks on commercial aircraft occur within the fuselage area
- The Aloha Airlines crash for example was due to multi-site fatigue cracking in riveted joints

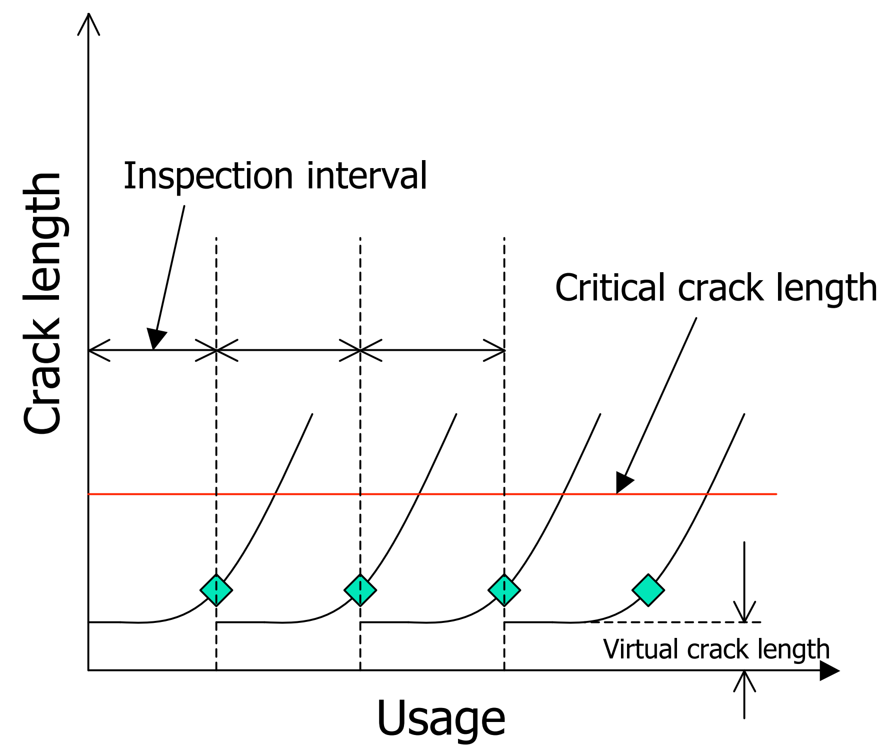




Motivation – Current Inspection Standards

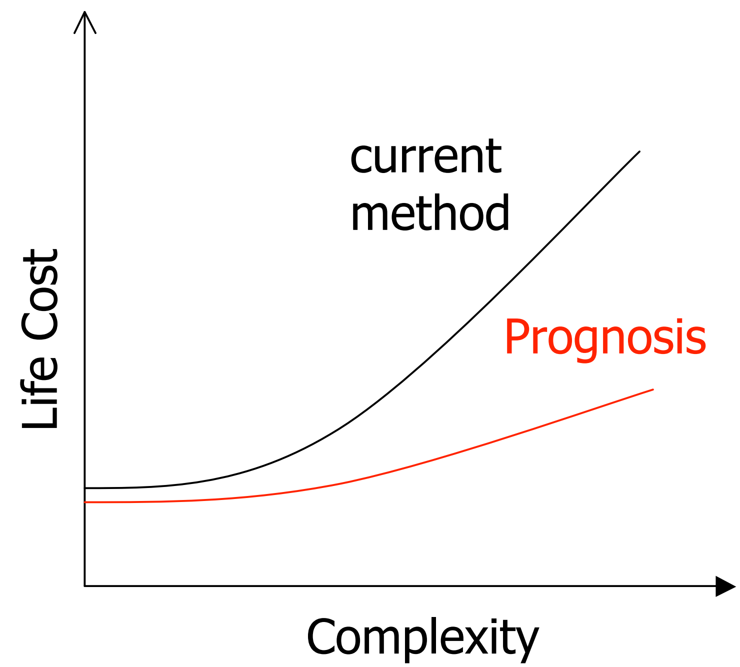
Damage Tolerance Design:

- A virtual crack is assumed to be present
- This virtual crack progresses to a critical crack length
- The inspection time is taken to be one half of the time to reach the critical crack length
- Inspection are time based, not condition based



