Conference JERI 2017

Agressivité du trafic pour les chaussées, les atterrisseurs d'avions

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CONTENTS

- Airfield pavement specificities
- Pavement design and pavement rating system
- New ACNs ➔ ACR
- New PCN procedure ➔ PCR
- PCR example

Airfield pavement specificity
Loads

- Uniform loads (~ 13t/axle, 6.5t/wheel

- Single Wheel ~ 5t
- (light aircraft, general aviation)

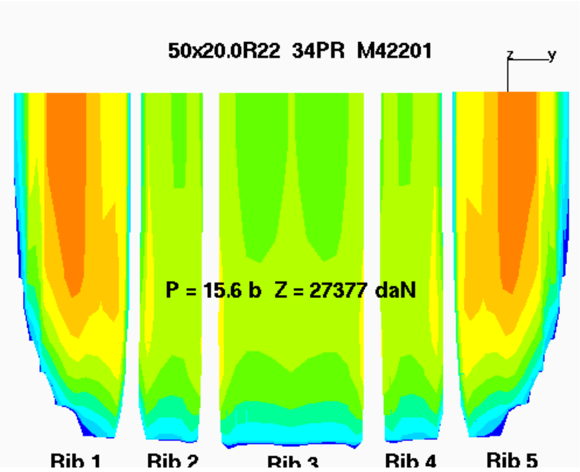
- Dual wheel ~ 5t to 40t
- (A320, 737, C-series…)

- 4-wheel bogie ~ 40t to 130t
- (A330, 767, A359…)

- 6-wheel bogie ~ 120t to 170t
- (A350-1000, 777…)

Airfield pavement specificity
Tyre pressure inflation

- Ranging from 0.2 to 0.7 MPa



- Light aircraft ~ 0.15MPa
- (general aviation)

- Dual wheel ~ 0.5MPa to 1.5MPa
- (A320, 737, C-series…)

- 4-wheel bogie ~ 1MPa to 1.7Mpa
- (A330, 767, A359…)

- 6-wheel bogie ~ 1.3Mpa to 1.6MPa
- (A350-1000, 777…)

Non-uniform tyre pressure contact

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Airfield pavement specificity
Traffic characteristics / density

- $>10^6$ movements along pavement life cycle
- Channelled traffic

- Between 10^4 and 10^6 movement along pavement life cycle
- Variable traffic

  Apron / Parking: Channelled traffic
  Taxiway: +/- 50cm wander
  Runway: +/-75cm wander

- Aircraft overall landing gear track ranging from 2m to 15m

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Airfield pavement specificity
Speeds

- Speed depends of traffic density and road attribute

- Urban road ~ 30 to 60 km/h
- Regional deserve ~ 90-110km/h
- Highways: 120 to 140 Km/h

- Speed depends of manoeuvre area and aircraft type

Runway
- General aviation: 100 to 120km/h
- ATR42: 150 to 180km/h
- 737/A320: 180 to 250km/h
- 747, A330…: 250 to 350km/h

Taxiway
- 40/60Km/h

The ACN/PCN method

The ACN-PCN system is the worldwide official airfield pavement rating method endorsed by ICAO since 1983

It relies on the comparison of 2 elements:

- **ACN** (Aircraft Classification Number)
  - A number expressing the relative effect on an aircraft on a pavement for a specified, standard subgrade strength
  - Computed and published by aircraft manufacturers.
- **PCN** (Pavement Classification Number)
  - A number (and series of letters) expressing the relative strength of a pavement
  - Computed and published in AIP by airport authorities.

