AIRCRAFT / PAVEMENT CLASSIFICATION RATING
ACR / PCR

A NEW ERA IN AIRPORT PAVEMENT ASSET MANAGEMENT

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ACR-PCR

WHICH CHANGES?

- The plain comparison of two numbers (ACR & PCR) will remain the core of the principle of the system: **ACR ≤ PCR ⇔ unrestricted operations**
- By retaining the same appearance and the simplicity of the current system, the changes would not be as substantial as they might otherwise appear for those who are unfamiliar with airfield pavement

- Only the way of determining the two components will be modified by incorporating a mechanistic-empirical procedure relying on the Linear Elastic Analysis for both flexible and rigid pavements
- This framework allows quantifying the contribution of each aircraft composing a mix to the max. damage produced by the whole traffic, through the Cumulated Damage Factor (CDF) concept

ACR-PCR

THE ACR

- The Aircraft Classsification Rating (ACR) is a number expressing the relative effect on an aircraft on a pavement for a specified standard subgrade strength
- 4 standard subgrade strength categories are define, common to flexible and rigid pavements

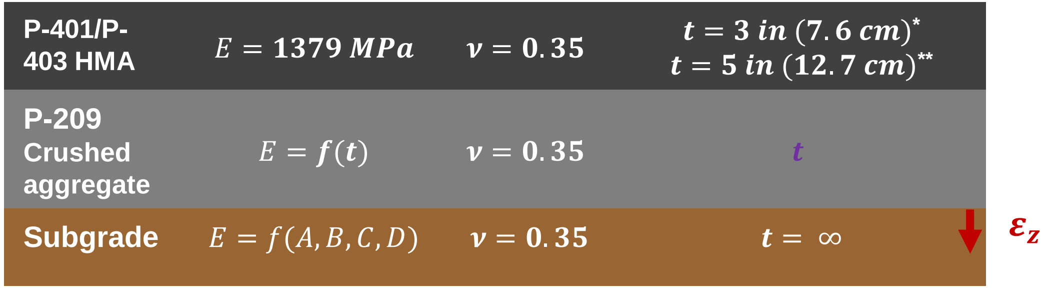
CAT A	CAT B	CAT C	CAT D
E = 200 MPa	E = 120 MPa	E = 80 MPa	E = 50 MPa

- The ACR is numerically defined as twice the Derived Single Wheel Load (DSWL), expressed in hundreds of kilograms
- The DSWL is defined as the single wheel load (with contact pressure of 1.50 MPa), that is equivalent (according to a defined criterion) to the aircraft on a given pavement structure

ACR-PCR

ACR – FLEXIBLE PAVEMENTS

1. Design the pavement structure for 36,500 aircraft passes (without wander)



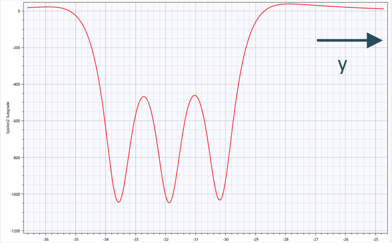
P-401/P-403 HMA	$E = 1379\ MPa$	$\nu = 0.35$	$t = 3\ in\ (7.6\ cm)^*$ $t = 5\ in\ (12.7\ cm)^{**}$
P-209 Crushed aggregate	$E = f(t)$	$\nu = 0.35$	t
Subgrade	$E = f(A, B, C, D)$	$\nu = 0.35$	$t = \infty$

* For aircraft with MLG ≤ 2 wheels
* For aircraft with MLG > 2 wheels

2. Calculate the DSWL (at 1.5 MPa) that produces the same damage (1.0) on the designed structure

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

DAMAGE MODEL



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

Continuous damage model:

