POLITECNICO
MILANO 1863

Application 1 – Part 2

Safe-life and damage tolerance analysis of TP400 propeller shaft

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Avio Aero

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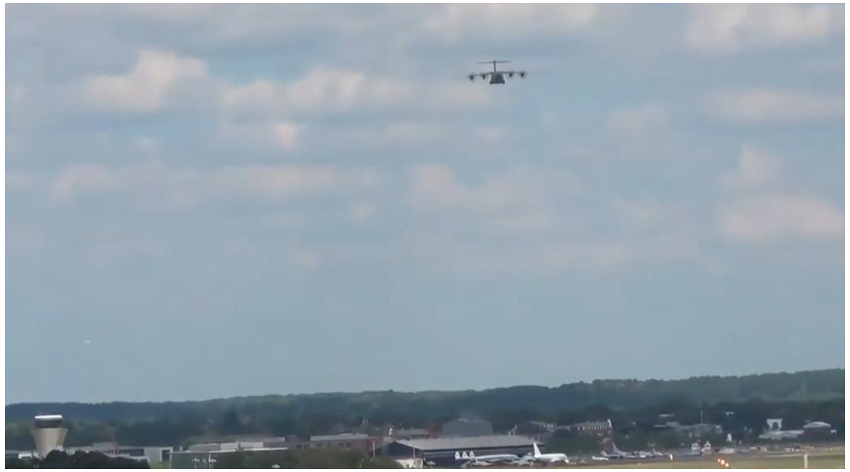
Introduction (1)

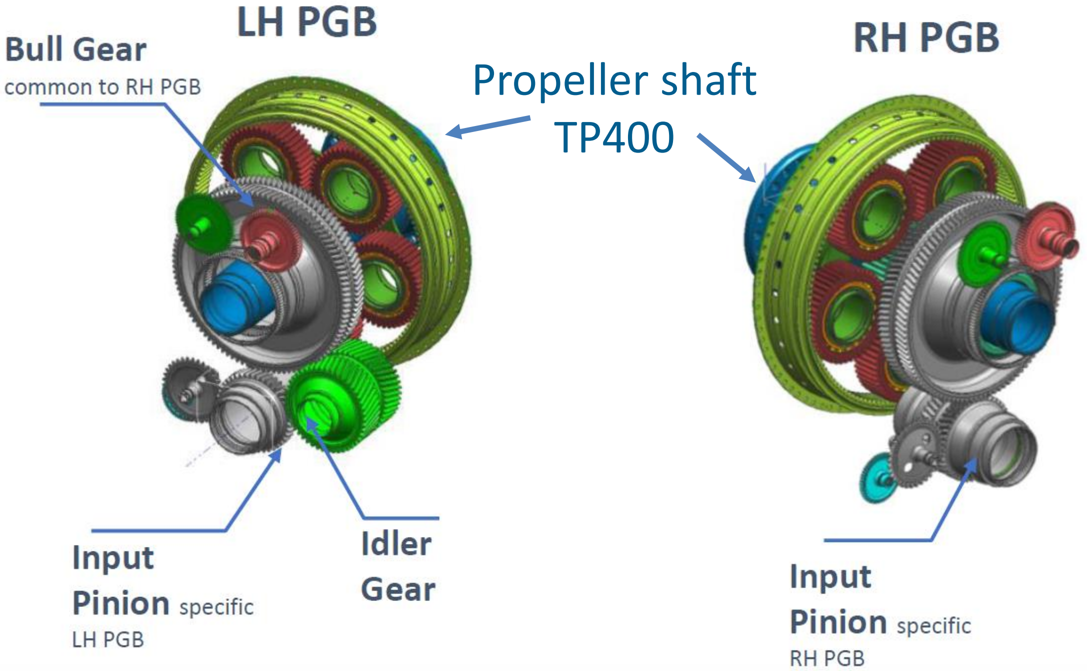


[Airbus A400M](#)