Easy-to-use and well-known system:

PCN ≥ ACN ⇨ Aircraft can operate **without restriction**

PCN < ACN ⇨ **Restrictions apply** (i.e. reduce weight and/or frequencies)

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CBR Design Procedure NO LONGER VALID FOR PAVEMENT DESIGN

- CBR Design procedure invalidated by pavement community
- But ACN/PCN system still continue to use it!
- New Pavement design method now base on the Multi-Layers-Linear-Elastic-Analysis (ML^2EA) – Rational (mechanistic) method
- ACN/PCN system MUST URGENTLY be based on the new pavement design procedure. Long time strategy and logic

ICAO DECISION TO UPGRADE ITS RATING SYSTEM

In 2012, the ICAO-AOSWG-PSG agreed that the introduction of an ACN/PCN determination procedure more consistent with modern pavement design methods needs to be addressed quickly knowing that the development of such a procedure would take time. Thoughts toward this new approach will be carried on during the 2012-2015 work cycle. ***Incorporation of new methodology expected in 2018 timeframe.****"*

OBJECTIVES:

- To align the new ACN procedure with the current practice for pavement design and analysis, multi-layered linear elastic systems (ML^2EA).
- Attempt to keep the current **ACN-PCN structure unchanged** (number, pavement type, subgrade code…).
- Develop and provide ICAO state members with a **new and unique procedure for PCN** determination using the same linear elastic methods.

BENEFITS:

- Eliminate inconsistency between new pavement design and pavement ratings which are based on different analysis methods.
- Alpha factors and thickness equivalency factors would no longer be needed.

Combined effort with FAA (NAPTF) and France (A380 PEP, HTPT) for new pavement design procedure and new pavement rating system

- Previously, it took 25 years to switch from the former LCN system to ACN/PCN

Pavement Design Method	Pavement Rating System (ACN/PCN)
CBR until 2004	Based on CBR from 1983
ML^2EA from 2004 (US), 2014 (France)	Based on ML^2EA in 2020

- Airport owners will make optimal use of their pavement infrastructure and be able to properly manage aircraft operating weights and frequencies.
- Ability to evaluate a pavement concession based on overload. This would be done by developing an acceptable overload factor for which the effect on the CDF would give the amount of pavement life reduction and would be balanced by the revenues that the overload ops would generate for the airport against provisions for pavement refurbishment
- The new system would require assistance to customers and/or Airport for assessing pavement compatibility in their respective airport network or by determining new PCNs according to the new method.

NEW ACN PROCEDURE ➔ Aircraft Classification Rational (ACR)

<table>
<tr><td rowspan="2">Reference structures</td><td colspan="2">Aircraft MLG with 2 wheels or less</td><td colspan="2">Aircraft MLG with more than 2 wheels</td></tr>
<tr><td colspan="2">P-401 / P-403 HMA E = 1379 MPa $\nu = 0.35$ 3 in (7.6 cm)
P-209 Crushed Aggregate E = f(t) $\nu = 0.35$ Design layer
Subgrade E = f(CAT) $\nu = 0.35$</td><td colspan="2">P-401 / P-403 HMA E = 1379 MPa $\nu = 0.35$ 5 in (12.7 cm)
P-209 Crushed Aggregate E = f(t) $\nu = 0.35$ Design layer
Subgrade E = f(CAT) $\nu = 0.35$</td></tr>
<tr><td rowspan="2">Subgrade categories & moduli</td><td>CAT A</td><td>CAT B</td><td>CAT C</td><td>CAT D</td></tr>
<tr><td>E = 200 MPa</td><td>E = 120 MPa</td><td>E = 80 MPa</td><td>E = 50 MPa</td></tr>
<tr><td>ACN computation procedure</td><td colspan="4">Step 1: Design the pavement structure for below parameters:
○ 36,500 cumulated aircraft passes
○ No lateral wander $(\sigma = 0)$
○ Design criterion: subgrade failure
○ Failure model: FAARFIELD v 1.41 failure model (Bleasdale + Wöhler)
○ Multi-peak damage integration for multi-axle loading

Step 2: Compute the Derived Single Wheel Load (DSWL) that will produce the same CDF (1.00) on the previously designed pavement structure. The DSWL is computed with a constant tire pressure of 1.5 MPa.