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

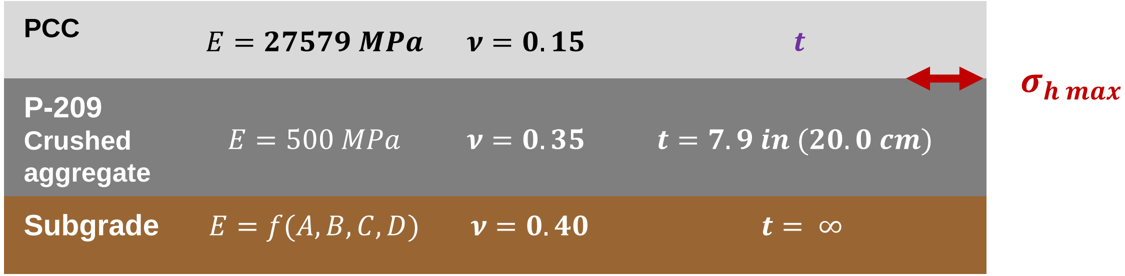
Elementary damage model:

$$D_e(\varepsilon_z) = 10^{-(a+b\varepsilon_z)^{-1/c}}$$

ACR-PCR

ACR – RIGID PAVEMENTS

1. Design the pavement structure for the aircraft such that the maximum horizontal stress induced at the bottom of the PCC layer is **2.75 MPa** (standard working stress for ACR)



PCC	$E = 27579\ MPa$	$\nu = 0.15$	t
P-209 Crushed aggregate	$E = 500\ MPa$	$\nu = 0.35$	$t = 7.9\ in\ (20.0\ cm)$
Subgrade	$E = f(A, B, C, D)$	$\nu = 0.40$	$t = \infty$

$\sigma_{h\ max}$

2. Calculate the DSWL (at 1.5 MPa) that produces the maximum horizontal stress (2.75 MPa) on the designed structure

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

ACR-PCR

THE PCR

- The Pavement Classsification Rating (PCR) is a number expressing, on the same scale than ACR, the load-carrying capacity of a pavement for unrestricted operations
- The PCR of a pavement should reflect the pavement design with respect to the traffic it is intended to serve
- The PCR procedure should ensure that:

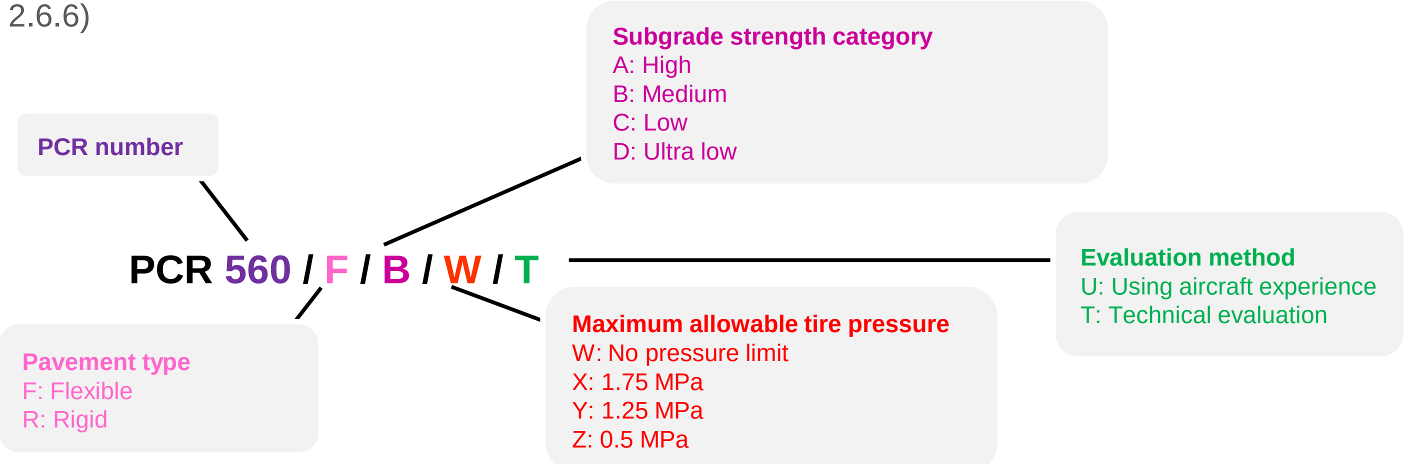
  - If the pavement CDF is equal to or lower than 1.0 (well or over-designed), no aircraft weight restriction should occur
  - If the pavement CDF is higher than 1.0, weight restrictions should apply to one aircraft at least

- A generic PCR computation procedure with several degrees of freedom (e.g. pavement damage model) is proposed