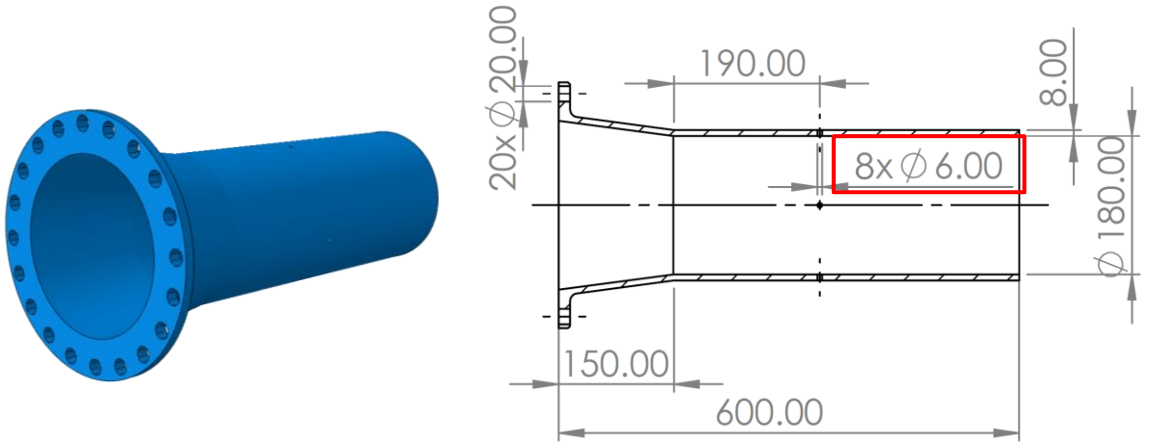
Military airlifter

Four-engine turboprop

Gear transmission

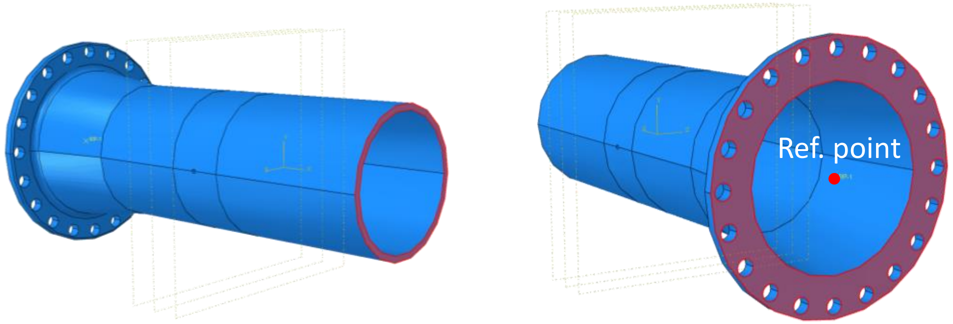


Introduction (2)



Shaft geometry

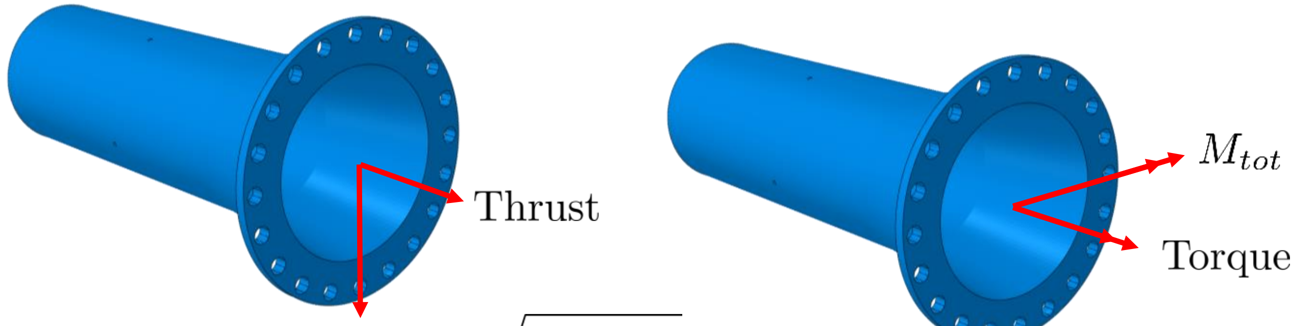
Numerical model for local stress identification



One end is encastered

The other is coupled with a ref. point for load application

Loads acting on the shaft



$$F_{tot} = \sqrt{F_x^2 + F_y^2}$$

For simplicity, we assume that radial forces generate a moment in phase with the bending moment (conservative assumption)

During operation, the shaft rotates:

→ Torque and thrust generate a costant state of stress (**mean stress**) in the section