Step 3: The Aircraft Classification Number for the corresponding subgrade category is given by twice the DSWL (in tons) computed in step 2.</td></tr>
</table>

NEW ACN PROCEDURE ➔ Aircraft Classification Rational (ACR)

- 3 main differences identified between FAARFIELD and Alizé-LCPC damage calculation procedures:

✓ Subgrade failure models (relation between vertical strain and allowable coverages)

FAARFIELD (since version 1.4) uses a Wöhler model (for high subgrade strain) and a Bleasdale model (for low subgrade strain)

Alizé-LCPC uses a Wöhler model with different parameters

✓ Treatment of multi-axle loading (wheels in tandem)

FAARFIELD uses a geometrical approach by considering load repetition attributable to wheels in tandem through the “Tandem Factor” embedded in P/C ratio

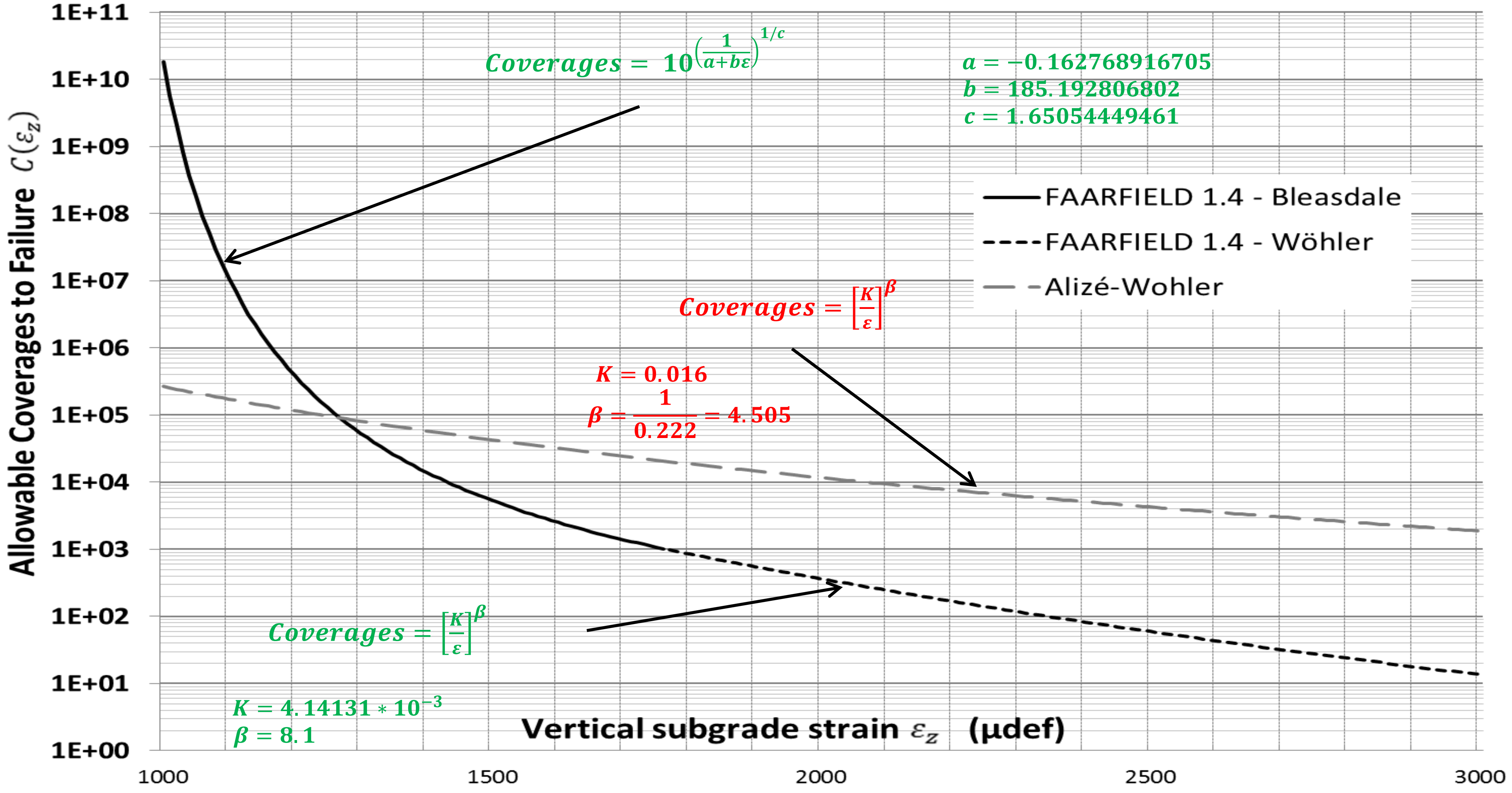
Alizé-LCPC uses a mechanical approach by integrating the multi-peak damage profile along the moving wheel axis according to Miner’s principle

