EASA
European Union Aviation Safety Agency

New method to report pavement strength (ACR-PCR)

Webinar, 06 October 2022

10:00 – 13:00 CET (UTC+2)

Simona TARLIE
Aerodromes Expert
EASA Aerodromes Standard & Implementation Section

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Agenda

Time	Session	Topics
10:00-10:10	**SETTING THE SCENE** Simona TARLIE, EASA	
10:10-10:30	**TRANSPOSITION OF ACR-PCR INTO THE EU REGULATORY FRAMEWORK** Simona TARLIE, EASA	- Feedback received from stakeholders - Applicability date - Q & A
10:30-11:00	**ACR-PCR – A NEW METHOD TO REPORT PAVEMENT STRENGTH** Michaël BROUTIN, French Civil Aviation Technical Centre/ICAO APEG	- Why a new method ? - What are the benefits ? - Q & A
11:00-11:30	**ACR** Cyril FABRE, Airbus/ICAO APEG	- What is the ACR ? - Where can I find the ACR values ? - Q & A
11:30-12:15	**PCR** Cyril FABRE, Airbus/ICAO APEG	- What is the PCR ? - What data do I need to calculate the PCR ? - How do I calculate the PCR ? - Are there any free tools to calculate the PCR ? - How do I manage overload operations ? - Q & A
12:15-12:45	**EXAMPLE OF PCR CALCULATION** Cyril FABRE, Airbus/ICAO APEG	- Real case aerodrome calculation - Q & A
12:45-13:00	**WRAP-UP & CLOSURE** Simona TARLIE, EASA	

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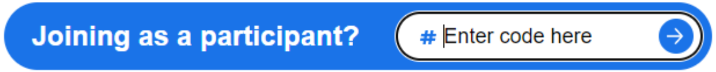
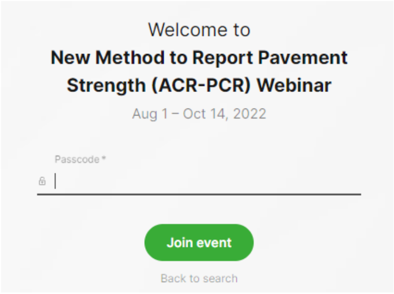
Ask questions using Slido

- Go to the [EASA ACR-PCR webinar]
  - Access Slido via link provided under ‘Description’

OR

- Go to [slido.com]
  - Insert event code: **Pave2022**
  - Insert passcode: **e6eftf**





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EASA

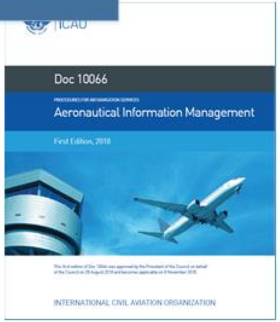
Transposition of ACR-PCR in EASA regulatory framework

ICAO State Letters 2020
Adoption of
ACR-PCR in:
- Annex 14
- PANS-AIM

ICAO Aerodrome Pavement Expert Group (APEG)

Origination of data

Publication of data



28 November 2024

Pavement bearing strength reported using new method ACR – PCR
(Aircraft Classification Rating – Pavement Classification Rating)

Pavement bearing strength reported using current method ACN-PCN
(Aircraft Classification Number – Pavement Classification Number)

27 November 2024

Transposition of ACR-PCR in EASA regulatory framework

Aerodromes

RMT.0591
Regular update of aerodrome rules

Published 17 Nov 2020 — NPA 2020-10 → 2023 Q1 — Opinion → 2024 Q1/Q2 — Commission IR → ED Decision

ACR-PCR (NPA 2020-10)

ACR-PCR (Commission IR / ED Decision)

NPA 2020-10 → ED Decision CS Issue 6 — Published 29 Mar 2022

ATM/ANS

RMT.0719
Regular update of ATM/ANS rules

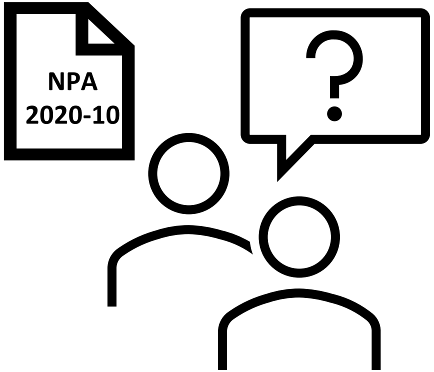
2022 — NPA → 2023 — Opinion → 2024 — Commission IR → ED Decision

ACR-PCR (NPA)

EASA

Transposition of ACR-PCR in EASA regulatory framework

Why a new method to report the pavement bearing strength



What are the benefits

Can I simply convert the current PCN into PCR?

How do I calculate the PCR

Can I keep the PCN values for the existing infrastructure and only publish PCR values for new infrastructure

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ACR-PCR

A new method to report pavement strength

Michaël Broutin

Head of the Airfield Pavement department

French civil Aviation technical centre, France

ICAO/APEG French representative

michael.broutin@aviation-civile.gouv.fr

EASA webinar, Thursday, 6 october, 2022

ACR-PCR – A NEW METHOD TO REPORT PAVEMENT STRENGTH

The objective of this presentation is to address those two questions:

- ***Why a new method?***
- ***What are the benefits?***

PRESENTATION OUTLINE

- ***Context: rational methods for the benefit of sustainable development***

-> rational approaches enables materials optimization,
-> rational methods are the doorway to green pavements

- ***Historical semi-empirical methods***

-> Overview
-> Limitations

- ***New rational methods***

-> Overview
-> Opportunities

CONTEXT

New challenges to be faced by airfield pavement engineers :

- ***Sustainable development is today of major concern (concept of "Green Airport")***

In the context of:

- ***Aging pavements***
  - From new pavement design to pavement testing, rehabilitation, overlay design
  - Asset management

- ***New generation aircrafts***
  - Higher single wheel loads
  - Higher contact pressures
  - Complex landing gears geometries

SEVERAL WAYS, MORE OR LESS DIRECT FOR RAW MATERIALS SAVINGS AND CARBON IMPACT REDUCTION

- *Materials optimization thanks to advanced design methods (rational methods) and full evaluation process*

- *Recycling and Reuse (R&R)*
- *Low-carbon materials or processes*
- *Enhanced durability*

Facilitated by rational methods

OPPORTUNITIES

- ***Computational power***

*-> From semi-empirical design methods to **rational/mechanistic methods**..*
*..which facilitates **material performance** approach and new materials emergence*

*-> **Big data** storage and processing*

- ***Electronic technological revolution***

-> Sensors for in-situ pavement monitoring and/or instrumented test facilities
..which facilitates numerical methods in-situ validation, especially rational methods calibration

HISTORICAL METHODS

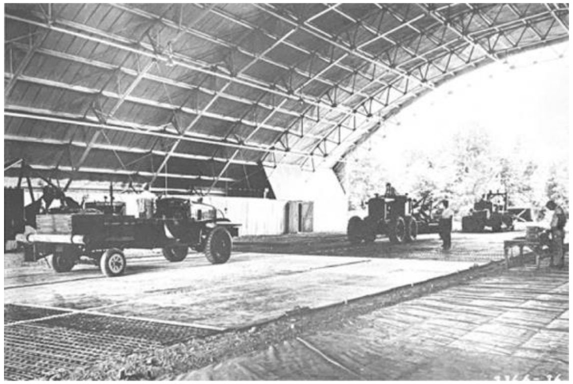
- ***Overview:***

-> Semi-empirical design methods developed by the USACE, 1940's - 1970's

-> Based on APT tests results

-> initially single and dual-wheels ; extended to 4-wheels boggie ; adapted to 6-wheels boggie 2000's through artificial coefficient called alpha-factor…

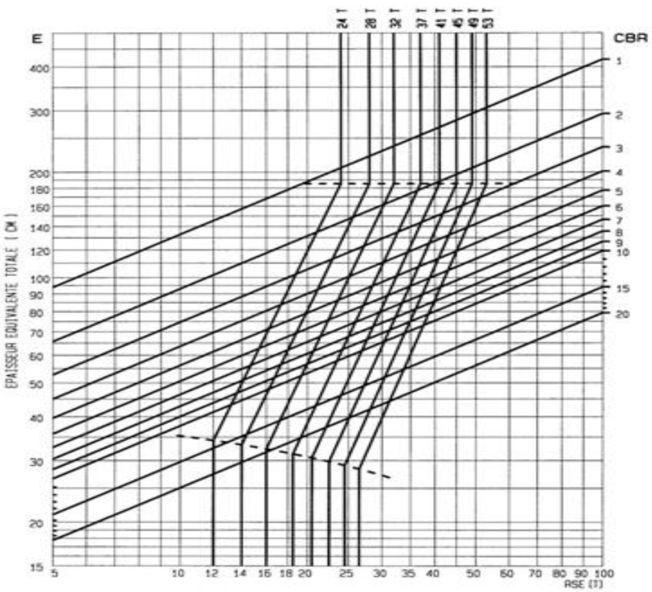
-> several effects neglected (temperature effects, interface behavior,..) ; huge safety coefficients included



(from T.W.Rushing, APT 2020)

- ***Overview:***

-> Empirical methods, established from limited in-situ tests
-> Simplified method based on abacus and concept of equivalent thickness



- ***Historical methods limitations:***

- No explicit consideration of material damage

- Subgrade bearing capacity characterized by CBR (flexible pavements)

- New materials not correctly considered

- No modeling of interface conditions between layers

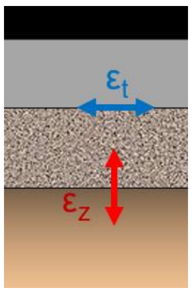
- No consideration of temperature and speed

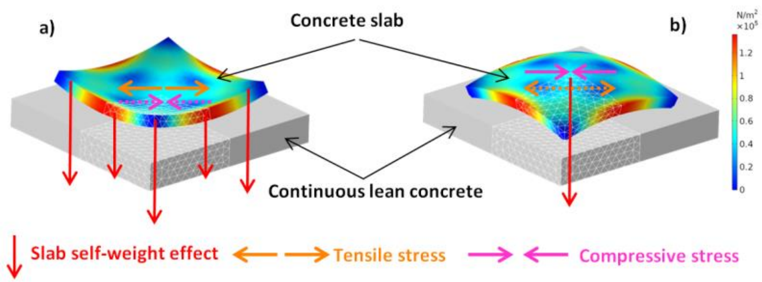
- Not appropriate for new landing gear configurations

NEW RATIONAL METHODS

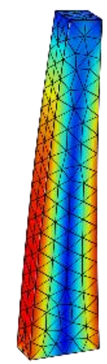
NEW RATIONAL DESIGN METHODS

- ***Combine :***
  - *Mechanical modelling (analytic or FE) to determine stress/strain in the pavement due to traffic and/or temperature effects*





  - *Performance approach involving materials lab testing*
  - *In-situ tests for calibration coefficients (generally)*



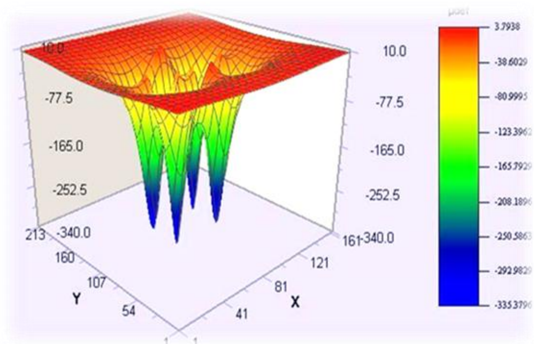
(Cerema device)

(Cerema device)

(PEP simulator, Airbus)

RECOMMENDED INNOVATION APPROACH

Modelling



Laboratory characterization

Test facilities/APT and in-service pavement testing

Implementation

TOWARDS A CONSISTENT RATIONAL METHODS FULL TOOLKIT

- ***New pavement design:***

- *State practice*
- *Ex: France: MLEA for flexible pavements and FE for rigid pavements*

- ***Pavement testing:***

- *Reference device = HWD*
- *State practice*
- *Mechanistic modelling + backcalculation*

- ***Pavement management/aircraft admissibilities:***

- *ACR/PCR, generic method developed by the ICAO/APEG + state practices (PCR)*
- *Mandatory from Nov. 2024 (no more ACN/PCN)*
- *Ex: France: PCR Alizé module, freely available*

- ***Overlay design:***

- *State practices ; same method than new design; but requires a previous testing step to characterize existing pavement layers*

NEW RATIONAL DESIGN METHODS

- ***Rational methods benefits:***

- *More accurate design :*

-> materials optimization

- *Adaptive methods :*

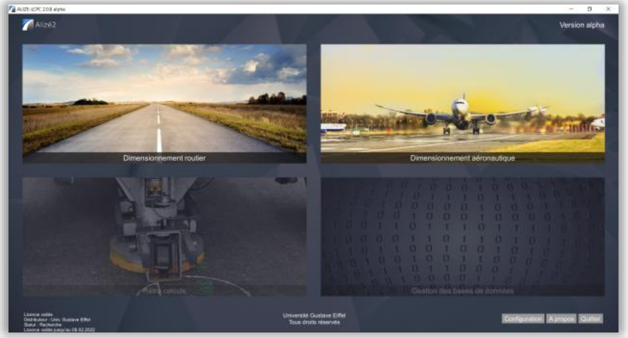
-> applicable to all input parameters (landing gear geometries, speeds, lateral wander, temperatures, ..)

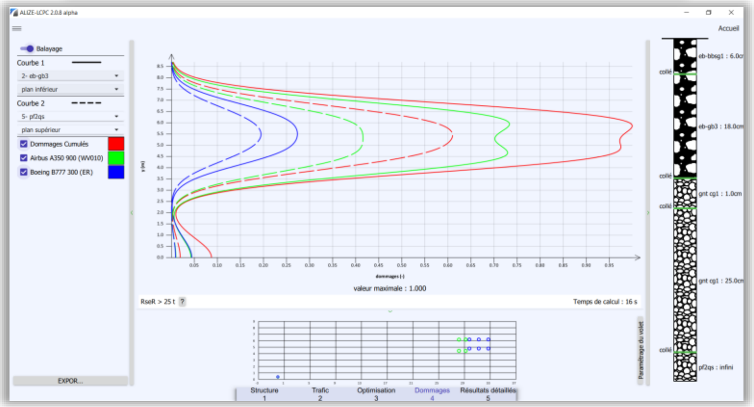
-> possible implementation of all materials (provided they are characterized through laboratory tests); facilitates the promotion of R&R, or the use of local alternative materials.