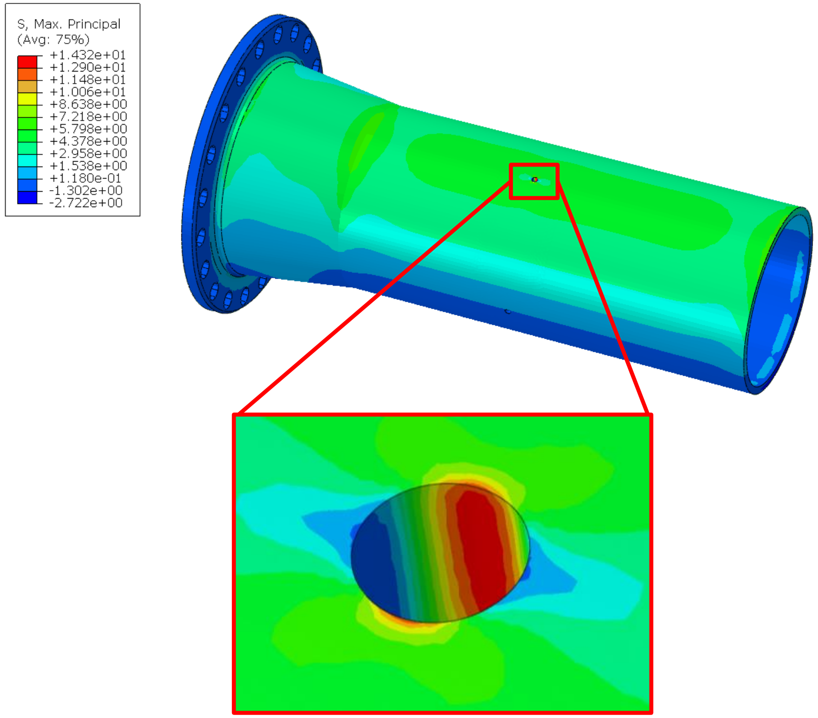
→ Bending moment and radial force generate an **alternate stress** state in the section

Stress history data (1)

We have the measurements of the loads acting on the shaft for 3 different mission profiles:

- Profile 1: approximately 3 hours of flight
- Profile 2: approximately 1 hours of flight
- Profile 3: extreme flight mission (to be used for maximum admissible crack)

→ A standard mission is composed by profile 1 + profile 2 (4 hours of flight)

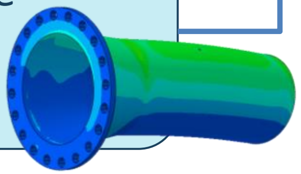


Most critical point is the drain hole

Time history of load components

$M_{tot}(t),\ F_{tot}(t),\ \ldots$

FE model of the component



→ Time history of equivalent amplitude and mean stress

$\sigma_a(t),\ \sigma_m(t)$

Stress history data (2)

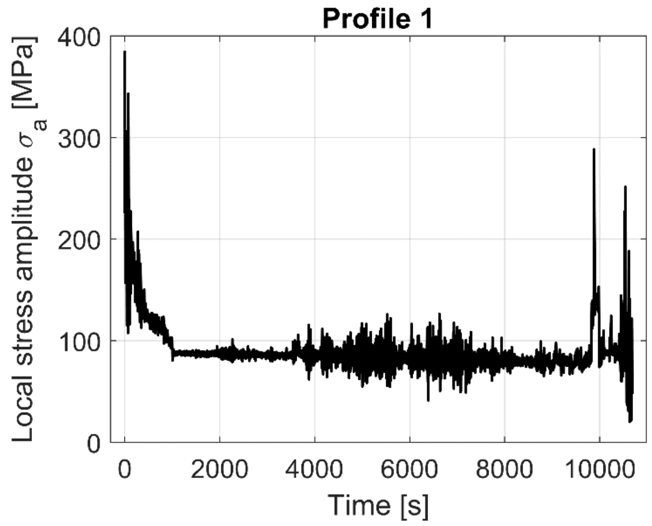
- For each profile, you have an excel file with three columns: time, alternate stress and mean stress (maximum value during the sampling time)
- The shaft rotates with a constant rotational speed ω of 900 rpm
- The stresses are given as local values, i.e. they already embed the concentration factor given by the hole (K_t = 3)