✓ Consideration of lateral airplane wander

FAARFIELD uses a statistical and geometrical approach through the concept of Pass-to-Coverage ratio

Alizé-LCPC uses a mechanical approach by computing lateral damage profiles considering airplane wander and combining individual damage according to Miner’s principle

Subgrade failure model



Cumulative Damage Factor (CDF)

- The cumulative damage factor (*CDF*) is the amount of the structural fatigue life of a pavement which has been used up. It is expressed as the ratio of applied load repetitions to allowable load repetitions to failure, for a traffic mix or, for one airplane and constant annual departures:

- $CDF \stackrel{\text{def}}{=} \frac{\text{Applied coverages}}{\text{Coverages to Failure}}$

- When CDF = 1, the pavement will have used up all of its fatigue life,

- When CDF <1, the pavement will have some remaining potential life, and the value of CDF will give the fraction of the life used,

- When CDF >1, All of the fatigue life will have been used up and the pavement will have failed.

Treatment of multi-axle loadings

- In Alizé-LCPC, the cumulated damage attributable to multi-axle loading is computed by considering the full strain temporal response signal

- This **mechanical approach** takes into account not only the maximum strain values at peaks, but also the strain unloading between peaks

- This is achieved through the continuous integration of the elementary damage D_e along the longitudinal strain profile (also referred as "multi-peak damage integration"):

$$D_e(\varepsilon) \stackrel{\text{def}}{=} \frac{1}{Cover(\varepsilon)} \qquad \text{(Miner's law)}$$

- The cumulated damage D for one aircraft pass is given by:

$$D = \int_{x=-\infty}^{x=+\infty} \frac{dD_e(x)}{dx} dx = \int_{x=-\infty}^{x=+\infty} \frac{dD_e(\varepsilon)}{d\varepsilon} \left\langle \frac{d\varepsilon(x)}{dx} \right\rangle dx \qquad \text{with } \langle u \rangle = \begin{cases} 0, & u \leq 0 \\ u, & u > 0 \end{cases}$$

ML²EA for ACR calculation

	FAARFIELD approach	Alizé-LCPC approach	Rationale
Subgrade failure model	Bleasdale + Wöhler	Wöhler	FAARFIELD failure model substantiated by more tests
Treatment of multi-axle loading	Tandem Factor [geometrical approach]	Multi-peak damage integration using Miner's principle [mechanical approach]	Alizé-LCPC more consistent with subgrade strain profiles
Consideration of lateral airplane wander	Pass-to-Coverage ratio (P/C) [geometrical and statistical approach]	Individual damage combination using Miner's principle [mechanical approach]	No impact since ACN to be computed without lateral wander

Retained approach for new ACN procedure

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ML²EA for ACR calculation

- **Note:** Since the Bleasdale/Wöhler failure model is adopted, the general differential form of multi-peak damage integration can be rewritten for this specific failure model

$$D = \int_{x=-\infty}^{x=+\infty} \frac{dD_e(x)}{dx} dx = \int_{x=-\infty}^{x=+\infty} \frac{dD_e(\varepsilon)}{d\varepsilon} \left\langle \frac{d\varepsilon(x)}{dx} \right\rangle dx$$