Motivation – Cost benefits

- Reducing design conservatism ($1 million/ pound over life of the plane)
- Individualizing service
- Safety
- Engineering support: *model validation, real full scale data, determining loads for validation.*
- Leveraging current maintenance methods



Challenges

- Potential crack location (rivets) are numerous (~1 million) and wide spread
- Loads (stresses, fretting, corrosion, vibrations) can vary widely throughout the fuselage structure
- Panel material properties (dislocation density) can vary throughout the structure
- Onset of initial crack is too late
- Consumer confidence

Solutions

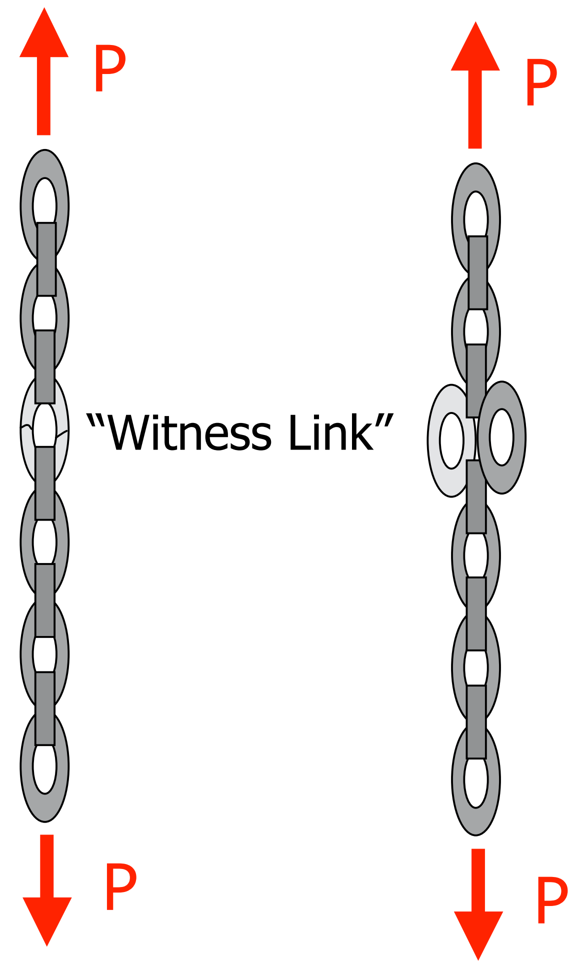
- Isolate damage locations
- Obtain stress information through strain gauges at select locations (hot spots)
- Collect material data through NDE methods, and cater specific panels with known characteristics to serve as "witness samples"
- Provide a system capable of predicting onset of crack
- Perform standard maintenance in parallel until confidence is gained

Strategy

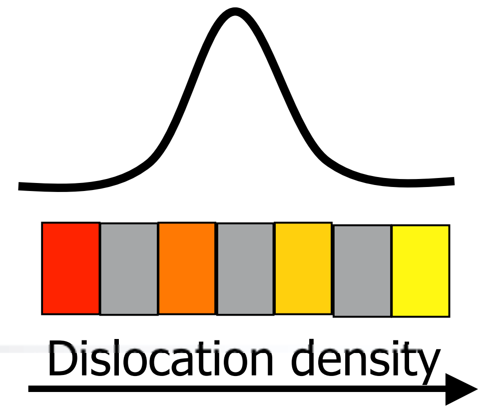
Witness Sample:

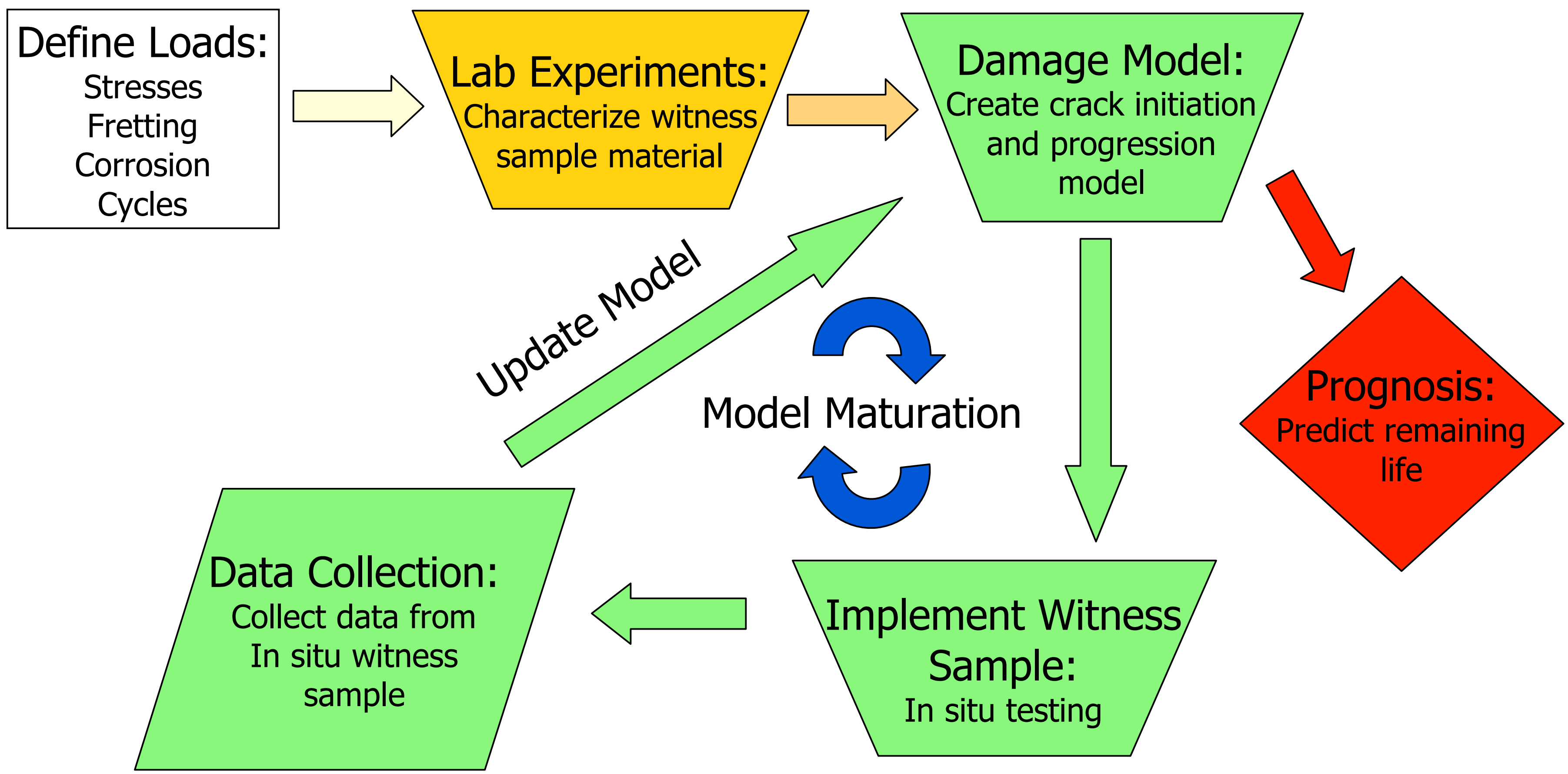
Material or component with catered properties such that the response of the material under given loads or environment is well characterized.