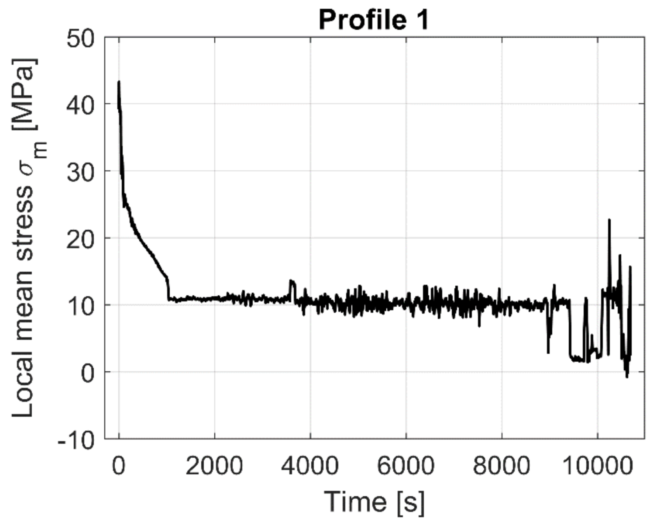
t [s]	σ_a [MPa]	σ_m [MPa]
0	225.707	39.179
0.156	259.589	40.100
0.313	272.900	40.566
0.469	295.062	40.900
0.625	340.689	41.814
0.781	364.744	42.269
0.938	360.365	42.503
1.094	370.745	42.809
1.25	384.434	43.201
1.406	380.566	43.282
1.563	376.857	43.148
…	…	…

Each line correspond to a number or cycles:

$$n_i = \omega(t_{i+1} - t_i)$$

!! ω in round per seconds !!

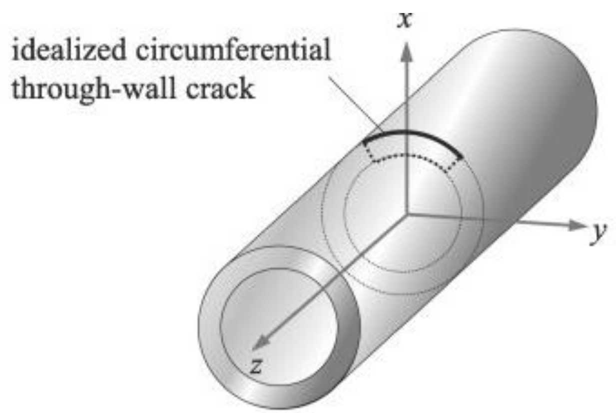




Part 2 – Task 1

Determine the critical crack size using the EPFM theory

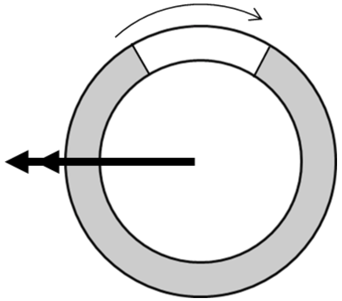
- Use FAD with option 1
- Use the maximum stress from profile 3 (tip: it corresponds approximately to a bending moment of 70 kN m applied in the critical section of the shaft)



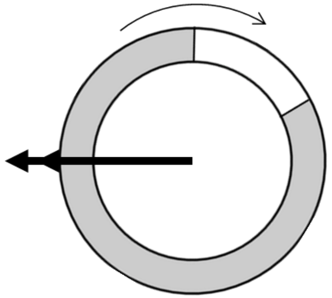
Once the crack grows, we can idealize the component as a pipe with a circumferentially oreinted crack

- The crack is fixed in the section
- The bending moment is rotating

→ **Consider the two following cases**



Configuration 1: the crack midpoint is in the maximum stress point
→ More critical for plastic collapse