	Bleasdale part (ε ≤1765.093 µdef)	Wöhler part (ε >1765.093 µdef)
Failure model	$\boldsymbol{Cover(\varepsilon) = 10^{\left(\frac{1}{a+b\varepsilon}\right)^{1/c}}}$	$\boldsymbol{Cover(\varepsilon) = \left[\frac{K}{\varepsilon}\right]^{\beta}}$
Elementary damage	$\boldsymbol{D_e(\varepsilon) = 10^{-(a+b\varepsilon)^{-1/c}}}$	$\boldsymbol{D_e(\varepsilon) = \left[\frac{\varepsilon}{K}\right]^{\beta}}$
Multi-peak damage	$\boldsymbol{D = -db\ \ln 10 \int_{-\infty}^{+\infty} M^{d-1}\, 10^{-M^d} < \frac{d\epsilon}{dx}(x,y,z_k) > dx}$ with $\begin{cases} d = -1/c \\ M = a + b < \boldsymbol{\varepsilon(x,y,z_k)} > \end{cases}$	$\boldsymbol{D = \frac{\beta}{K^{\beta}} \int_{-\infty}^{+\infty} < \varepsilon(x,y,z_k) >^{\beta-1} < \frac{d\epsilon}{dx}(x,y,z_k) > dx}$

$\varepsilon(x, y, z_k)$ is the longitudinal strain profile along (y, z_k)

- This multi-peak damage integration procedure has been implemented in Alizé-LCPC

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NEW PCN PROCEDURE ➔ Pavement Classification Rational (PCR)

1. Enter pavement data (Thickness, E-Modulus, Poisson's ratio),
2. Determine the traffic mix in terms of aircraft type, number of departures and weight that the evaluated pavement is supposed to experience over its design or remaining potential life,
3. Compute the max CDF of the entire fleet and record the value,
4. Select the aircraft with the highest contribution to the max CDF,
5. Keep the most contributing aircraft and remove all other aircraft (steps 3, 4, 5 consist in converting the traffic mix into a single equivalent aircraft which produces the same damage as produced by the traffic mix)
6. Adjust the annual departure of the equivalent aircraft until the max aircraft CDF is equal to the value obtained in (3). Note the equivalent annual departure,
7. Adjust the aircraft weight to obtain a max CDF of one with a number of annual departures obtained at step (6). The new weight is noted Maximum Allowable gross Weight (MAGW)
8. Compute the aircraft ACR at its MAGW. Note the value obtained (ACR1),
9. Remove the previous aircraft and re-introduce the other aircraft composing the mix,
10. Compute the max CDF of the <u>entire new fleet</u> and select the most contributing aircraft to the max CDF (this CDF is obviously different than the one obtained in (3) since one aircraft is missing,
11. Repeat step 4-10. By keeping the max CDF of the initial traffic mix. Note the values obtained (ACR_i),
12. RUNWAY PCR=Max ACR_i (from step 1 to 9)

PCR: Subgrade Strength Categories

- Since CBR design procedure is no longer the reference for ACR calculation, the four subgrade categories are characterized by the subgrade modulus of elasticity (E) instead of CBRs. High, medium, low and very low subgrade strength are respectively represented by:

- Category A (currently CBR 15): *E* = 200 MPa (29 008 PSI), representative of all values of *E* greater than or equal to 150 MPa;

- Category B (CBR 10): *E* = 120 MPa (17 405 PSI), representative of values of *E* from 100 MPa up to but not including 150 MPa;

- Category C (CBR 6): *E* = 80 MPa (11 603 PSI), representative of values of *E* from 60 MPa up to but not including 100 MPa;

- Category D (CBR 3): *E* = 50 MPa (7 252 PSI), representative of all values of *E* strictly less than 60 MPa.