eg. Corrosion sensors, shear pins



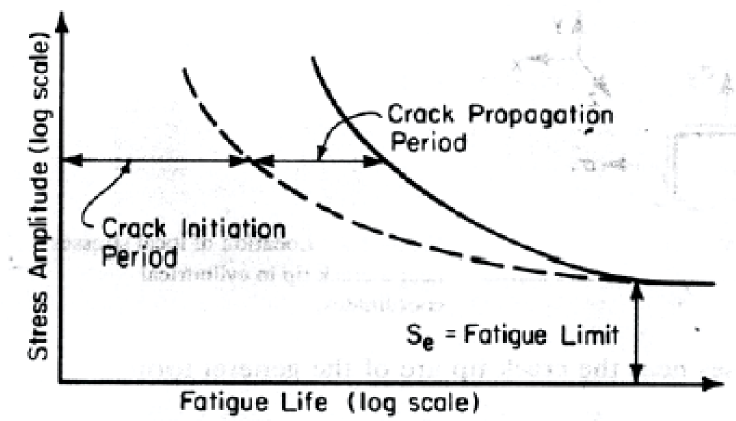
Prognosis algorithm

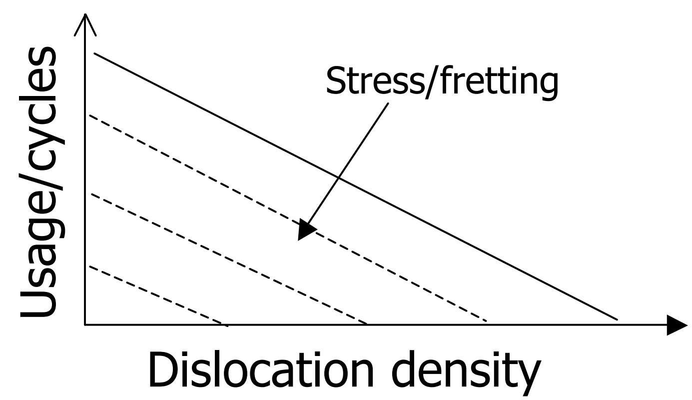




Damage models

- Damage type of interest:
  - Cracks
- Damage models:
  - Phenomenological crack initiation model
  - Crack propagation model





Plastic flow model

- Prandlt-Reuss Model

$$\dot{\lambda} = \frac{H(f)}{h}\left\langle \frac{\partial f}{\partial \sigma} : \dot{\sigma} \right\rangle$$

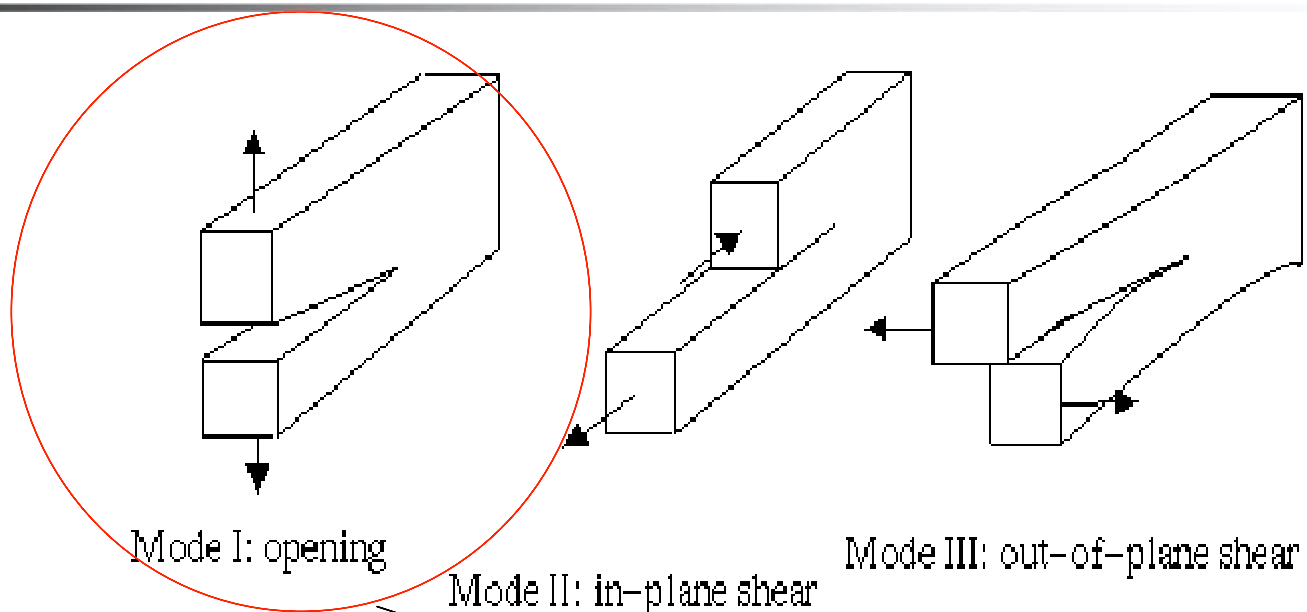
H=Heaviside function
f=load function, defines the elastic-plastic domain