NEW RATIONAL DESIGN METHODS

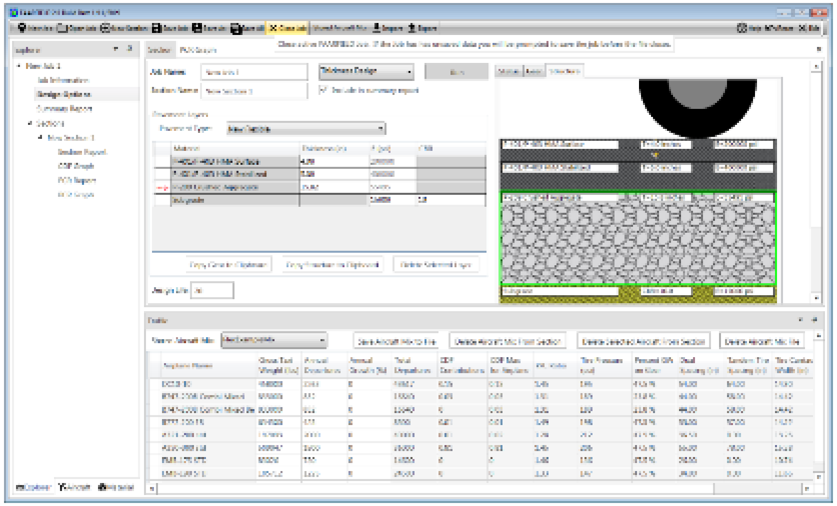
Example: FR and US new flexible pavement design methods

- ***Alizé-Airfield 2.0***





- ***Faarfield***



- ***Same theory: multilayered elastic model, Burmister***
- ***Different fatigue laws***

NEW RATIONAL DESIGN METHODS

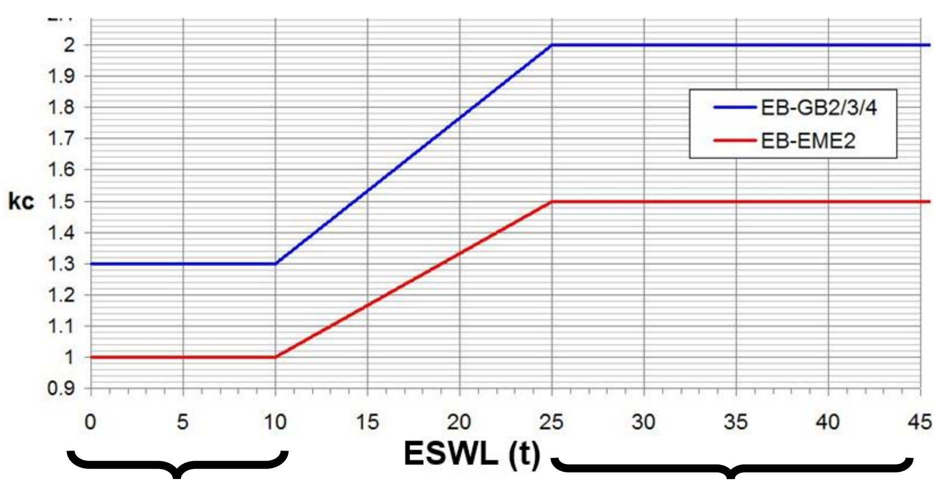
- ***US method***

- *Calibrated from NAPTF flexible construction cycles data*

NEW RATIONAL DESIGN METHODS

- ***French method***

- *Derived from road and highways one*
- *Road calibration for low loads, PEP and HTPT* data for heavy loads (small data)*



** resp. Pavement Experimental Program and High Tire Pressure Test; 2 Airbus-funded research program involving STAC, Cerema and Univ. Gustave Eiffel*

EVOLUTIONARY METHODS

- ***Continuous improvements :***

- *Calibration coefficients,*
- *AC fatigue law,*
- *Input parameters (reference temperature, lateral wandering,..)*

- ***And possibly at longer term:***

- *Pressure distribution,*
- *VE models,*

- ***Several advantages to rational methods***

- *More accurate designs*
- *Materials optimization and enhanced asset management policies*
- *High adaptability to input parameters and open to all new materials*
- *Evolutionary methods*

- ***A coherent set of rational methods***

- *For all steps of the airfield pavement life : new design, asset management and testing, overlay design*
- *Compatible with each other*

The ACR/PCR method

Cyril FABRE

ICAO/APEG Chair.

Speaker – Biography (short)

- *Cyril FABRE, Head of Airfield Pavement and Expert at AIRBUS has 20+ years' experience in Airport compatibility and in particular for all airfield pavement matters by addressing all pavement issues at airports to Airbus customers, programmes (civil & military) and marketing.*
- *From 1999 to 2007, he managed the A380 Pavement Experimental Programme (A380 PEP)*
- *In 2008, he initiated and performed the High Tire Pressure test (HTPT) which served, with the FAA findings, the new ICAO tire pressure limits code endorsed by ICAO in 2012 with applicability by ICAO member States since Nov.2013.*
- *He led the ICAO ACN/PCN Task force which built the new ICAO Pavement rating system (ACR/PCR).*
- *He is nominated Rapporteur of the ICAO APEG in September 2020*
- *In 2021, he founded a pavement consulting company (A2PT-Consulting) to support airports transitioning from a curative to predictive pavement management approach (maintenance costs optimisation, CO_2 footprint reduction, rating system etc.)*
- *He has a university post-graduate technical degree in Aeronautics and space techniques with 10+ year's continuous training in civil engineering.*
- *He authored many papers and articles related to airfield pavement design and analysis, full-scale testing, modelling and pavement rating system.*
- *Members of the ICAO-APEG, TRB-AV070, FAA NAPTF WG, ALACPA*

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- Main features
  - CDF
  - ACR
  - PCR
  - Examples
  - Overload Ops.

- Benefits

- Reference documents

Key changes

- What **DOES NOT** change is the comparison of ACR and PCR as the core principle of the method:

  If ACR ≤ PCR, the aircraft can operate on the pavement without restriction
  If ACR > PCR, the aircraft may be excluded, or may be allowed to operate subject to weight and/or frequency limitations

- What **DO** change are the procedures / model for determining the ACR and PCR:

  – Now based on rational models allowing the calculation of pavement mechanical response (surface deflections, internal stresses, strains within the pavement) induced by surface traffic loads from Layered Elastic Analysis (LEA)

  – Pavement **damage** is then quantified based on on a specific damage model, using as an input these responses (especially strains for flexible pavements and stresses for rigid pavements)

Key changes

- In **practical terms**, the ACR-PCR method will lead to:
  - New ACR values (calculated and published by aircraft manufacturers)
    - Still computed based on the combined result of aircraft wheel loads, tire pressures and landing gear geometry

  - New PCR values (calculated and published by airports)
    - Reporting format (one number and a series of four letters) is unchanged
    - A generic procedure for PCR determination is provided by ICAO (addressing the lack of ICAO guidance for PCN evaluation). **The generic procedure is general enough to accommodate most national or local (e.g. the generic procedure does not specify a particular subgrade failure model) design procedure**
    - The PCR is computed based on the accumulated pavement damage produced by entire traffic mix **(CDF Concept)**
    - Subgrade are now characterized by the elastic modulus E for both flexible and rigid pavements (unified characterization)

  - **Unchanged general approach** (comparison of ACR and PCR)

  - A new approach for overload operations (i.e. when ACR > PCR)
    - “ICAO allowance” is increased to 10% of the PCR for both flexible and rigid pavements
    - Overloads in excess of 10% may be allowed if justified through a technical analysis of the impact on pavement damage, consistent with the PCR philosophy

Both ACR and PCR numerical values are approximately one order of magnitude (10x) higher than the ACN and PCN numbers
However, **there is <u>no ability to convert between ACN and ACR, nor between PCN and PCR</u>**

Contents

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- **Main features**
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CUMULATIVE DAMAGE FACTOR (CDF) - DEFINITION

- The (subgrade) 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, or, for one airplane and constant annual departures:

- $CDF = \frac{Applied\ coverages}{Coverages\ to\ failure}$

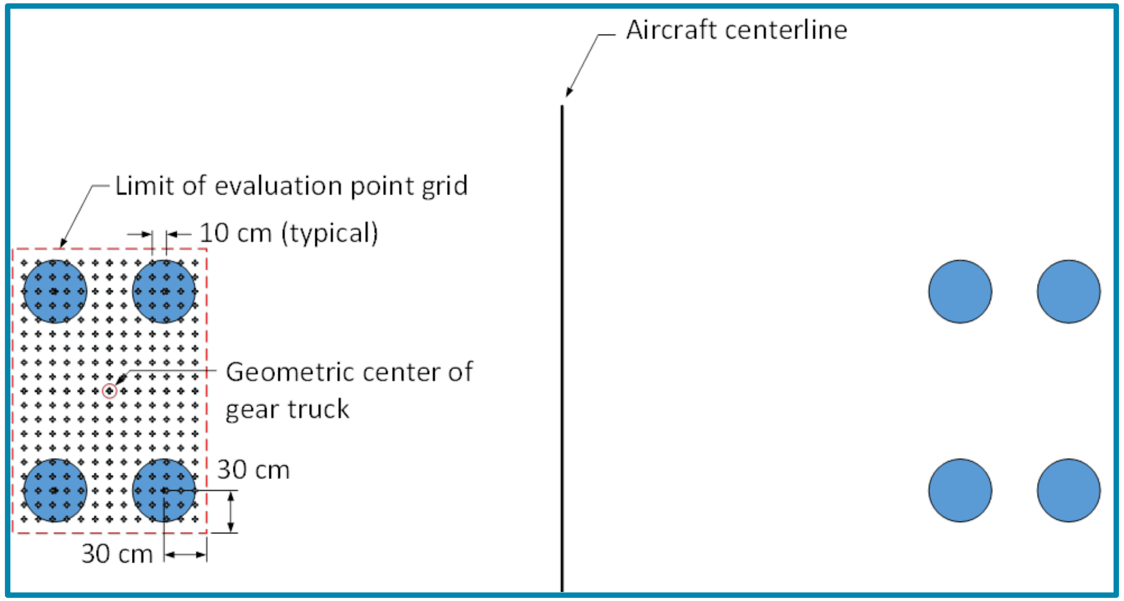
- where a coverage is one application of the maximum strain or stress due to load on a given point in the pavement structure.

- When CDF = 1, the pavement subgrade will have used all of its fatigue life;
- When CDF < 1, the pavement subgrade will have some remaining 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 and the pavement subgrade will have failed.

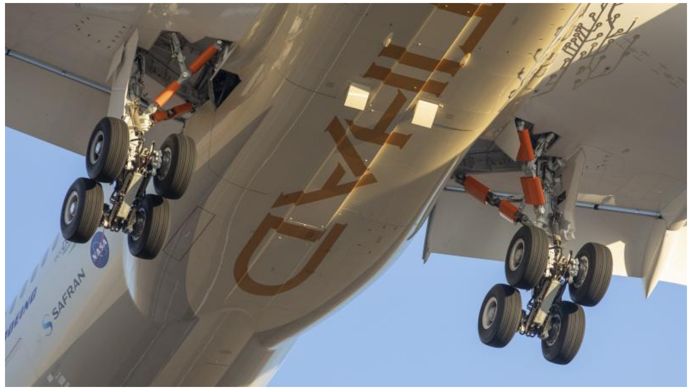
- For multiple aircraft (Miner's Rule):
- $CDF = CDF_1 + CDF_2 + \cdots + CDF_N$ (Where CDF_i is the CDF for each airplane in the traffic mix and N is the number of airplanes in the mix.

GRID DEFINITION (EXAMPLE)

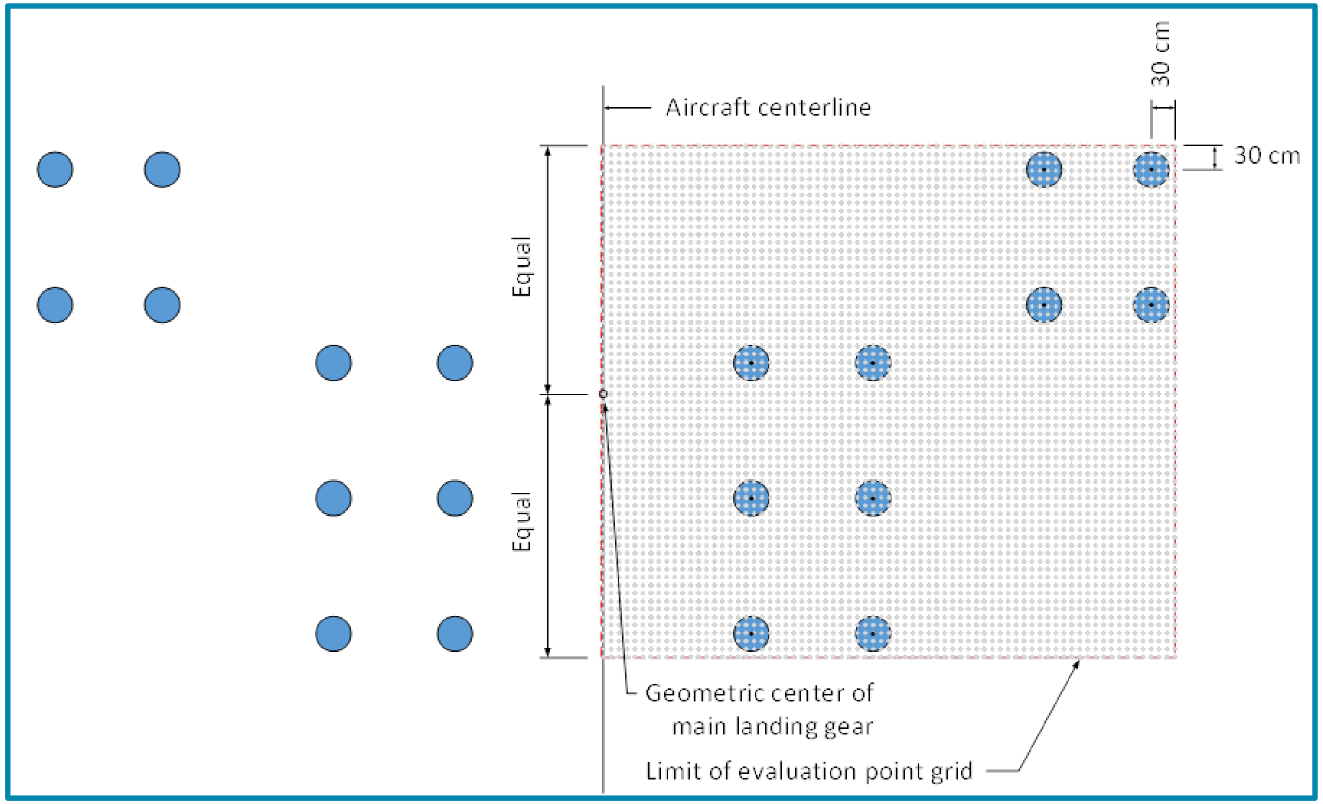
- Grid generation (recommended mesh size 10 cm x 10 cm grid)