PCR EXAMPLE – Step 1 & 2, Data collection

PAVEMENT CHARACTERISTICS				
Layers	Designation	E-Modulus (MPa)	Poisson’s ratio	Thickness (cm)
Surface course	EB-BBSG3	E=f(q,freq.)	0.35	6
Base course	EB-GB3	E=f(q,freq.)	0.35	18
Subbase (1)	GNT1	600	0.35	12
Subbase (2)	GNT1	240	0.35	25
Subgrade		80 (Cat. C)	0.35	∞

TRAFFIC MIX ANALYSED			
#	Aircraft model	Max Taxi Weight (t)	Annual departure
1	A321-200	93.9	14600
2	A350-900	268.9	5475
3	A380-800	571	1825
4	737-900	79.2	10950
5	787-8	228.4	3650
6	777-300ER	352.4	4380

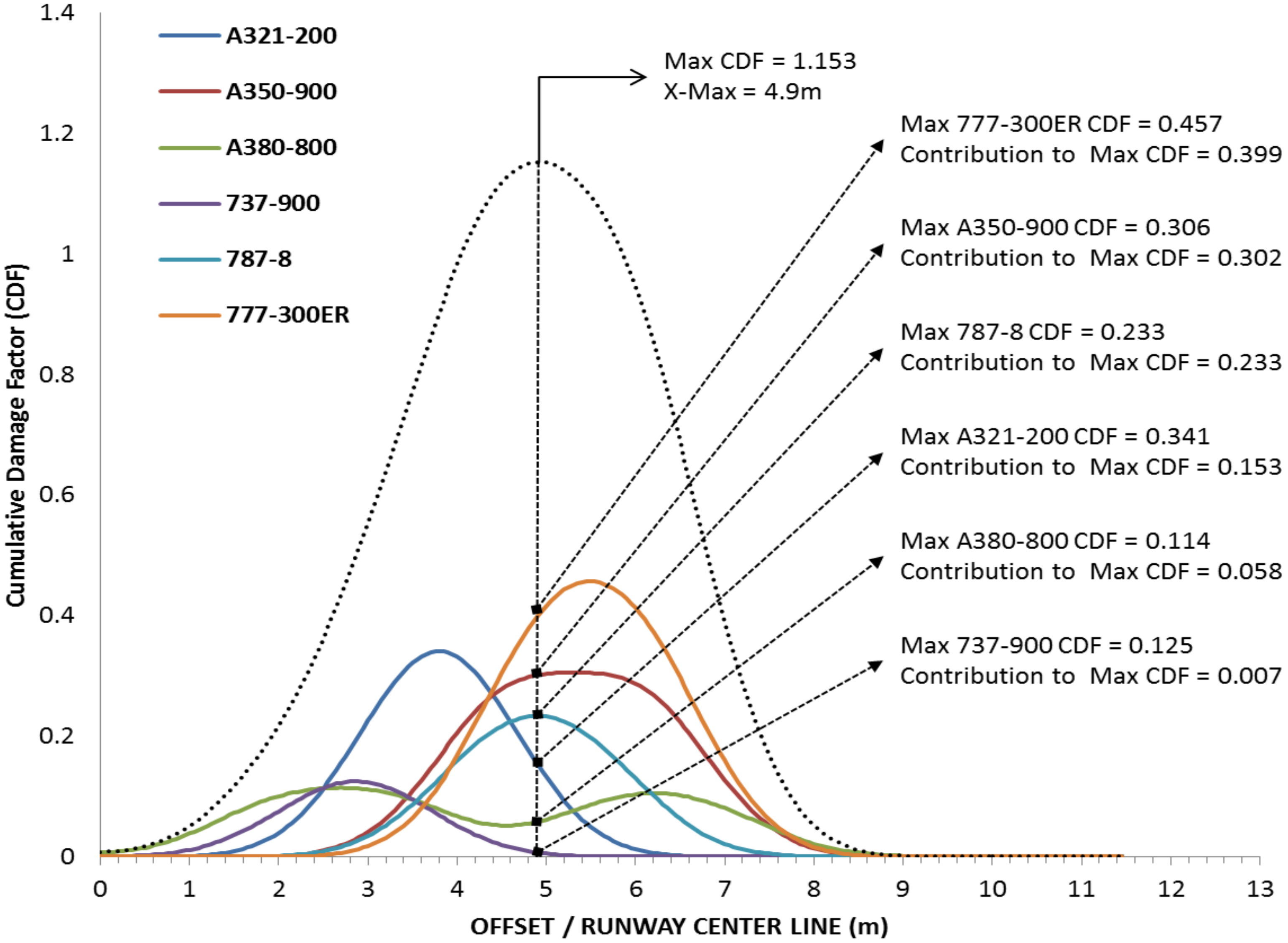
Note: For a runway each aircraft is attributed with a standard deviation of 1.5m
Should it be a taxiway, the standard deviation would have been 1m and 0 for apron/parking