- We can use the Prandlt-Reuss model to define the flow of the material

$$\dot{\lambda} \geq 0$$

- If this condition is satisfied we will have material flow. If the stress increases beyond the rupture stress a crack will form

Damage models (cont'd)



Only relevant fracture mode for crack evolution in this problem

Fracture mechanics, Paris model

The size of the crack is monitored by the Paris model.

$$\frac{da}{dN} = C(\Delta K)^m$$

$$N_f = \int_{a_i}^{a_f} \frac{da}{C(\Delta K)^m}$$

$$a_f = \frac{1}{\pi}\left[\frac{K}{\sigma f(g)}\right]^2$$

a= crack size

N=cycle number

K=intensity factor

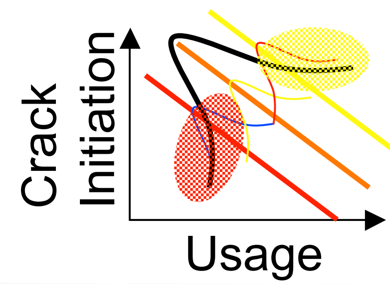
C=material property

m=material property

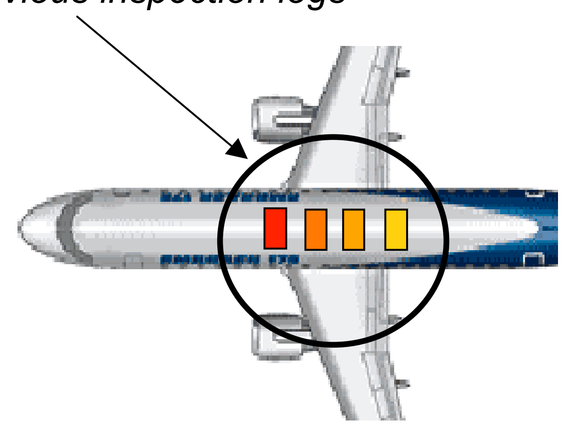
_=stress state

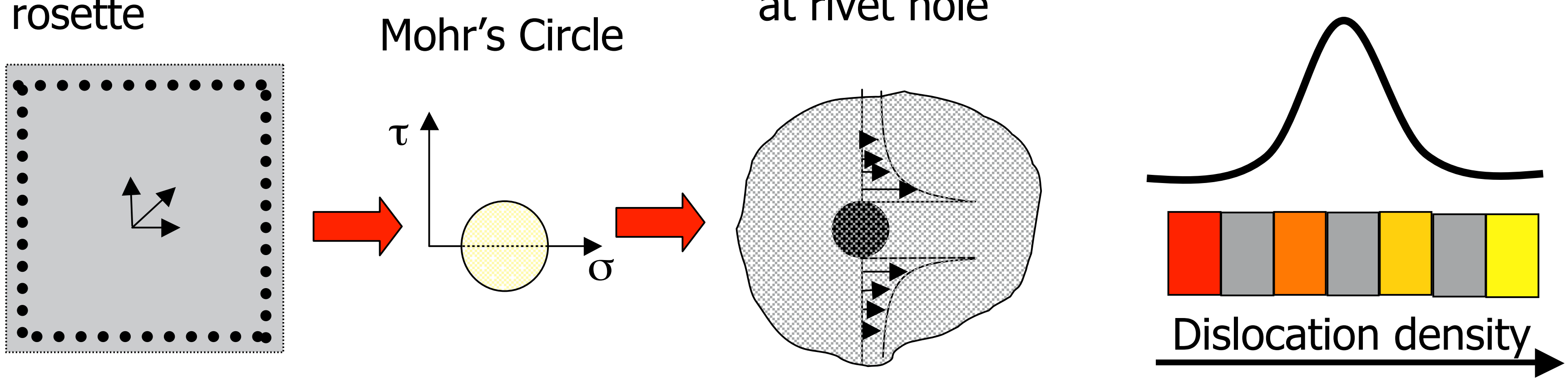
f(g)=correction factor