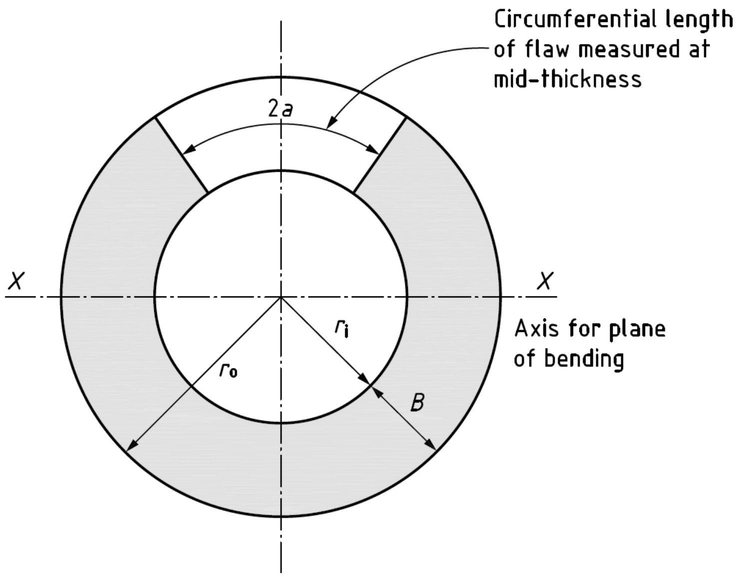


Configuration 2: the crack tip is in the maximum stress point
→ More critical for instability

The critical crack size is the smallest value among the two

Part 2 – Task 1

Determine the critical crack size using the EPFM theory – Configuration 1



J = pi*(De-Di)^4/65

I will input a in NASGRO

λ	M_3	M_4
0	0	1
0.251	0.021	0.828
0.502	0.028	0.733
1.505	0.054	0.544
2.257	0.063	0.45
3.261	0.069	0.364
4.515	0.074	0.299
5.518	0.079	0.264
6.772	0.088	0.23
7.776	0.1	0.205
9.032	0.119	0.179

Stress intensity factor solutions

$$K_I = M_b P_b \sqrt{\pi a}$$

$$\begin{cases} M_b = M_3 + M_4 \\ P_B = \frac{64M}{\pi(D^4 - d^4)} D/2 \\ \lambda = \left[12(1-\nu^2)\right]^{0.25} \frac{a}{\sqrt{r_m B}} \end{cases}$$

Ligament yielding factor

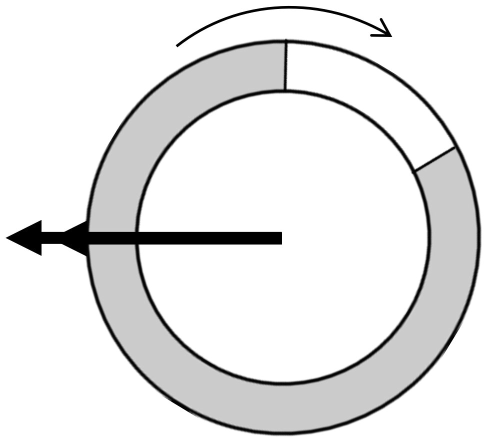
$$L_r = \frac{\sigma_{ref}}{\sigma_Y} \qquad \alpha = \frac{a}{r_m}$$

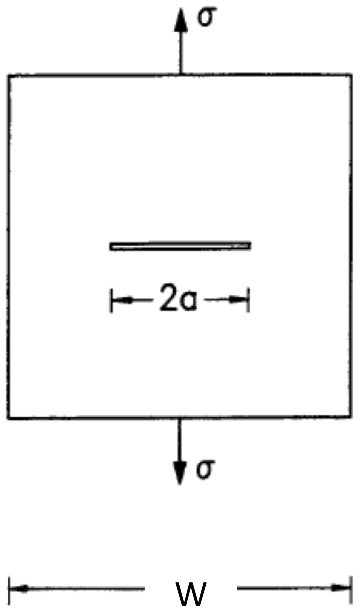
$$\sigma_{ref} = \frac{\pi P_B}{\pi - \alpha - 2\frac{\sin^2\alpha}{\pi - \alpha} - \frac{\sin(2\alpha)}{2}}$$

Part 2 – Task 1

Determine the critical crack size using the EPFM theory – Configuration 2

→ The cylinder is approximated with a plate subjected to tension, with width equal to half of the circumference. The stress is the maximum bending stress.