Simple MLG general arrangement



Complex MLG general arrangement



DAMAGE MODEL (EXAMPLE: WÖHLER / Subgrade criteria)

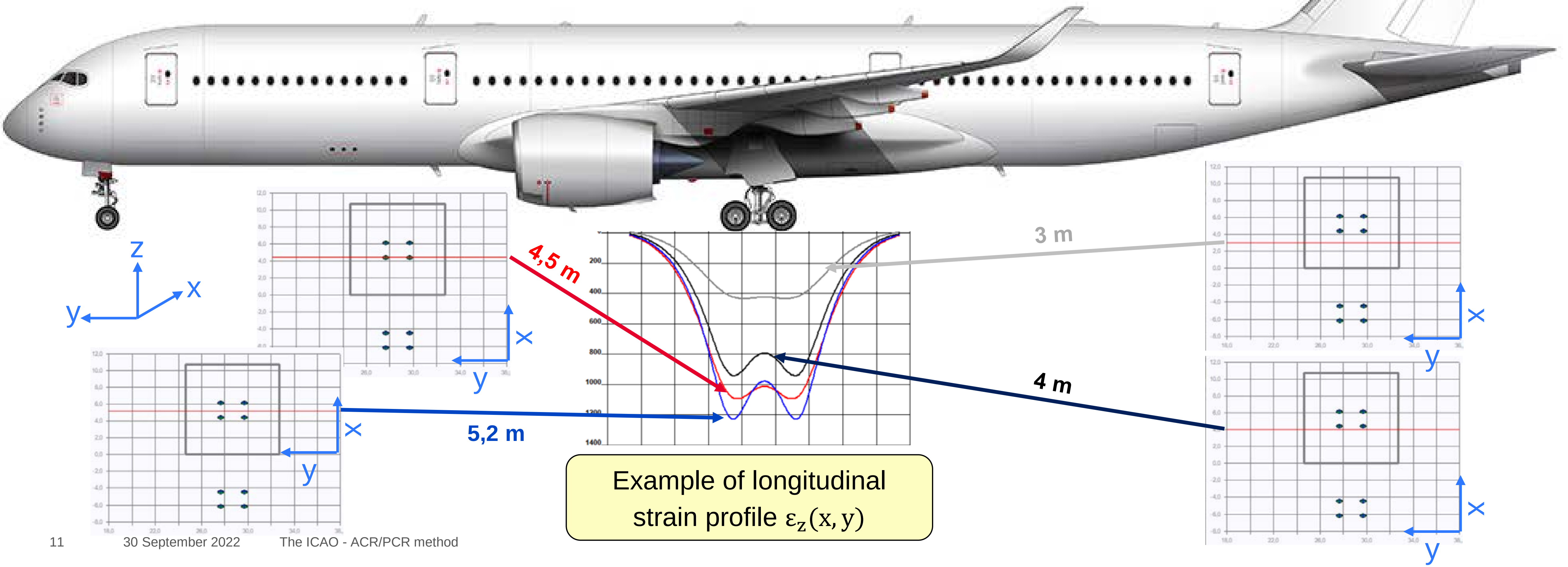
$$D_e = \frac{1}{C_e(\varepsilon_{z\,max.})} = \left[\frac{\varepsilon_{z\,max.}}{K}\right]^{\beta}$$

Wöhler

Elementary damage model

$$D(x) = N_{passes} * \int_{y=-\infty}^{y=+\infty} \frac{dD_e[\varepsilon_z(x,y)]}{dy}\,dy$$

Continuous damage model

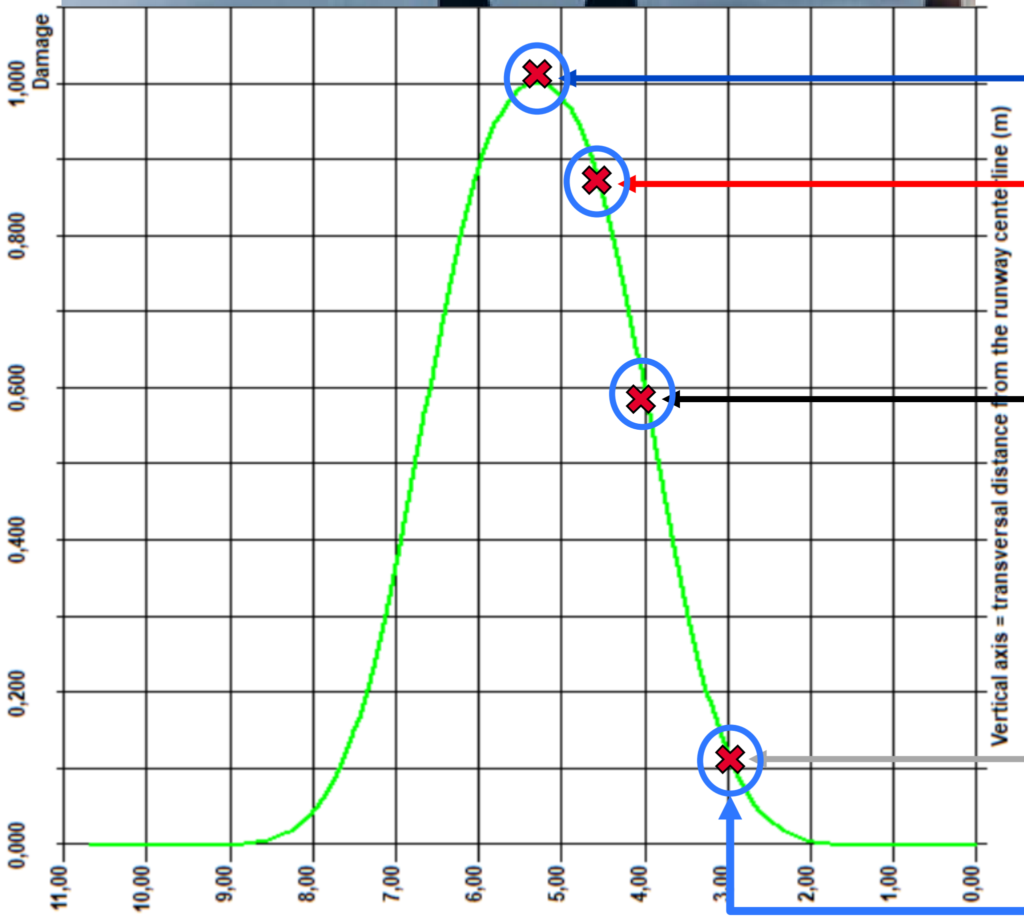


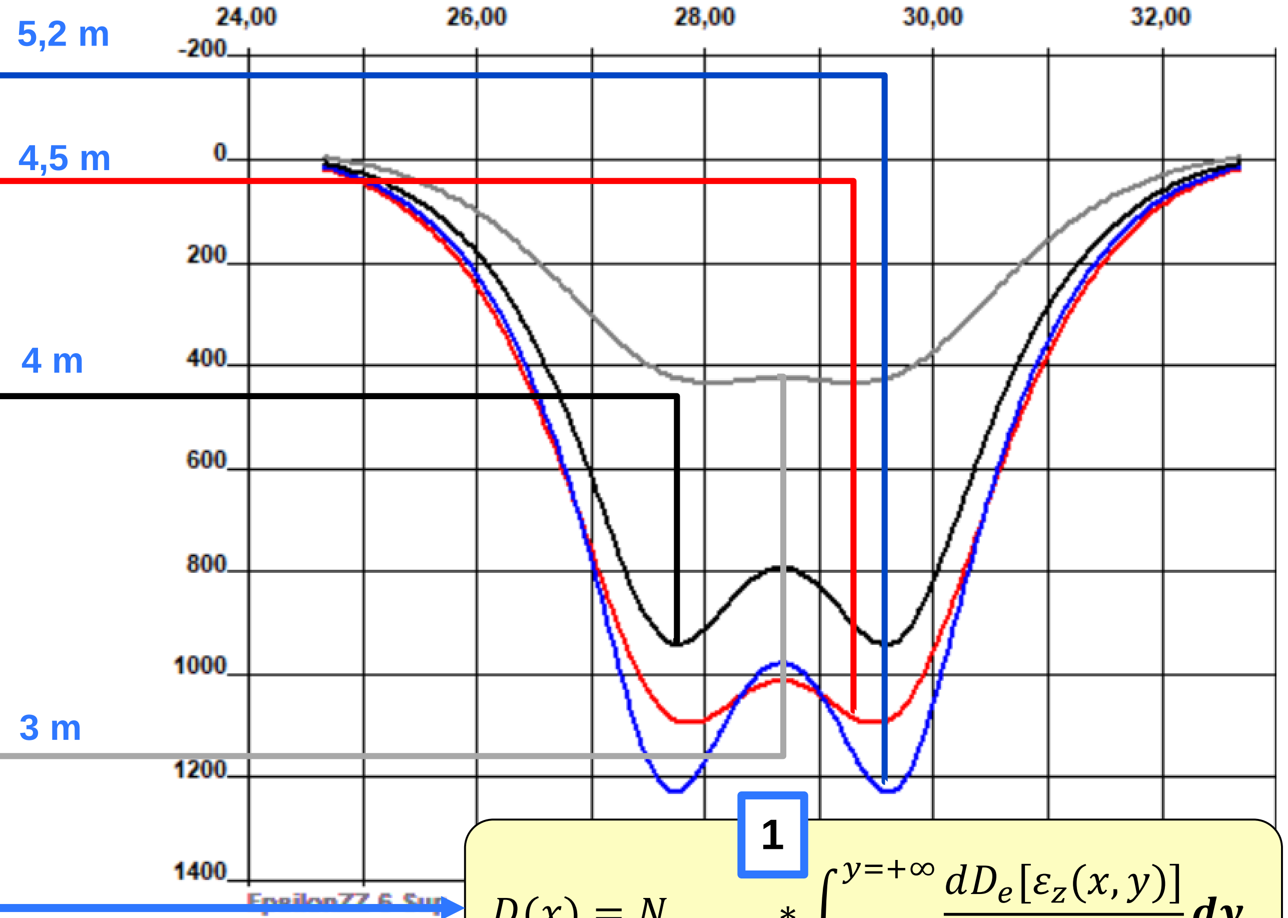
Example of longitudinal strain profile $\varepsilon_z(x,y)$

HOW IS CDF CURVE CALCULATED?

2

$$D(y,z_k) = \frac{\beta}{K^{\beta}}\int_{-\infty}^{+\infty} < \varepsilon(x,y,z_k) >^{\beta-1} < \frac{d\varepsilon}{dx}(x,y,z_k) > \boldsymbol{dx}$$





1

$$D(x) = N_{passes} * \int_{y=-\infty}^{y=+\infty} \frac{dD_e[\varepsilon_z(x,y)]}{dy}\boldsymbol{dy}$$

EXAMPLE: CDF OF A MIX

PAVEMENT CROSS SECTION STRUCTURE

Display the pavement structure

Titre : AC flexible pavement - Mf1 template

Interface	thick. (m)	Young (MPa)	Nu	Material type	Design criterion	Risk (%)	Sig6 or Epsi6 or A	-1/b	SH	SN	Kr	1/Ks	1/Kd	Kc
	0,06	f(T,F)	0,350	eb-bbme3										
bonded	0,18	f(T,F)	0,350	eb-gb3										
bonded	0,10	600,0	0,350	gnt1										
bonded	0,25	240,0	0,350	gnt1										
bonded	infinite	80,0	0,350	pf2qs	EpsilonZ-sup		16000	-0,222						