Implementation: Witness Sample

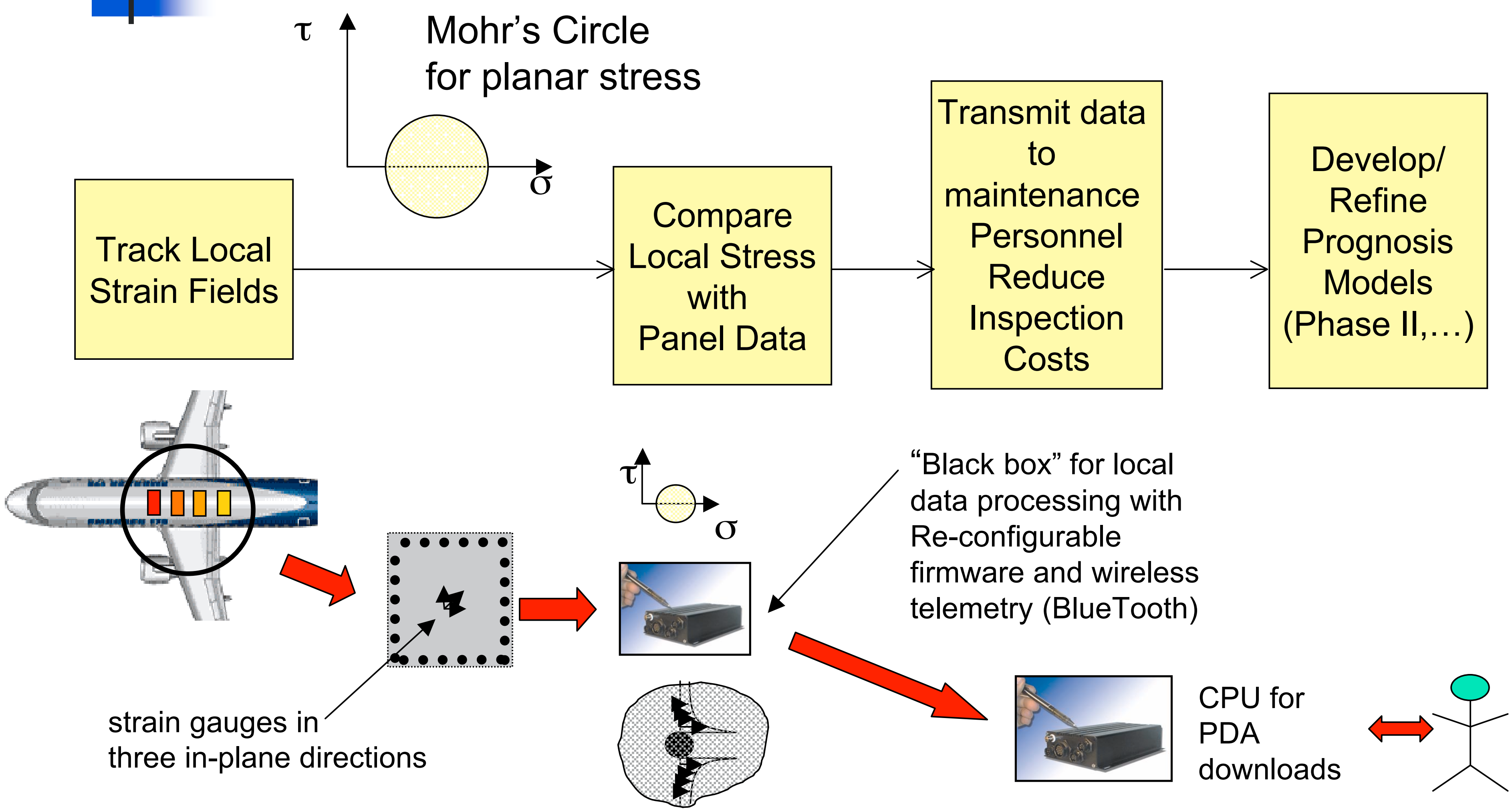


- An array of witness panels with known dislocation densities will be located at points of critical loading "hot spots".





Implementation: Monitoring



Prognosis: Phase II

- As the system matures with increased data from in situ monitoring of witness panels, predictions could be made to forecast remaining life
- Though this system would ideally be implemented on new aircraft, the same concept could be used on existing aircraft by selecting existing panels to act as the witness samples.
- After this method proves itself, some piezo-based health monitoring technique (Impedance-based/ Lamb-wave based/others) will be used which will be augment the model-based predictions and possibly eliminate visual inspections