PCR EXAMPLE – Step 3 & 4, CDF of the complete traffic mix

- Note1: The total CDF is equal to 1, meaning the actual pavement was under-designed

- Note2: don't confuse the individual contribution of each aircraft to the max CDF with the max individual damage of each aircraft. For instance, the A321-200 damage contribution to the max CDF is 0.153 while its max damage is equal to 0.341. In the same way, the A350-900 produces a max damage of 0.306, lower than the A321, but its contribution to the max CDF is of 0.302, higher than the A321 contribution. This is due to their landing gear geometry (distance from CL) and their positioning against the location of the max CDF of the mix.

- The most demanding aircraft is the 777-300ER



PCR EXAMPLE – Step 5-11

- Step 5 & 6: The 777-300ER associated to its initial annual departure gives a max CDF of 0.457. The annual departure is then adjusted so that the max 777-300ER CDF equals 1.153. This step is obtained with a simple linear interpolation.
-
- Step 7: The 777-300ER weight is then adjusted to obtain a max CDF of 1 i.e. the pavement is now correctly designed for accommodating the single equivalent aircraft at its adjusted weight and equivalent annual departure. The MAGW is
-
- Step 8: The **777-300ER ACR at its MAGW is 74.3 FCWT=PCN1**
-
- Step 9: The 777-300ER is removed, and all other aircraft reintroduced in the mix
-
- Step 10: The new most contributing aircraft is the A321-200 since the location of the max CDF has changed by removing the 777-300ER.
-
- Step 11: Repeat step 4-10

PCR EXAMPLE – Step 12

	777-300ER	A321-200	A350-900	787-8	737-9	A380-800
MTW	352.4	93.9	268.9	228.4	79.2	571
MAGW	341.3	90.9	260.5	221	76.75	553
Equivalent Annual dep.	110506	493660	206292	180620	1 010 028	184581
ACRi@MAGW	74.3	53	69.3	65	43.3	62.4
PCRi	74.3	53	69.3	65	43.3	62.4

Retained PCR= Max PCRi = **74 FCXT**

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Summary

- Individual aircraft pavement loading has to be considered in line of traffic mix

- The aircraft with the highest ACR is not necessarily the most demanding aircraft within a mix

- Aircraft Manufacturer to publish new aircraft ACR in their manuals (ACAP)

- Airport to determine and publish new PCR (ICAO procedure + local design parameters)

- New ACR could not be used with current PCN based on the CBR design procedure
Reciprocally, new PCR used only with new ACR

- PCR procedure flexibility, i.e. using national pavement design procedure, provided it comply with linear elastic method' principles

- New ICAO pavement rating system (ACR/PCR) applicability 2020, effectivity 2022

- Overload operations will be part of PCR procedure, based on the same CDF principles

Thank you

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