H1= 0,060 m

Gnt1/Gnt1

Runway

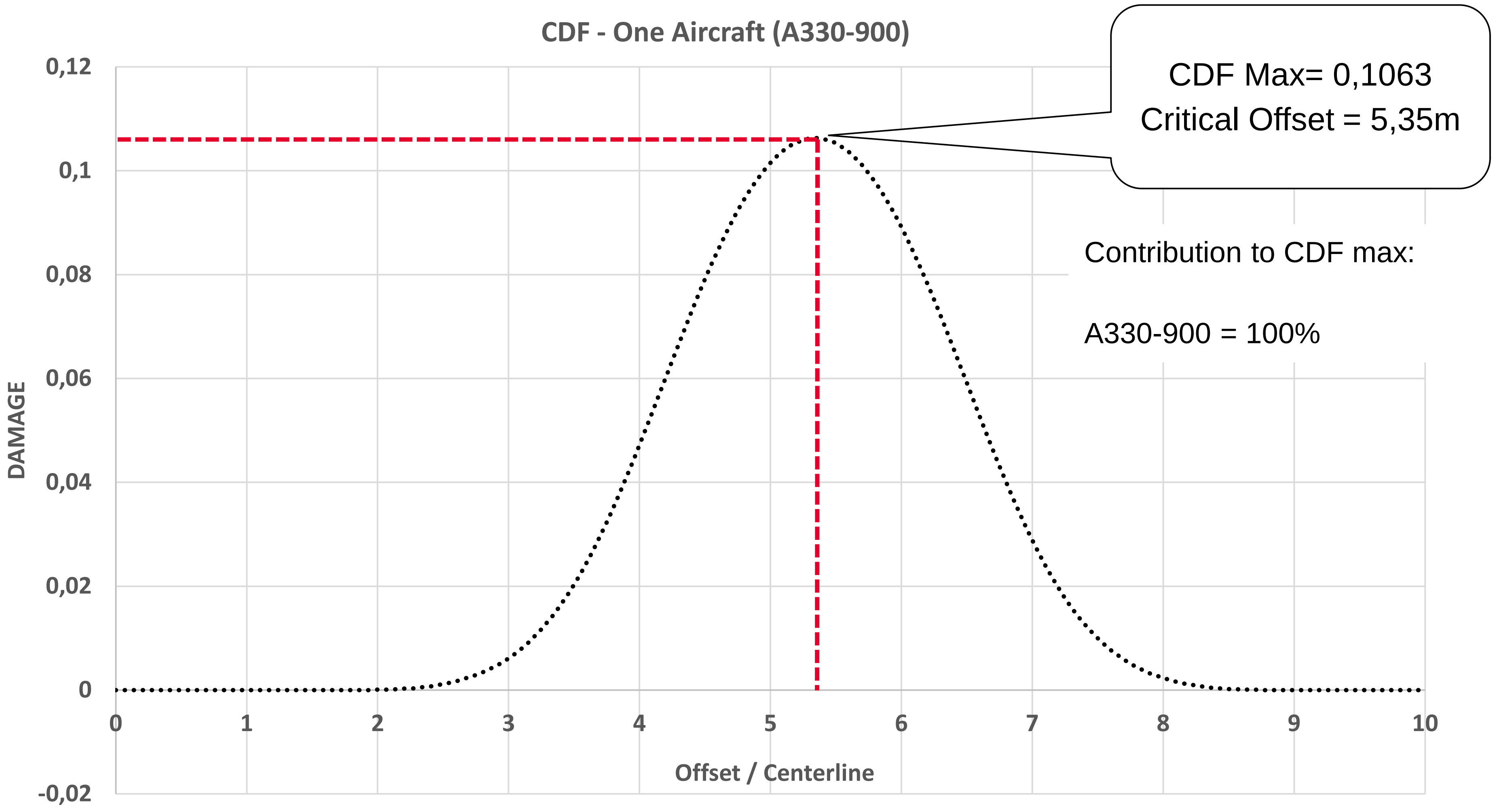
French subgrade failure model

AIRCRAFT MIX

Design life of the pavement (years): 10,0

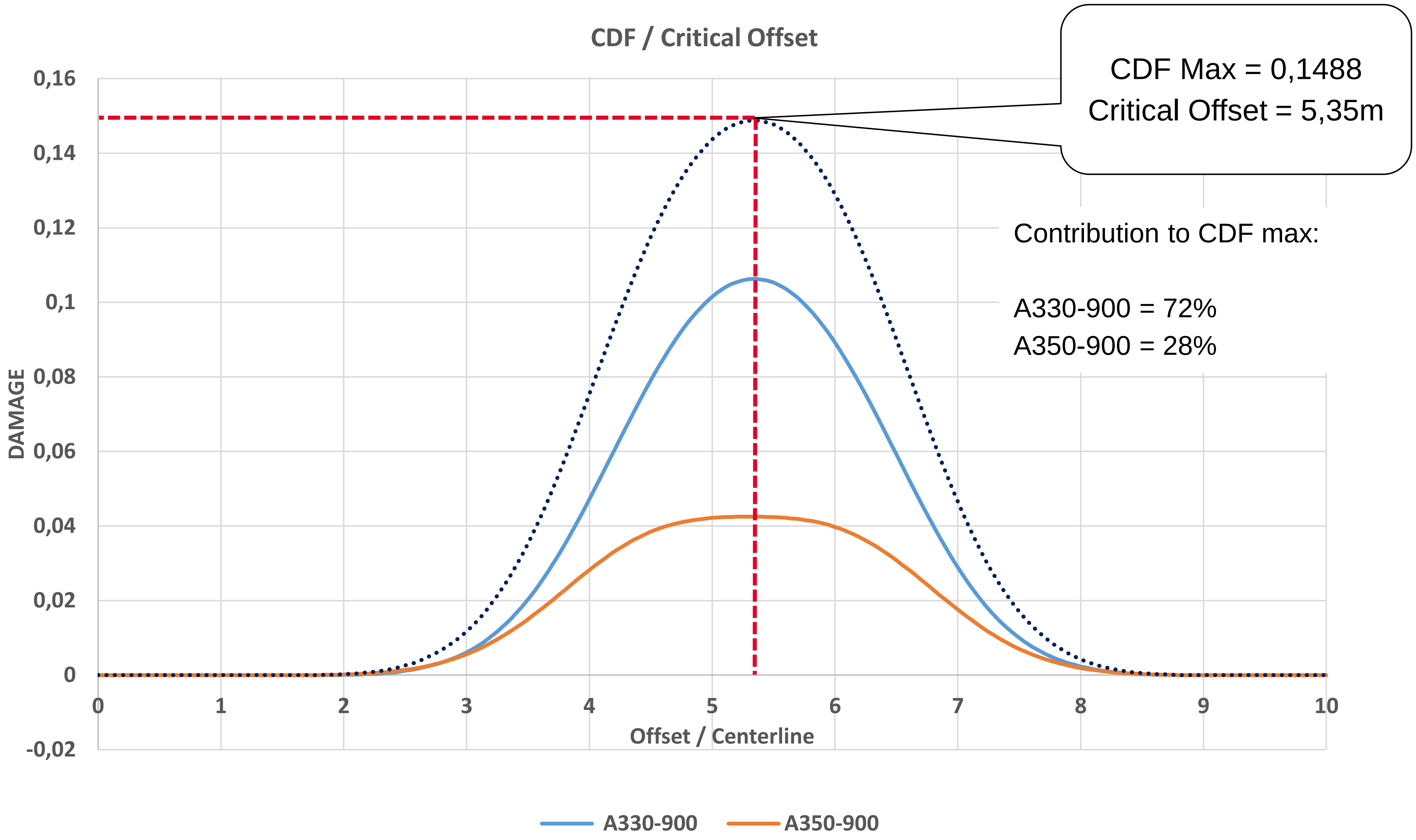
Aircraft of the traffic mix	Weight (t)		Aircraft passes Number	Aircraft passes Units	Aircraft passes Ta(%)	Cumulated traffic	Wandering= 2xStanDev(m)	Speed (km/h)	Temperature TetaEq
1-AIRBUS A 330 900 (Mrw=251,9t) - G5	Mrw	251,900	4	Passes/day	2,00	15 987	1,50	100,0	15,00
2-AIRBUS A 350 900 (Mrw=268,9t) - G5	Mrw	268,900	2	Passes/day	4,00	8 764	1,50	100,0	15,00
3-BOEING B 747 400ER (Mrw=414,1t) - G5	Mrw	414,130	1	Passes/day	0,00	3 650	1,50	100,0	15,00
4-BOEING B 777 300 ER (Mrw=352,4t) - G5	Mrw	352,441	5	Passes/day	3,00	20 922	1,50	100,0	15,00
5-BOEING B 737 MAX9 (Mrw=88,5t) - G3	Mrw	88,541	30	Passes/day	2,00	119 899	1,50	100,0	15,00
6-AIRBUS A 380 800 (Mrw=571,0t) - G5	Mrw	571,000	1	Passes/day	0,00	3 650	1,50	100,0	15,00
7-AIRBUS A 320 NEO (Mrw=79,4t) - G3	Mrw	79,400	40	Passes/day	2,00	159 866	1,50	100,0	15,00
8-AIRBUS A 321 200/NEO (Mrw=93,9t) - G3	Mrw	93,900	15	Passes/day	1,00	57 281	1,50	100,0	15,00

CDF – 1 (A330-900)



$CDF_{mix} = CDF_{A330\text{-}900}$

CDF – 2 (A330-900, A350-900)



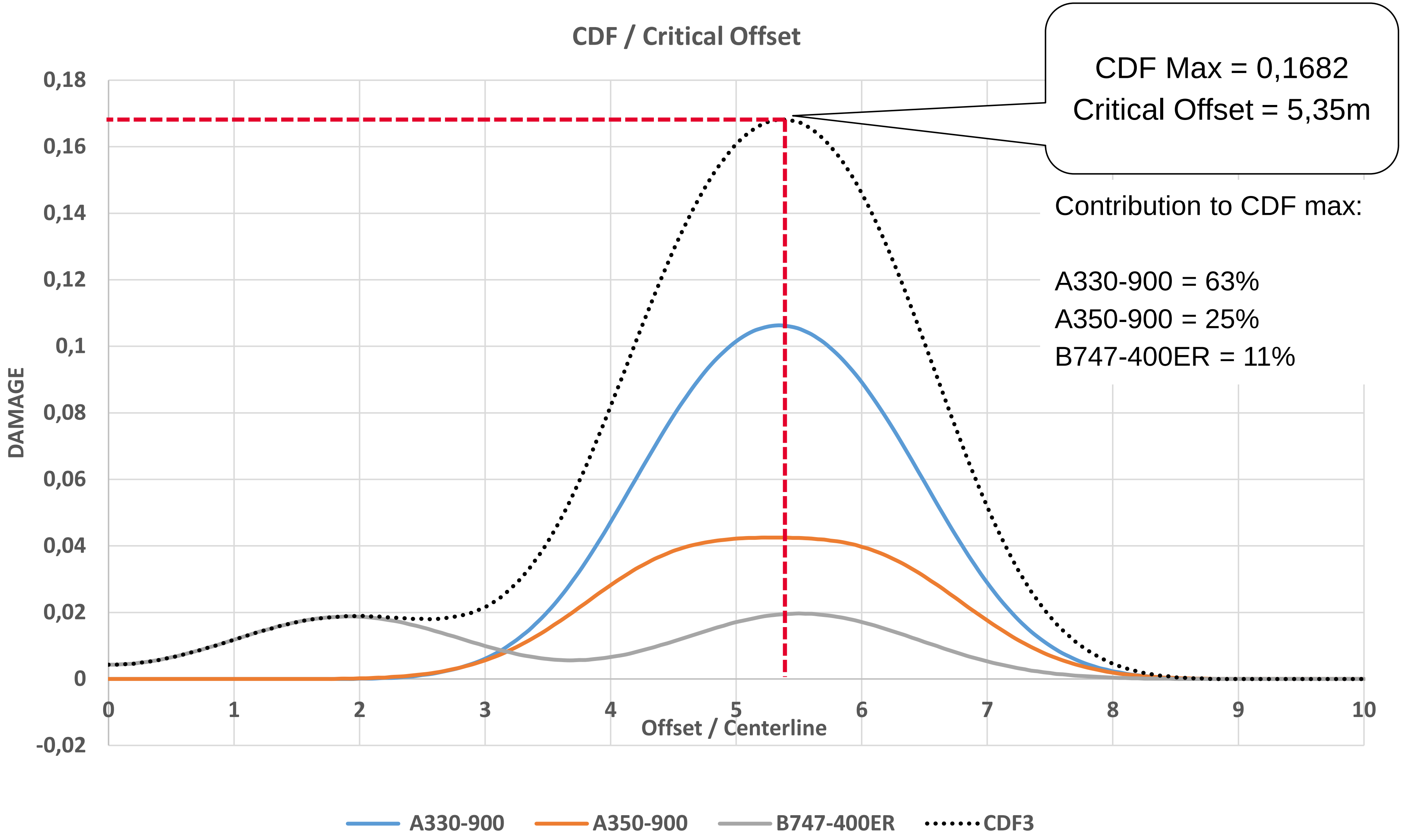
Contribution to CDF max:

A330-900 = 72%

A350-900 = 28%

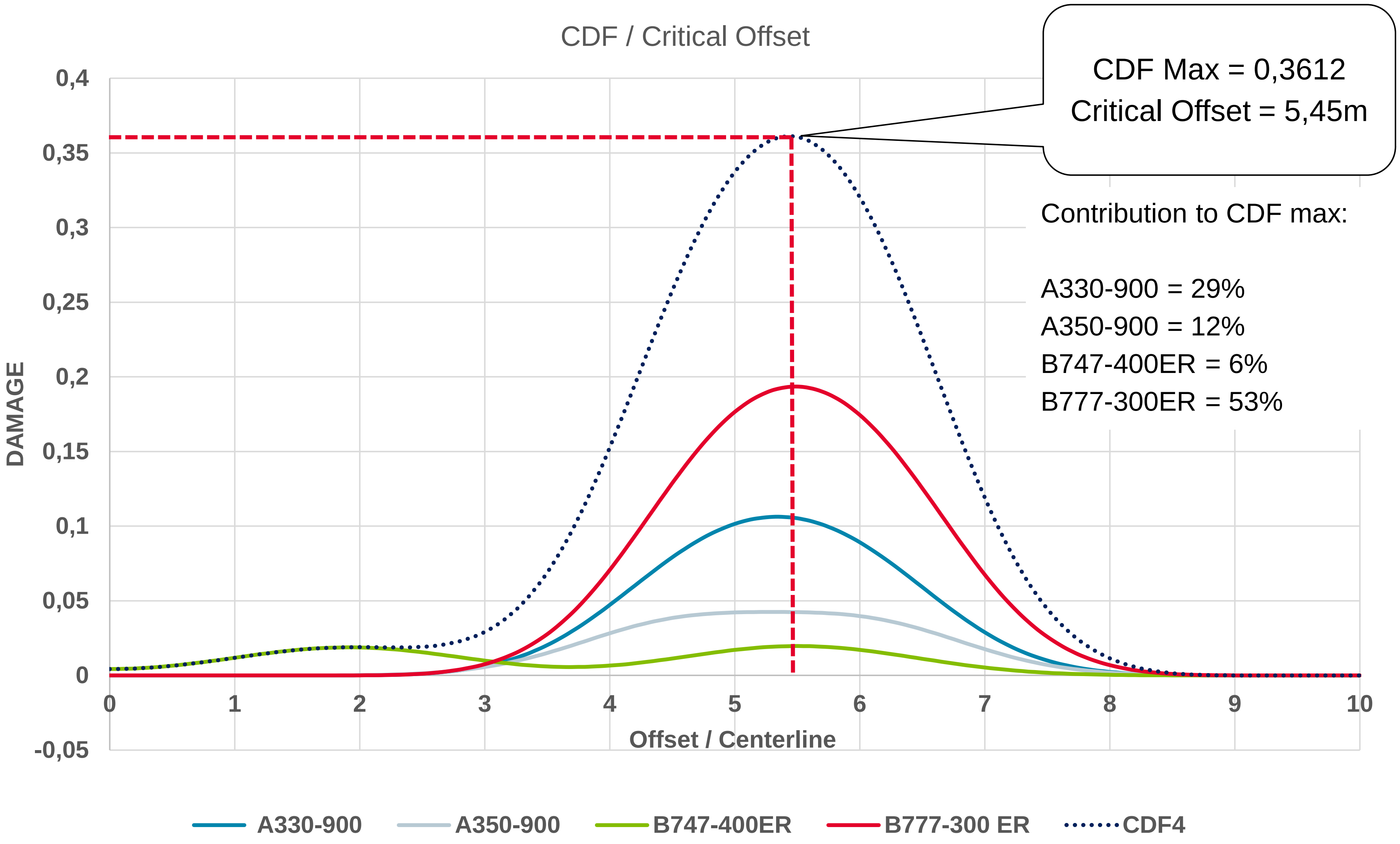
$CDF_{mix} = CDF_{A330\text{-}900} + CDF_{A350\text{-}900}$