$$\sigma = P_B$$

$$W = \pi r_m$$

Stress intensity factor

$$K_I = Y \sigma \sqrt{\pi a}$$

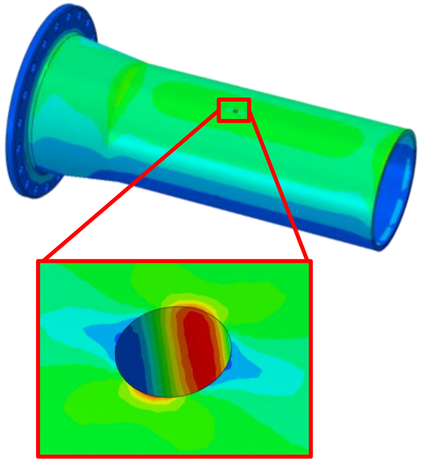
$$Y = [\sec(\pi a / W)]^{0.5}$$

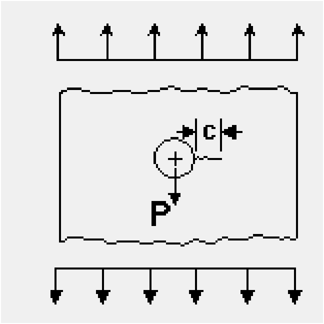
Ligament yielding factor

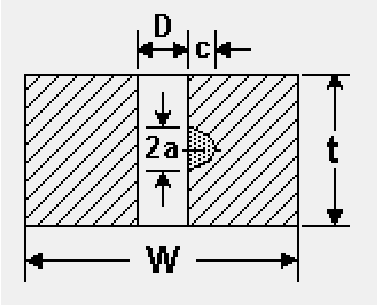
$$L_r = \frac{\sigma / (1 - 2a/W)}{\sigma_Y}$$

Part 2 – Task 2

Perform a damage tolerance analysis considering an initial semi-elliptical surface crack at hole. Consider an initial semi-circular defect with a = 0. 38 mm. Use the maximum admissible crack computed for task 2.







Model the component with a plate of width half of the circumference, with a surface crack at hole. Apply the suitable remote stress (Kt = 3, ≠ local stress)

Material: AISI430 steel, different grades according to your project code

Project Code	Material name	NASGRO Material code
1	4340, 1103-1241 UTS	C-4-DE-13AB1
2	4340, 965-1103 UTS	C-4-DD-11AB1
3	4340, 1241-1380 UTS	C-4-DF-13AB1
4	4340, 1379-1571 UTS	C-4-DG-13AB1

Part 2 – Task 2

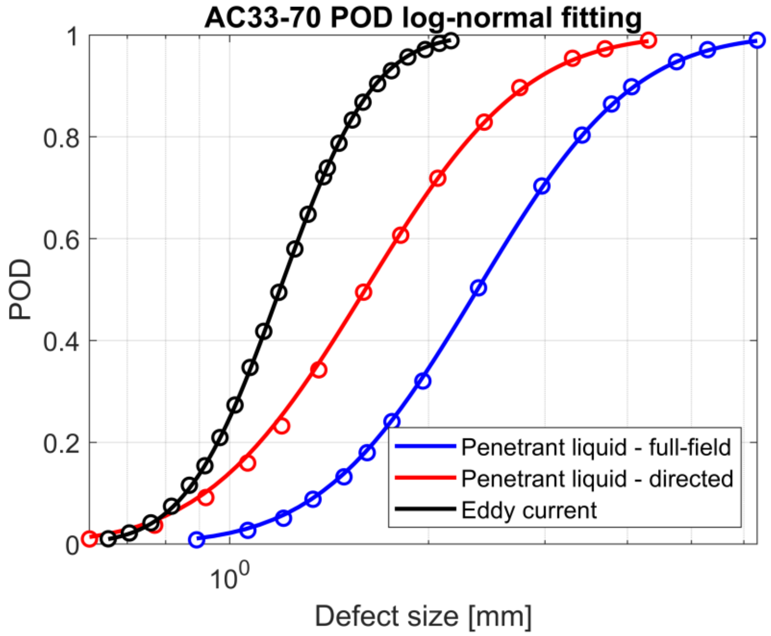
Perform a damage tolerance analysis considering an initial semi-elliptical surface crack at hole. Consider an initial semi-circular defect with a = 0.38 mm. Use the maximum admissible crack computed for task 2 (correct the material properties if needed).

Mandatory tasks (deterministic assessment):

3.1) Find the maximum number of missions for Profile 1. Lump the signal and randomize the sequence.

3.2) Find the maximum number of standard mission (Profile 1 + Profile 2). Lump the signal and randomize the sequence.

3.3) If the target life of 3000h is not met, find the number of inspections ensuring a failure probability compliant with regulations (2e-5). Use the POD curves in the Advisory Circular AC 33-70.2 (Appendix 4)



From Lesson 9…