CDF – 3 (A330-900, A350-900, B747-400ER)



$CDF_{mix} = CDF_{A330\text{-}900} + CDF_{A350\text{-}900} + CDF_{B747\text{-}400ER}$

CDF – 4 (A330-900, A350-900, B747-400ER, B777-300ER)

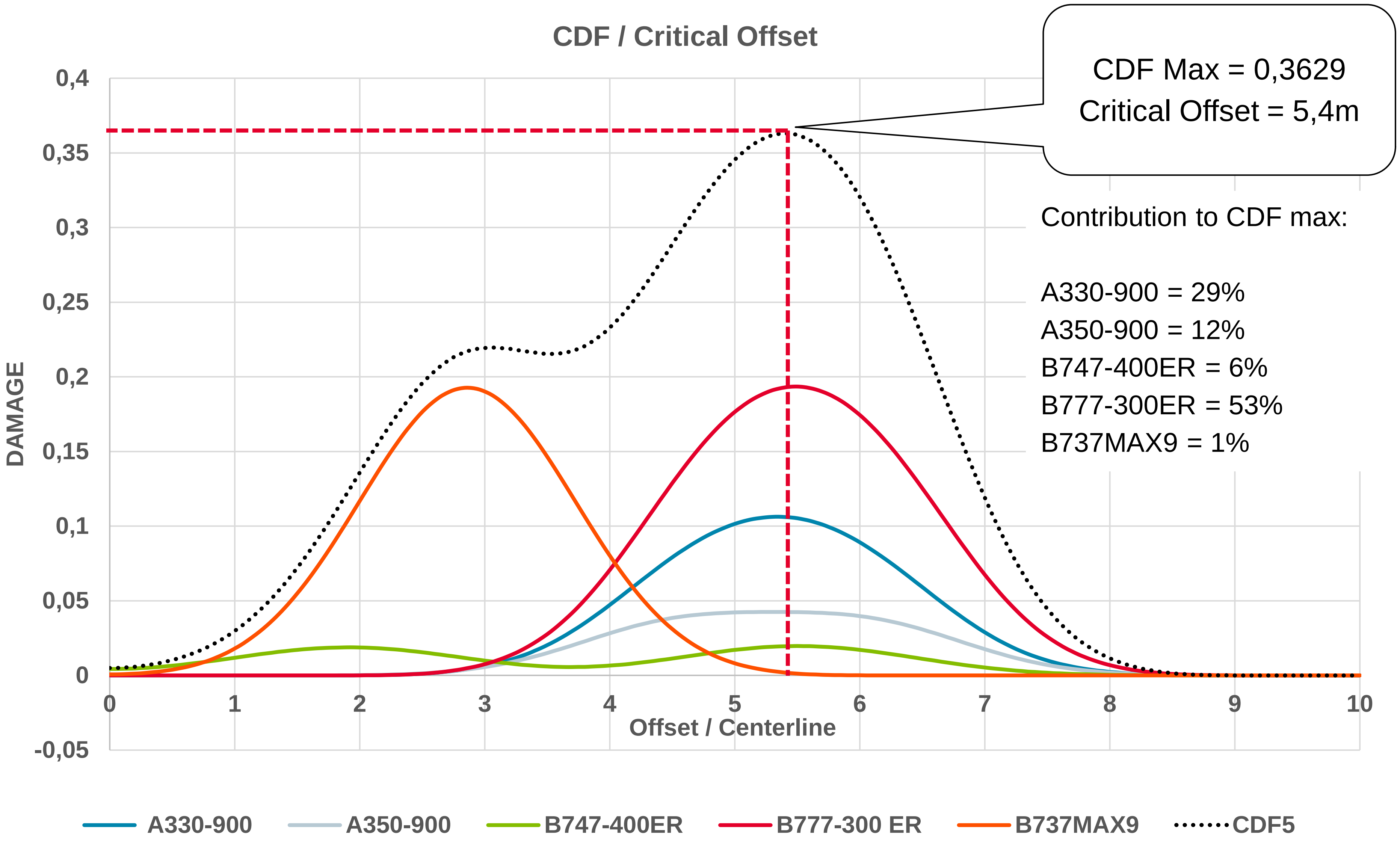


Contribution to CDF max:

A330-900 = 29%
A350-900 = 12%
B747-400ER = 6%
B777-300ER = 53%

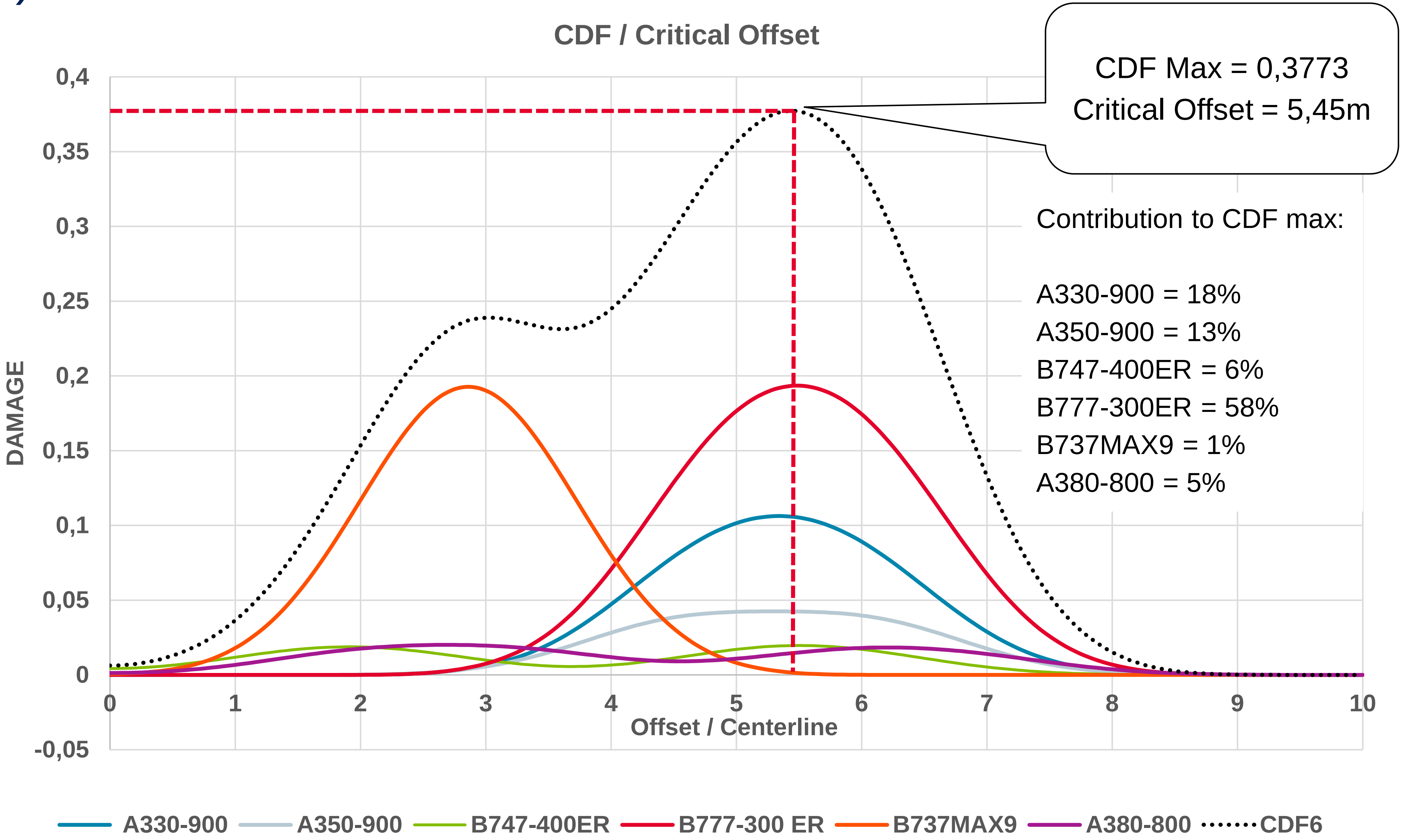
CDFmix = CDFA330-900 + CDFA350-900 + CDFB747-400ER + CDFB777-300ER

CDF – 5 (A330-900, A350-900, B747-400ER, B777-300ER, B737MAX9)



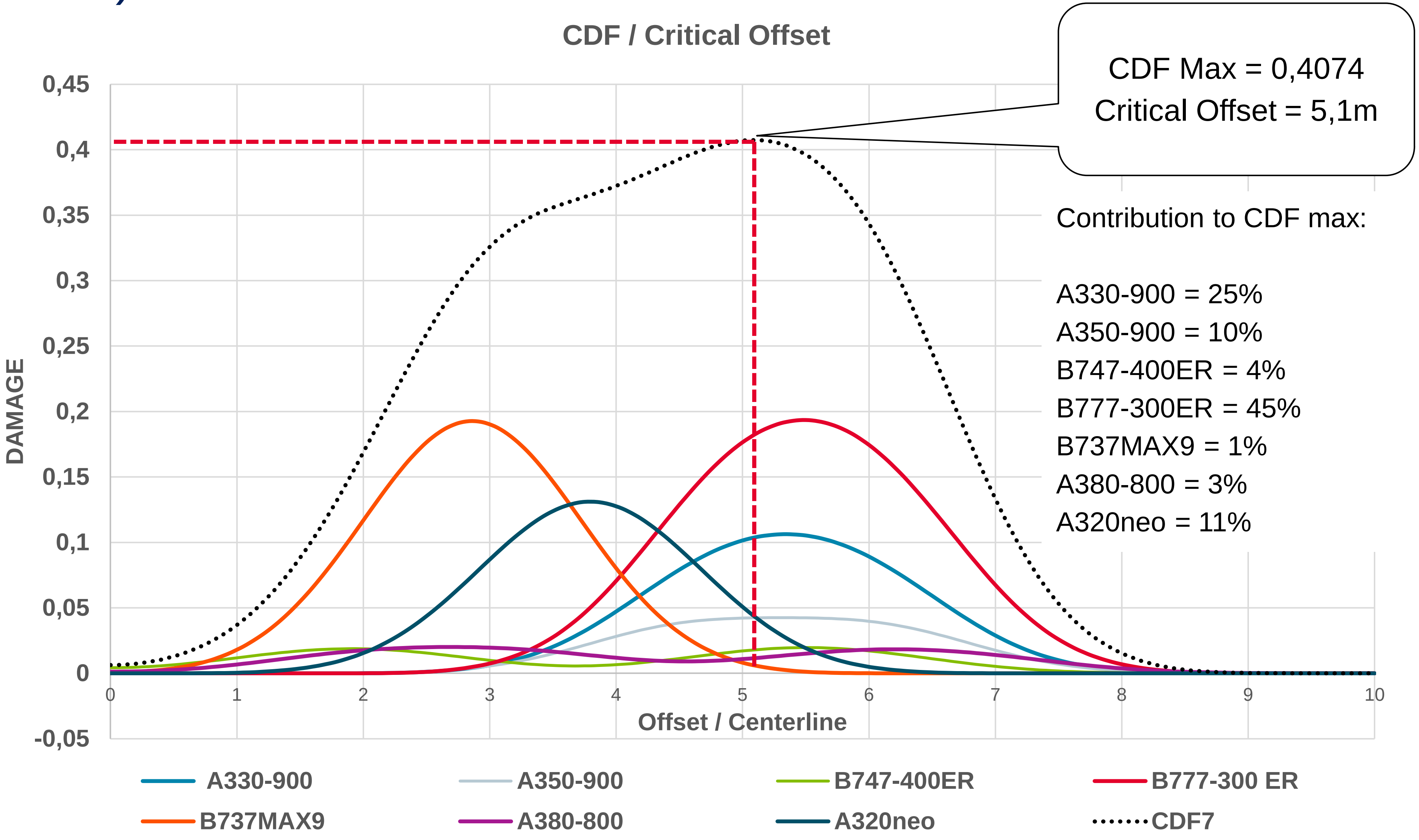
$CDF_{mix} = CDF_{A330\text{-}900} + CDF_{A350\text{-}900} + CDF_{B747\text{-}400ER} + CDF_{B777\text{-}300ER} + CDF_{B737MAX9}$

CDF – 6 (A330-900, A350-900, B747-400ER, B777-300ER, B737MAX9, A380-800)



CDFmix = CDFA330-900 + CDFA350-900 + CDFB747-400ER + CDFB777-300ER + CDFB737MAX9 + CDFA380-800

CDF – 7 (A330-900, A350-900, B747-400ER, B777-300ER, B737MAX9, A380-800, A320neo)

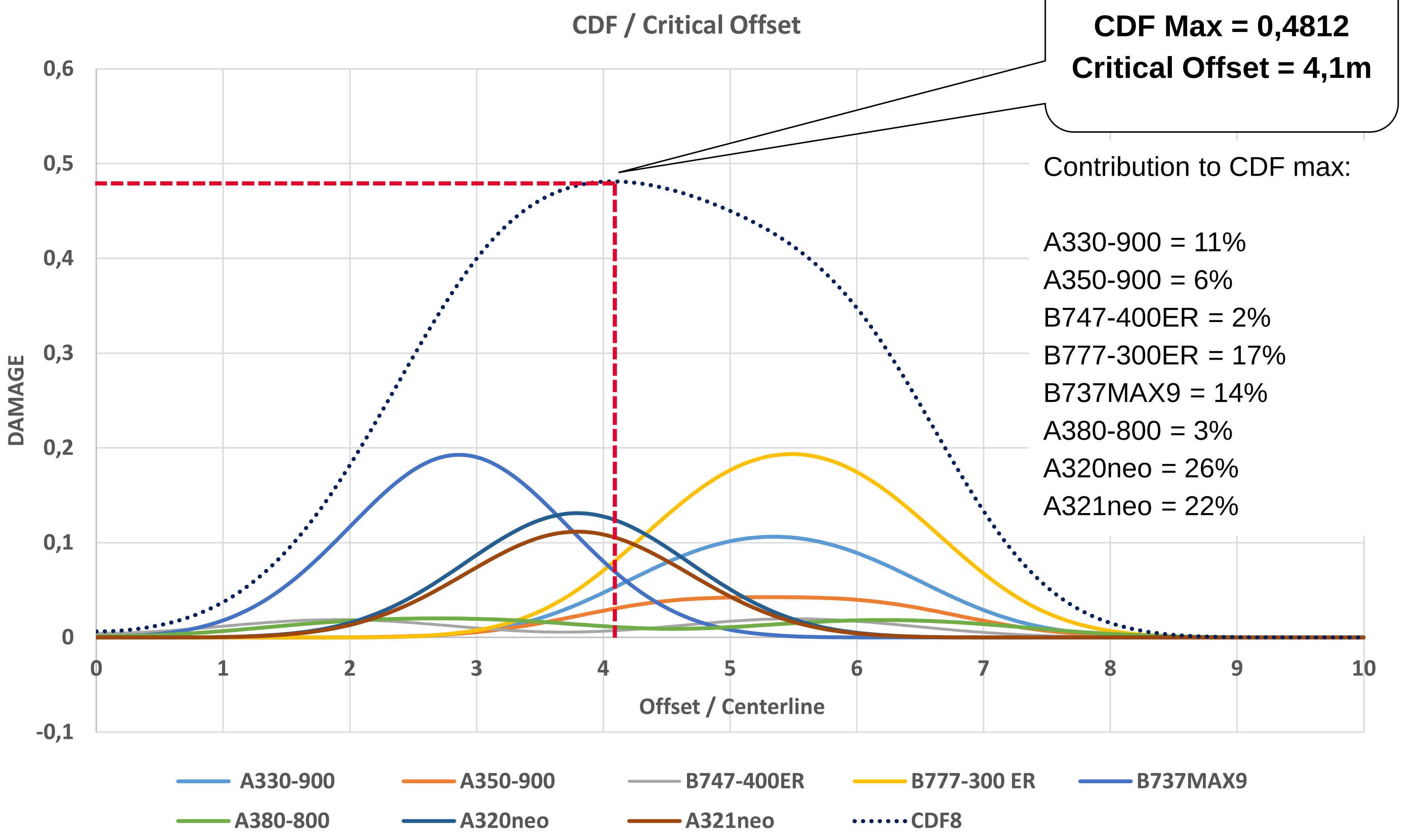


Contribution to CDF max:

A330-900 = 25%
A350-900 = 10%
B747-400ER = 4%
B777-300ER = 45%
B737MAX9 = 1%
A380-800 = 3%
A320neo = 11%

$CDF_{mix} = CDF_{A330\text{-}900} + CDF_{A350\text{-}900} + CDF_{B747\text{-}400ER} + CDF_{B777\text{-}300ER} + CDF_{B737MAX9} + CDF_{A380\text{-}800} + CDF_{A320neo}$

CDF – 8 A330-900, A350-900, B747-400ER, B777-300ER, B737MAX9, A380-800, A320neo, A321neo)



Contribution to CDF max:

A330-900 = 11%
A350-900 = 6%
B747-400ER = 2%
B777-300ER = 17%
B737MAX9 = 14%
A380-800 = 3%
A320neo = 26%
A321neo = 22%

CDFmix = CDFA330-900 + CDFA350-900 + CDFB747-400ER + CDFB777-300ER + CDFB737MAX9 + CDFA380-800 + CDFA320neo + CDFA321neo

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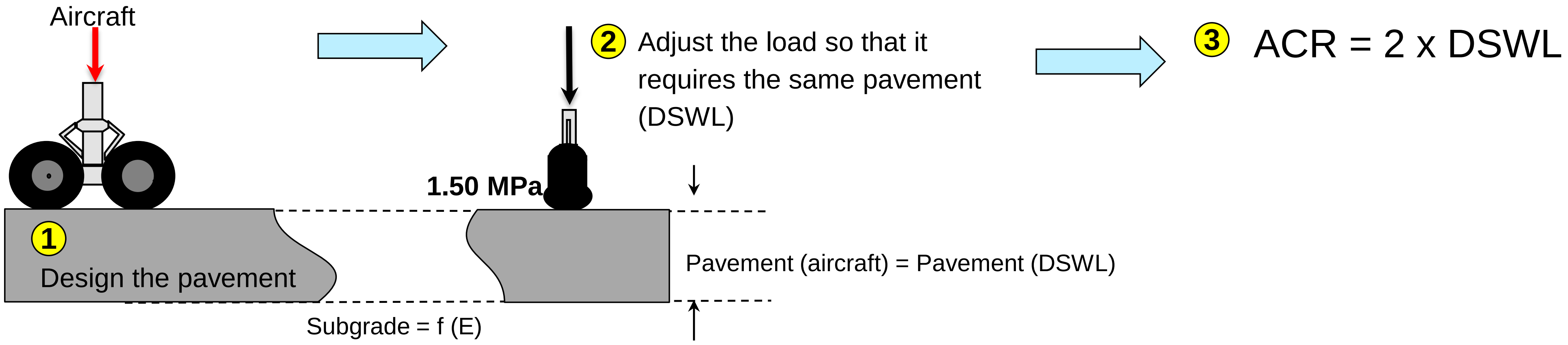
Definition

Aircraft Classification Rating(ACR)

”A number expressing the relative effect of an aircraft on a pavement for a specified standard subgrade strength.”

ACR concept

- Similarly to the ACN, the ACR is computed as twice the standard **Derived Single Wheel Load (DSWL)**, which is the load on a single, isolated wheel (with fixed tire pressure) requiring the same pavement thickness than the considered aircraft



- The changes vs. ACN are:
  1. The pavement is designed according to a rational pavement design procedure (vs. CBR or Westergaard procedures): **this is the major change vs. ACN and the key part of ACR computation**
  2. The DSWL is computed for a tire pressure of 1.50 MPa (vs. 1.25 MPa)
  3. The ACR is expressed in hundreds of kilograms (vs. thousands)

ACR concept
Standard subgrade strength categories

- As for the ACN, the ACR is computed for 4 standard subgrade strength categories ranging from “high” (A) to “ultra-low” (D)

- The subgrade strength is now characterized by its elastic modulus (Young’s modulus) for both flexible and rigid pavements
- There is now a **unified subgrade strength characterization** for both pavement types

	CAT A **High**	**CAT B** **Medium**	**CAT C** **Low**	**CAT D** **Ultra-low**
ACR (flexible & rigid)	E = 200 MPa	E = 120 MPa	E = 80 MPa	E = 50 MPa
ACN (flexible)	CBR 15	CBR 10	CBR 6	CBR 3
ACN (rigid)	K = 150 MN/m3	K = 80 MN/m3	K = 40 MN/m3	K = 20 MN/m3

- The Young’s modulus E may be obtained by the following means:
  – In-situ tests (plate load test)
  – Laboratory tests
  – Approximate conversion from CBR or K value

Flexible ACR

Calculation procedure

1 Design the pavement (P-209 crushed aggregate layer) for 36500 passes of the considered aircraft
Target: CDF = 1 for the US subgrade failure model

	Layer	Modulus	Poisson's ratio	Thickness
	P-401/P-403 Hot Mix Asphalt	$E = 1379\ MPa$	$\nu = 0.35$	$t = 3\ in\ (7.6\ cm)^*$ $t = 5\ in\ (12.7\ cm)^{**}$
Design layer	P-209 Crushed aggregate	$E = f(t)$	$\nu = 0.35$	t
	Subgrade	$E = f(A, B, C, D)$	$\nu = 0.35$	$t = \infty$

ε_z

* For aircraft with Main Landing Gear ≤ 2 wheels
** For aircraft with Main Landing Gear > 2 wheels

$$t_{min} = 1\ in\ (2.54\ cm)$$

Reference pavement structure for the ACR

Sensitivity analysis showed that the ACR is relatively insensitive to the choice of the reference pavement structure (thicknesses and material types)

2 Determine the single isolated wheel load, inflated at 1.50 MPa**, that produces the same damage (i.e. CDF = 1)** on the pavement structure (DSWL) for the same number of passes

3 ACR = 2 x DSWL (in hundreds of kilograms)

Rigid ACR

Calculation procedure

1. Design the pavement (cement concrete layer) for the considered aircraft
Target: Maximum horizontal stress at the base of the cement concrete layer $\sigma_{h\ max} = \sigma_{h\ target}$ = 2.75 MPa

Design layer				
PCC Cement Concrete	$E = 27579\ MPa$	$\nu = 0.15$	t	$\sigma_{h\ max}$
Base layer	$E = 500\ MPa$	$\nu = 0.35$	$t = 7.9\ in\ (20.0\ cm)$	
Subgrade	$E = f(A, B, C, D)$	$\nu = 0.40$	$t = \infty$	

$$t_{min} = 2\ in\ (5.1\ cm)$$

Reference pavement structure for the ACR

Sensitivity analysis showed that the ACR is relatively insensitive to the choice of the reference pavement structure (thicknesses and material types)

2. Determine the single isolated wheel load, inflated at 1.50 MPa, **that produces the same maximum horizontal stress** (i.e. $\sigma_{h\ target}$ = 2.75 MPa) at the bottom of the cement concrete layer (DSWL)

3. ACR = 2 x DSWL (in hundreds of kilograms)

How to get ACR?

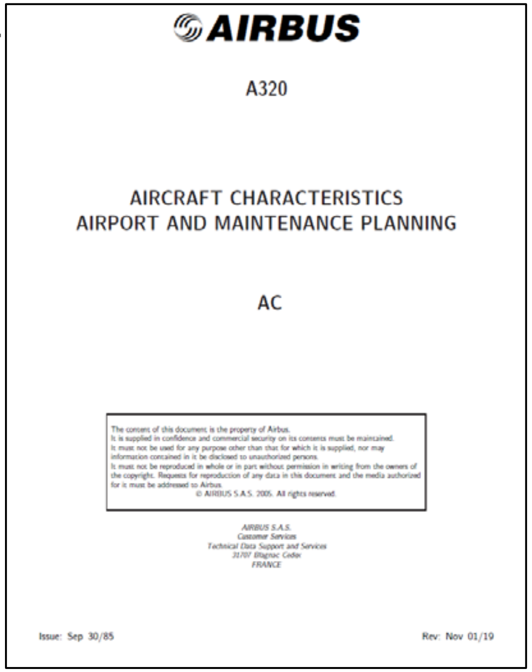
- Aircraft manufacturers will publish their product's ACR in their *Aircraft Characteristics* manuals for the critical weight and center of gravity configuration (usually Maximum Ramp Weight and the corresponding maximum aft CG position)

- The ACR may be also provided for a lower weight in order to allow interpolation to get an approximate ACR for any operating weight

- A dedicated software ICAO-ACR (similar to the current ICAO-ACN) is available with the following features:
  - Built-in airplane library
  - Possibility to define customized aircraft configurations
  - Computation of flexible and rigid ACR for the desired weight / percentage of load on the main landing gear / tire pressure

- Available at:

https://www.airporttech.tc.faa.gov/Products/Airport-Safety-Papers-Publications/Airport-Safety-Detail/icao-acr-13



AIRBUS

A320

AIRCRAFT CHARACTERISTICS
AIRPORT AND MAINTENANCE PLANNING

AC

AIRBUS S.A.S.
Customer Services
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31707 Blagnac Cedex
FRANCE

Issue: Sep 30/85 Rev: Nov 01/19

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Definition

Pavement Classification Rating(PCR)

” A number expressing the bearing strength of a pavement for unrestricted operations.”

PCR concept / Reporting format

- Similarly to the PCN, the PCR represents the pavement structural bearing strength (on the ACR scale) for <u>unrestricted operations</u>
- A PCR should be determined by the airport operator for all the pavements intended for aircraft of mass greater than 5.7 tons
- The PCR should be published in the Aeronautical Information Publication (AIP) according to the format defined in ICAO Annex 14 (§ 2.6.6)

PCR number

Subgrade strength category
A: High
B: Medium
C: Low
D: Ultra low

PCR 560 / F / B / W / T

Evaluation method
U: Using aircraft experience
T: Technical evaluation

Pavement type
F: Flexible
R: Rigid

Maximum allowable tire pressure
W: No pressure limit
X: 1.75 MPa
Y: 1.25 MPa
Z: 0.5 MPa

General principles

Determination of subgrade strength category (A/B/C/D)

- The subgrade strength is now characterized by its elastic modulus (Young's modulus) for both flexible and rigid pavements
- There is now a **unified subgrade strength characterization** for both pavement types

	CAT A High	CAT B Medium	CAT C Low	CAT D Ultra-low
PCR (flexible-**F** and rigid-**R**)	E ≥ 150 MPa	100 ≤ E < 150 MPa	60 ≤ E < 100 MPa	E < 60 MPa
PCN (flexible)	CBR > 13	8 < CBR ≤ 13	4 < CBR ≤ 8	CBR ≤ 4
PCN (rigid)	K > 120 MN/m3	60 < K ≤ 120 MN/m3	25 < K ≤ 60 MN/m3	K ≤ 25 MN/m3

- The Young's modulus E may be obtained by the following means:
  - In-situ tests (plate load test) and/or lab testing (for new pavement construction)
  - Conversion from CBR or K value (for in-service pavements)

Example of conversions: $\mathrm{E} = 10\ \mathrm{CBR}$ (E in MPa) **Flexible**

$\mathrm{E} = 20.15\ \mathrm{K}^{1.284}$ (E in psi, K in pci) **Rigid**

General principles

Determination of tire pressure category (W/X/Y/Z)

- The tire pressure categories remain unchanged compared to the PCN

	Code W Unlimited	Code X High	Code Y Medium	Code Z Low
PCR (and PCN)	No pressure limit	P ≤ 1.75 MPa	P ≤ 1.25 MPa	P ≤ 0.50 MPa

- The results of pavement research and reevaluation of old test results reaffirm that except for unusual pavement construction (i.e. flexible pavements with a thin asphaltic concrete cover or weak upper layers), tire pressure effects are secondary to wheel load and wheel spacing

- **Rigid pavements** generally do not require tire pressure restrictions (except cases of spalling joints or unusual surface defects)

- For **flexible pavements** (or rigid pavements with flexible overlays), it is usually acceptable to establish category limits only when experience with high tire pressures indicates pavement distress

PCR determination – Technical evaluation (T)

Overview of generic procedure

- The ACR/PCR method does permit States to use the design/evaluation procedure of their choice when determining the PCR rating for their pavements, provided it remains consistent with the overall parameters of the ACR-PCR method

- Unlike the PCN, the ICAO developed a *generic procedure* for the PCR technical evaluation in order to fill the gap for states or Airport that may lack the expertise in the area

- The PCR determination is based on the concept of Cumulated Damage Factor (CDF) implementing Miner's rule:

  $CDF = CDF_1 + CDF_2 \ldots + CDF_N$ where $i = 1..N$ denotes the different aircraft in the mix

- A valid PCR procedure must ensure that:
  - If the pavement CDF is lower than or equal to 1.0 (well or over-designed), no weight restriction should occur for aircraft in the evaluated traffic
  - If the pavement CDF is higher than 1.0 (under-designed), at least one aircraft from the evaluated traffic will be weight-restricted

- As the **PCR is related to the *structural* pavement life**, the CDF for flexible pavements should be based on the **subgrade failure model**

PCR determination – Technical evaluation (T)

Damage model selection

- Although a full damage model is prescribed for the ACR calculation, the **generic PCR procedure does not dictate the use of a preferred damage model**

- The following elements can therefore be adjusted to obtain the best PCR accuracy:
  - Elementary (subgrade damage) law
  - Consideration of multi-axle loads (tandem wheels)
  - Handling of aircraft lateral wander (two methods) and standard deviation
  - Aircraft speed (frequency) and temperature adjustment ($E=f(f,\theta)$)
- **Using the same damage model as for pavement design** will ensure consistency between what the actual pavement is able to withstand and the PCR assignment

Inconsistency between the damage models used for pavement design and PCR determination may result in:

- PCR underestimation (hence unoptimized use of pavement, potential denial of aircraft operations, loss of revenues)
- PCR overestimation (hence accelerated pavement deterioration, reduced pavement life and premature pavement repairs / rehabilitation)

- Understanding and selecting the appropriate damage model and associated parameters for PCR calculation is of **paramount importance**

PCR determination – Technical evaluation (T)

Procedure flowchart

Traffic | **Pavement**

1. Identify aircraft with the highest ACR (at operational weight) in the traffic AC_{max}

$i = 1$

2. Calculate the maximum pavement damage $D_{max}{}^{(1)}$ for the current traffic
3. Select aircraft $AC^{(i)}$ that contributes the most to $D_{max}{}^{(i)}$
4. Keeping only $AC^{(i)}$ in the traffic, adjust its number of passes $N^{(i)}$ so that the pavement damage is the same than the full traffic $D_{max}{}^{(1)}$ — Make aircraft equivalent to the full traffic
5. Keeping only $AC^{(i)}$ in the traffic with its adjusted number of passes $N^{(i)}$, adjust its weight $W^{(i)}$ so that the pavement damage is D = 1.0 — Make equivalent aircraft compatible with the pavement
6. $PCR^{(i)}$ = ACR of aircraft $AC^{(i)}$ at adjusted weight $W^{(i)}$
7. $AC^{(i)}$ is aircraft with the highest ACR AC_{max} ?

No → Remove $AC^{(i)}$ from current traffic; $i = i + 1$ (return to step 2)

Yes → $$PCR = \max_{i} PCR^{(i)}$$

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Examples of PCR technical evaluation

Flexible pavement – Under-designed (CDF > 1.0)

- **An existing flexible** taxiway had been designed according to the US FAA design procedure.
- The subgrade modulus is estimated as: $E = 59\ MPa$ ⇨ subgrade **category D**
- There is no evidence of pavement distress attributable to excessive tire pressure ⇨ tire pressure **category W**
- The damage model for the PCR evaluation is the same than used for pavement design (FAA damage model for flexible pavements)

Pavement input data

P401 HMA Wearing course	$E = 1378\ MPa$	$\nu = 0.35$	$t = 12.7\ cm\ (5\ in)$
P403 HMA Base course	$E = 2757\ MPa$	$\nu = 0.35$	$t = 13.97\ cm\ (5.5\ in)$
P209 Crushed agg. Sub-base	$E = 358.3\ MPa$	$\nu = 0.35$	$t = 17.78\ cm\ (7\ in)$
P209 Crushed agg. Sub-base	$E = 233.5\ MPa$	$\nu = 0.35$	$t = 25.4\ cm\ (10\ in)$
Subgrade	$E = 59\ MPa$	$\nu = 0.35$	$t = \infty$

Examples of PCR technical evaluation

Flexible pavement – Under-designed (CDF > 1.0)

- Traffic forecasted over the expected remaining pavement life

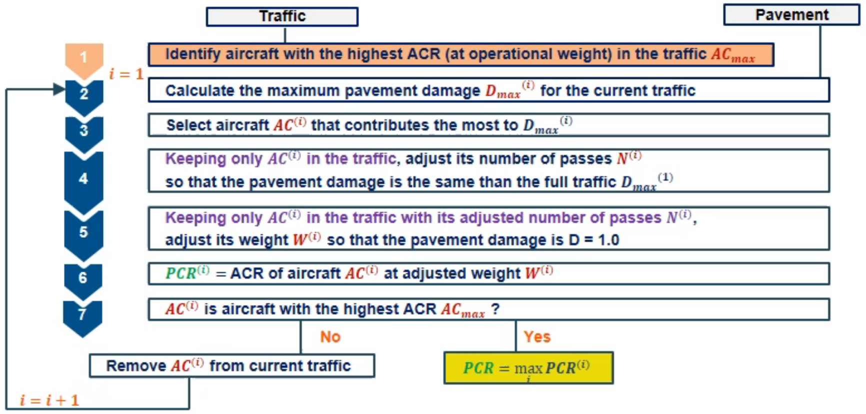
Aircraft	Operating weight (t)	Passes
ATR 42	18.8	172 042
ATR 72	22.7	151 032
E195	49.0	132 042
A319neo	75.9	32 043
A320neo	79.4	35 674
737-700	70.3	40 059
737-800	79.2	30 784
737-900ER	85.4	20 842

Trafic input data

- Aircraft wander is considered as per the FAA Pass-to-Coverage method (Standard deviation, σ = 30.54 in = 77.57 cm)

Examples of PCR technical evaluation

Flexible pavement – Under-designed (CDF > 1.0)



Examples of PCR technical evaluation

Flexible pavement – Under-designed (CDF > 1.0)

- The PCR should be reported as **550 F/D/W/T**

- The ACR of the 737-900ER (563 F/D) exceeds the PCR and would therefore be weight-limited (consistently with the pavement being under-designed for the traffic, CDF > 1.0)

- The PCR would be computed as 620 F/D/W/T if the French damage model is used
- The PCR would therefore be overestimated and no limitation would apply to the aircraft within the traffic, leading to reduced pavement life vs. expectations (as per design)
- This highlights the importance of the **damage model selection for PCR calculation**

Examples of PCR technical evaluation

Flexible pavement – Over-designed (CDF < 1.0)

- A new constructed flexible taxiway had been designed according to the French design procedure.
- The subgrade modulus is estimated as: $E = 80\ MPa$ ⇨ subgrade category C
- There is no evidence of pavement distress attributable to excessive tire pressure ⇨ tire pressure category W
- The damage model for the PCR evaluation is the same than used for pavement design (French damage model for flexible pavements)
- Design life = 20 yrs,
- HMA E-Modulus (15°C/3Hz)

Pavement input data

Surface – BBSG 1	$E = 4512\ MPa$	$\nu = 0.35$	$t = 6\ cm$
Base – GB3	$E = 7383\ MPa$	$\nu = 0.35$	$t = 12\ cm$
Sub-base (top)	$E = 600\ MPa$	$\nu = 0.35$	$t = 16\ cm$
Sub-base (bottom)	$E = 240\ MPa$	$\nu = 0.35$	$t = 25\ cm$
Subgrade	$E = 80\ MPa$	$\nu = 0.35$	$t = \infty$

Examples of PCR technical evaluation

Flexible pavement – Over-designed (CDF < 1.0)

- Traffic forecasted over the pavement design life

Aircraft	Operating weight (t)	Passes
ATR 72	20,02	24 000
A320-100	68,4	40 000
A320-200	77,4	50 000
A320neo	79,4	30 000
A321-100	89,4	20 000
B737-900	79,2	50 000
B737-800	79,2	30 000
B757-300	122,9	10 000
A330-200	233,9	10 000

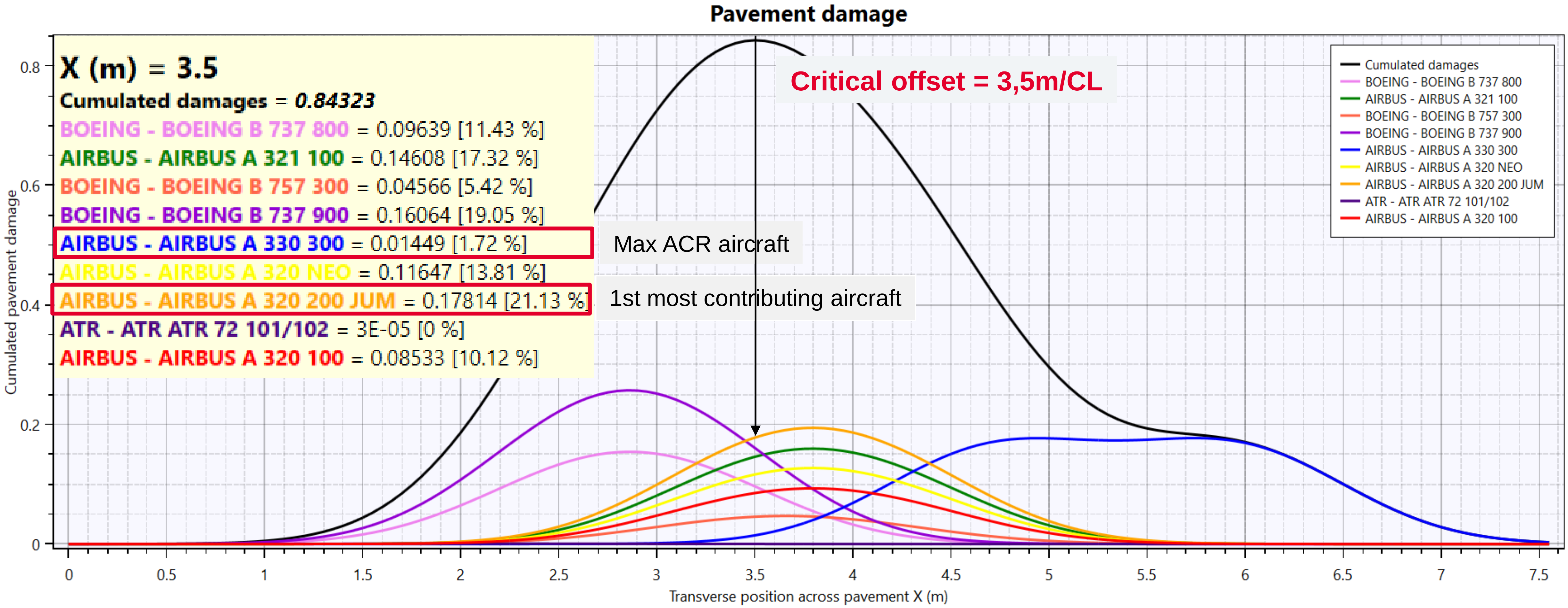
Trafic input data

- Aircraft wander is considered as per the French method / Normal distribution on all damage profiles (Standard deviation, σ = 0,5m for taxiway)

Examples of PCR technical evaluation

Flexible pavement – Over-designed (CDF < 1.0)

CDF



PCR: 690/F/C

Examples of PCR technical evaluation

ANALYSIS

Flexible pavement – Over-designed (CDF < 1.0)

Max Individual aircraft CDF (737-900)

Most contributing aircraft (A320-200)

Max ACR aircraft (A330-300)

First Run PCR (A320-200)

PCR: 690/F/C

Aircraft	Operating weight (kg)	Passes	CDF max.	CDF contri[illegible]	CDF contrib. (%)	Max damage location (m)	Max d[illegible]e offset	ACR at ops weight	PCR rank	Eq. Passes	MAGW ([illegible])	PCR	
AIRBUS - AIRBUS A 320 200 JUM	77400	50000	0.19450	0.17814	21,1	3.80	0.30	421.25	1	216768.82	80469.15	440	■■■
BOEING - BOEING B 737 900	79243	50000	0,26	0.16064	19.05	2.85	-0.65	448.92	2	163867.49	82392.27	471.47	■■■
AIRBUS - AIRBUS A 321 100	89400	20000	0.15965	0.14608	17.32	3.80	0.30	517.50	3	105635.25	92962.07	543.41	■■■
AIRBUS - AIRBUS A 320 NEO	79400	30000	0.12724	0.11647	13.81	3.80	0.30	431.46	4	198816.8	82550.23	452.90	■■■
BOEING - BOEING B 737 800	79243	30000	0.15437	0.09639	11.43	2.85	-0.65	448.92	5	163867.49	82392.18	471.47	■■■
AIRBUS - AIRBUS A 330 300	233900	10000	0.17735	0.01449	1.72	5.75	2,25	655	6	47546.75	243384.27	690	■■■
AIRBUS - AIRBUS A 320 100	68400	40000	0.09317	0.08533	10.12	3.80	0[illegible]0	361.45					■■■
BOEING - BOEING B 757 300	122930	10000	0.04699	0.04566	5.42	3.65	[illegible]	377.64					■■■
ATR - ATR ATR 72 101/102	20020	24000	0.00075	0.00003	0.00	2.05	[illegible]	107.49					■■■
Cumulated damages			0,84			3,5							

690 FCWT

Max CDF (@critical offset)

Critical offset

Max distance to the critical offset (A330-300)

Last PCR loop (A330-200) = PCR to be published

Examples of PCR technical evaluation

Flexible pavement – Over-designed (CDF < 1.0)

Inconsistent parameters for PCR calculation – Examples:

Design Parameters	CDF	PCR (F/C/W/T)	Delta (%)	Structural life (Years)
Consistent with pavement design*	**0,84**	**690**	**Ref.**	**23,8**
Wandering with P-to-C ratio (1)	1,02	650	-5,8	19,6
FAA subgrade failure model (2)	0,43	710	2,9	46,5
(1)+(2)=(3)	1,17	650	-5,8	17,1
T°(Corrected E) = 30°C (4)	2,41	500	-27,5	8,3
Frequency (speed) = 10Hz (100km/h) (5)	0,7	730	+5,8	28,6
(4)+(5)=(6)	1,91	540	-21,7	10,5
(3)+(6)=7	16,9	470	-31,9	1,2

*HMA@15°C/3Hz

Lateral wandering, standard deviation and subgrade failure model as per French practice

Examples of PCR technical evaluation

Rigid pavement (Concrete flexural strength = **5,17 MPa**) / CDF = 1,05 (Slightly under-designed)

Aircraft	Operating weight (t)	Passes	ACR (RB)
COMAC C919	72,5	1 600	460
EMB-195	48,95	24 000	280
A320neo	70,4	30 000	430
A321-200	89,4	40 000	605
B737-900ER	85,4	20 000	590
B737-9MAX	88,5	18 000	600

R

P-501 PCC Surface	$E = 27\,579\ MPa$	$\nu = 0.15$	$t = 36\ cm$
P-306 Lean Concrete	$E = 4826\ MPa$	$\nu = 0.20$	$t = 13\ cm$
P209 Crushed agg. Sub-base	$E = 278\ MPa$	$\nu = 0.35$	$t = 15\ cm$
Subgrade	$E = 100\ MPa$	$\nu = 0.35$	$t = \infty$

B

New Apron construction ➔ No tire limitation / Code **W**

RESULTING PCR = 600 **RBWT**

Consequences of PCR inaccuracies

A. Over-estimated PCR (underestimated CDF):

➔ More traffic acceptance (weight/volume) than what the pavement is able to withstand over its design life
➔ Premature pavement damage, increase of maintenance / repairs **COSTS**

B. Under-estimated PCR (overestimated CDF):

➔ Aircraft weight / annual departure restriction/limitation, loss of airport revenues, pavement under use

C. Optimized PCR (CDF consistent with the initial pavement design parameters):

➔Maximize the use of pavement, reduced maintenance needs and cost, increase airport revenues through airport charges (Landing charges, parking charges etc…)

➔ All of that contributes to GHG* emissions reduction through a well mastered pavement life cycle (from raw material to end-life…)

* Green House gaz

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Overload operations

- Overloading of pavements can result from:
  - Loads larger than the design or evaluation load
  - A substantially increased application rate of existing traffic

- With the exception of massive overloading, pavements in their structural behavior are not subject to a particular limiting load above which they suddenly fail

- ICAO provides general pavement overload evaluation guidance for minor overloading, sometimes referred to as “ICAO allowance”

- Larger overloads may be assessed thanks to a detailed technical analysis, consistent with the PCR technical evaluation philosophy

- Specific state practices for overload operations is no longer available

Overload operations

ICAO and EASA allowance

- For those operations in which magnitude of overload and/or the frequency of use do not justify a detailed analysis the following criteria are suggested:
  - For flexible <u>**and**</u> rigid pavements, occasional movements by aircraft with ACR not exceeding **10 per cent above the reported PCR** should not adversely affect the pavement
  - The annual number of overload movements should not exceed approximately **5 per cent of the total annual movements excluding light aircraft**.

<u>Note:</u> ICAO allowance was previously 10 % of PCN for flexible pavements and 5 % of PCN for rigid pavements.

- Overloads should not be permitted:
  - On pavements exhibiting signs of distress
  - During periods of thaw following frost penetration
  - When the strength of the pavement (or subgrade) could be weakened by water

- The pavement condition should be regularly monitored when overload operations are conducted

- Excessive overloads may significantly reduce the pavement structural life life

Overload operations

Technical analysis

- Overloads in excess of 10% can be considered on a case by case basis if supported by a technical analysis

- The ACR, even if exceeding the reported PCR, cannot predict accurately how the overload will affect the pavement damage (hence pavement life) since it is strongly dependant on its offset to the location of the maximum pavement damage

- The technical analysis should therefore determine how the overload operations **contribute to the maximum pavement damage** (maximum CDF) when mixed with the other traffic

- The inputs required to perform such analysis are the same than for the PCR technical evaluation:
  - Pavement structure
  - Aircraft traffic (including overload operations)
  - Damage model (consistent with the PCR calculation and pavement design)

- The ultimate decision to grant overload operations belongs to the airport operator, depending on the impact of such operations on pavement life and its pavement management policy

- A cost-benefit analysis (loss of pavement life vs. additional revenues) can support such decision-making

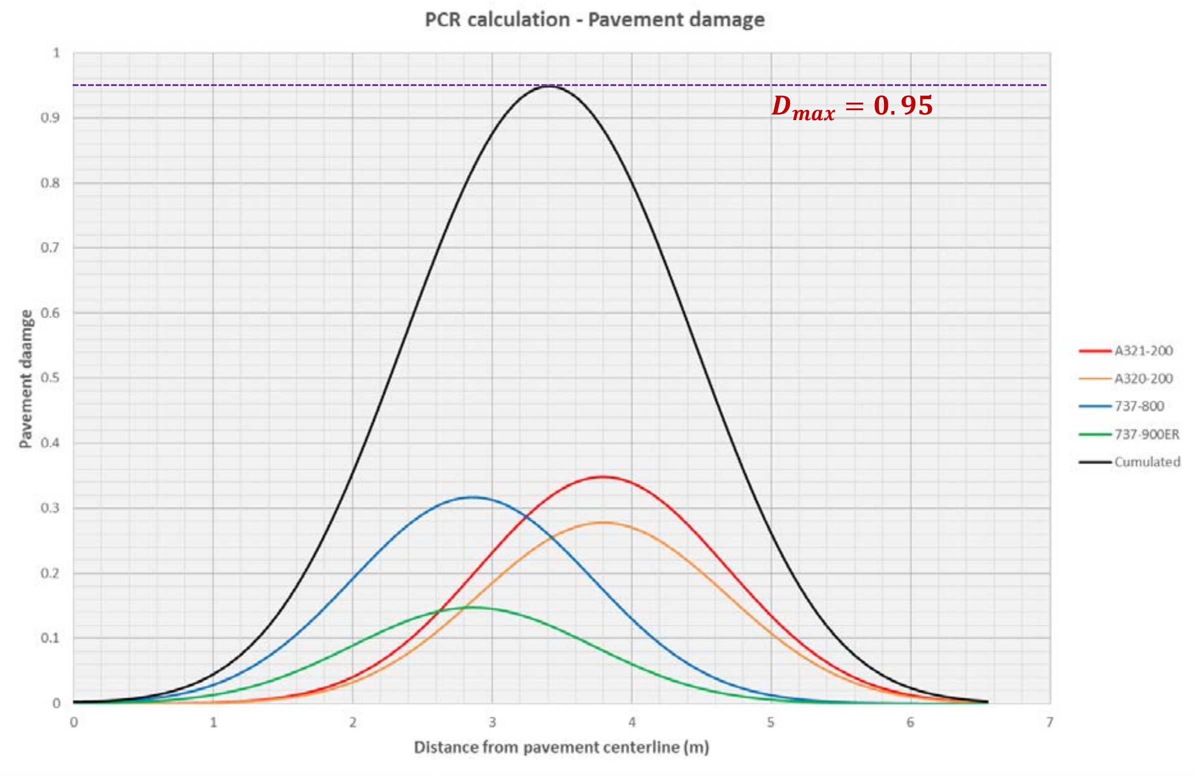
Overload operations

Example

- A flexible pavement runway has been designed (using the French rational design method) to accommodate a pure single-aisle/medium-range aircraft traffic over a period of 10 years

Aircraft	Operating weight (t)	Passes	ACR @ operating weight
A320-200	77.4	34 500	450 F/C
A321-200	93.9	17 000	550 F/C
737-800	79.2	30 000	420 F/C
737-900ER	85.4	14 500	440 F/C

- The designed pavement structure has a maximum CDF = 0.95
- The PCR is calculated and published as **PCR 560 F/C/W/T**



Overload operations

Example

- A new airline is willing to operate **one daily departure** to a long-haul destination with a fully loaded A321neo LR

- The ACR of the A321neo LR at Maximum Ramp Weight (97.4 t) is **580 F/C** and therefore exceeds the PCR (560 F/C)

- The ACR exceeds the PCR by less than 10 %

And

- The number of overload movements (1/day) would not exceed 5 % of the total movements (25/day)

⇨ Overload operations can be granted as per the "ICAO and EASA allowance"

Overload operations

Example

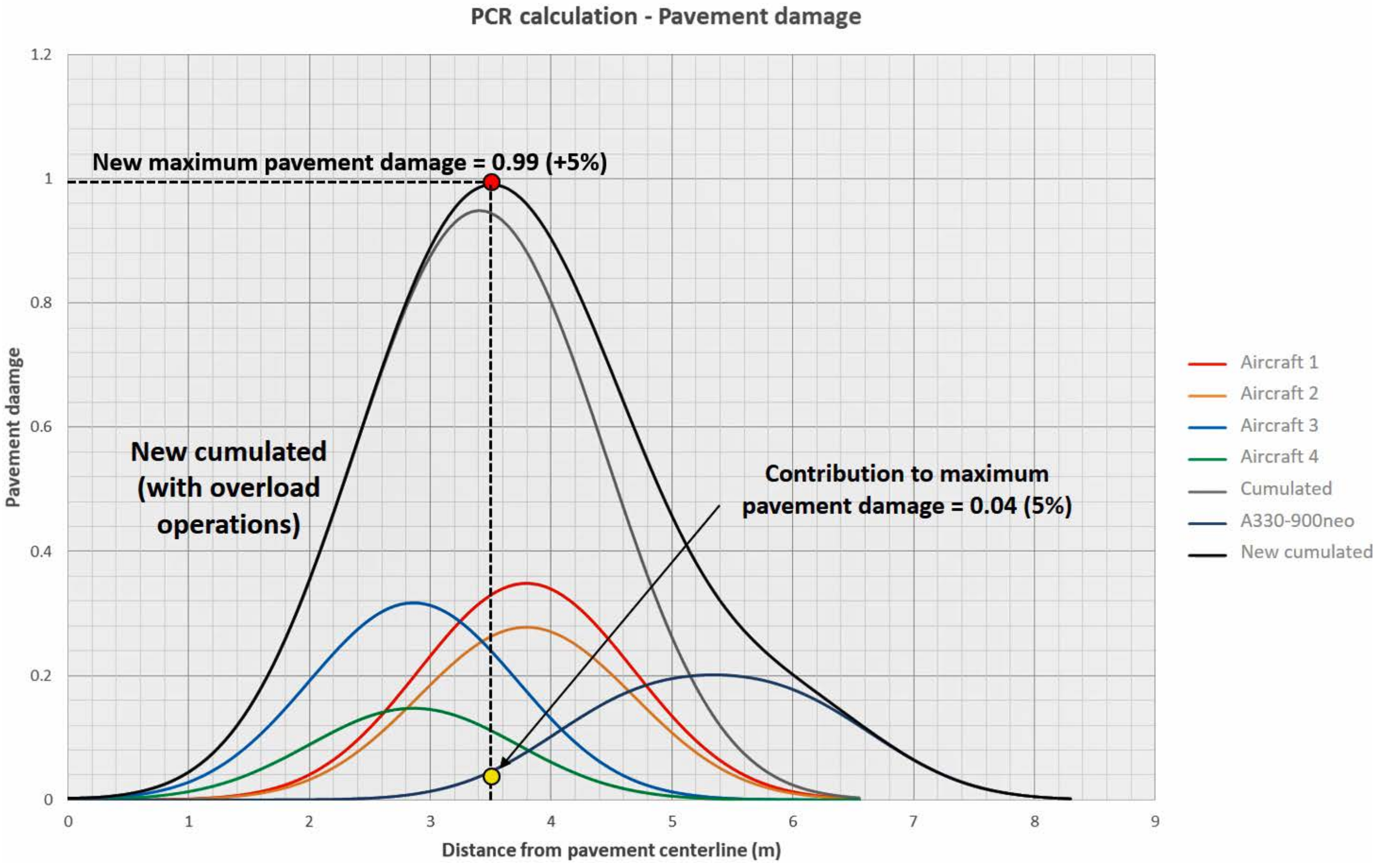
- The airline now contemplates the introduction of one daily departure of A330-900neo

- The ACR of the A330-900neo at Maximum Ramp Weight (251.9 t) is **710 F/C** and therefore exceeds the PCR (560 F/C) by more than 25 %

- The technical analysis shows that the actual impact is limited to an increase of pavement damage by 5 %

⇨ **Based on its cost-benefit analysis, the airport may allow these overload operations**

- If overload operations are allowed, the pavement condition should be regularly be inspected



Contents

- Key changes
- Main features
  - CDF
  - ACR
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  - Examples
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- **Benefits**
- Reference documents

Benefits

- The ACR-PCR system overcomes the deficiencies of the ACN-PCN system and allows consistency and alignment between pavement design and pavement rating systems

- The new system enables an optimized usage (in terms of allowable aircraft weights and frequencies) of existing and future pavements, without excessive conservatism

- For **aircraft operators**, it should lead to fewer pavement-induced weight restrictions. (Local exceptions are possible.)

- For **airport operators**, it provides a consistent damage-based approach:
  - optimize the use of their pavements;
  - assess the impact of overload operations; and
  - improve pavement life predictions.

- For **aircraft manufacturers,** it will allow them to optimize landing gear geometry (both leg geometry and overall geometry) of their future products

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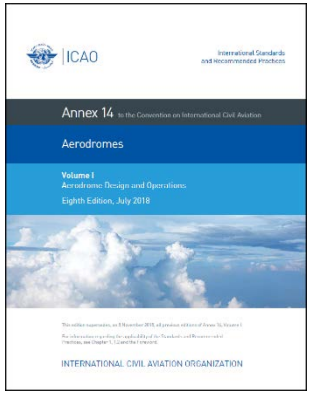
Reference documents

- The ACR-PCR method is fully documented in ICAO documents:
  - Annex 14 including Amendment 15 (method overview, definitions and PCR reporting format)



https://store.icao.int/en/aerodrome-design-manual-part-3-pavements-doc-9157-part-3

  - Aerodrome design manual doc 9157 part 3, 3rd edition (implementation details)

2nd Edition
(1983)

3rd Edition
(2022)

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QUESTIONS ?

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