ACR-PCR

THE REPORTING FORMAT

- Similarly to the PCN, the PCR represents the pavement bearing strength (on the ACR scale) for unrestricted operations
- 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

PCR 560 / F / B / W / T

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

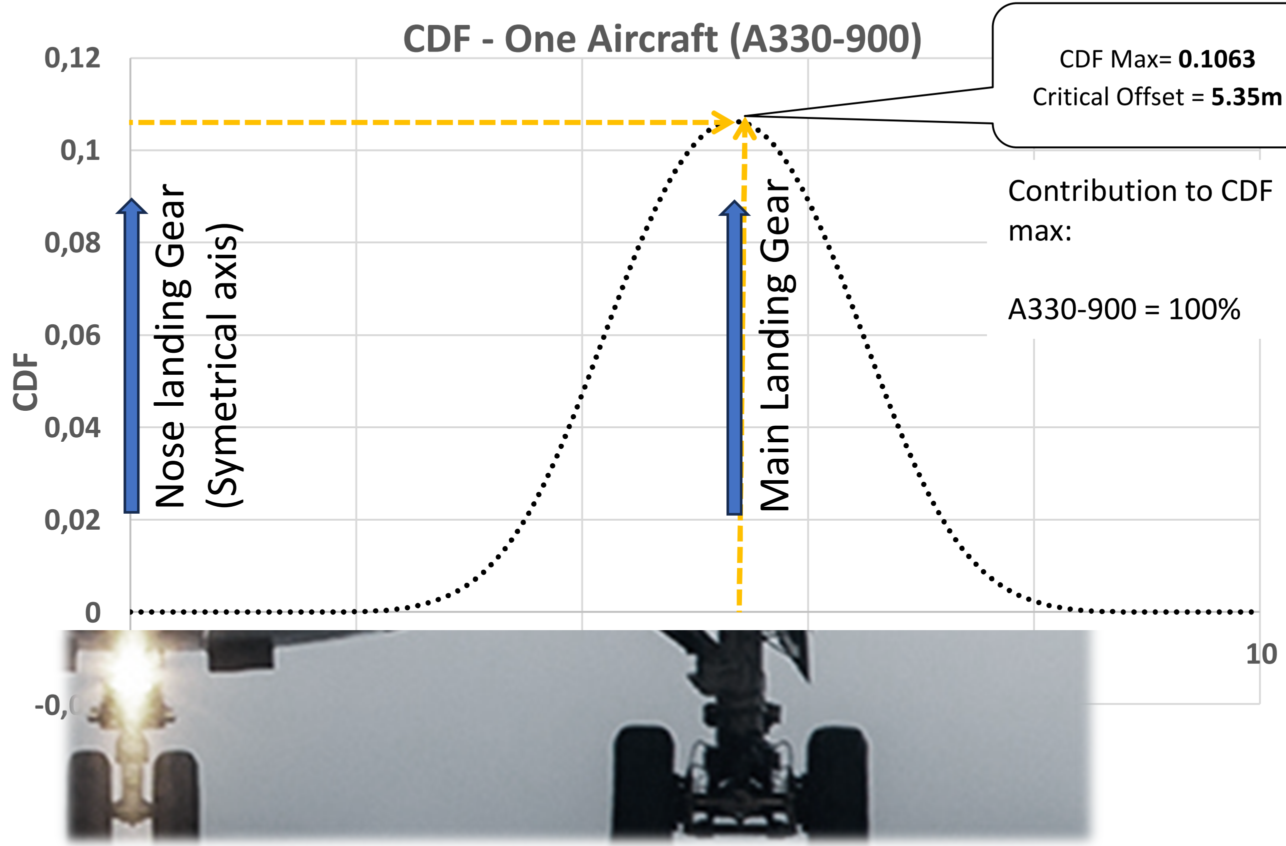
Evaluation method
U: Using aircraft experience
T: Technical evaluation

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

THE CUMULATIVE DAMAGE FACTOR (CDF)

15 987 passes **A330-900**

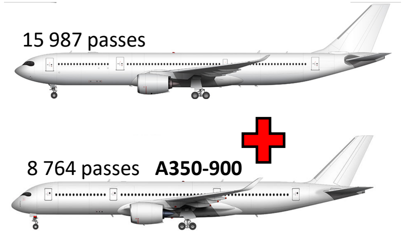


CDF Max= **0.1063**
Critical Offset = **5.35m**

Contribution to CDF max:

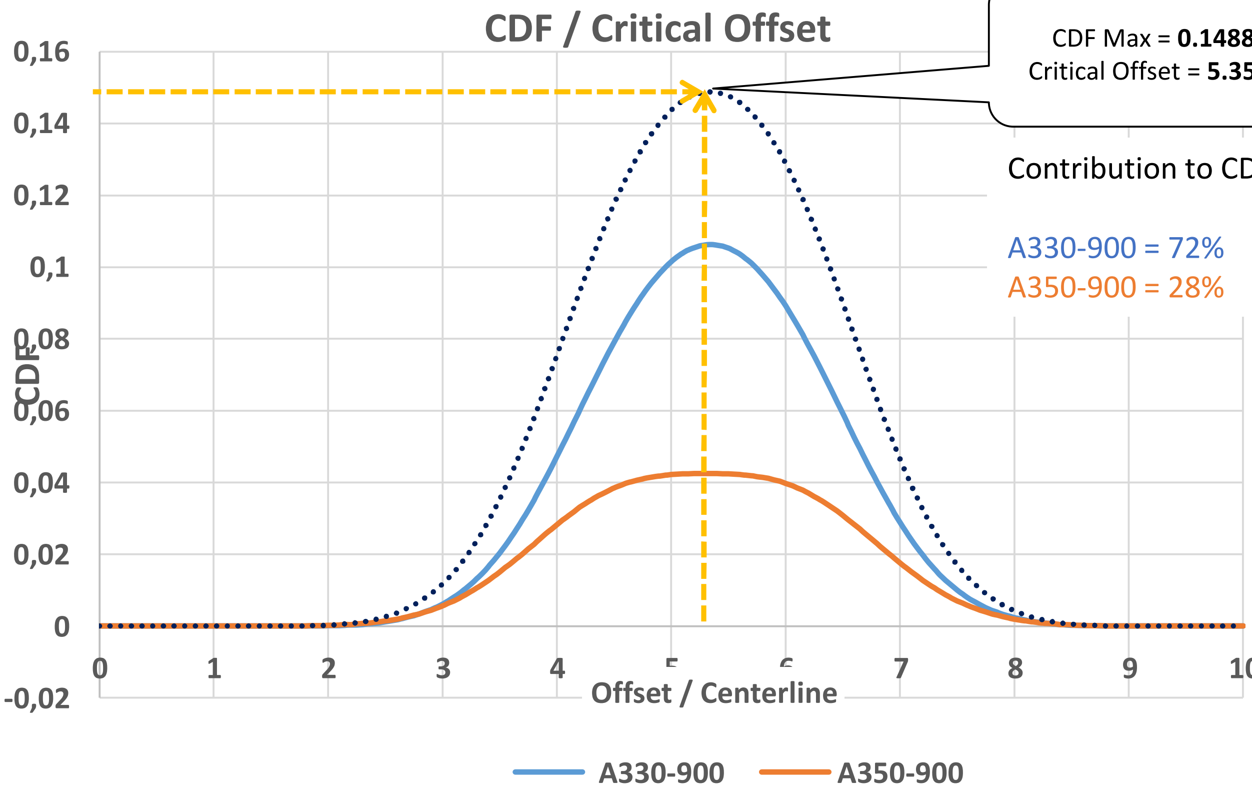
A330-900 = 100%

THE CUMULATIVE DAMAGE FACTOR (CDF)



15 987 passes

8 764 passes **A350-900**



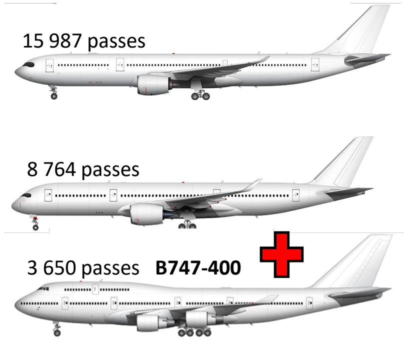
CDF / Critical Offset

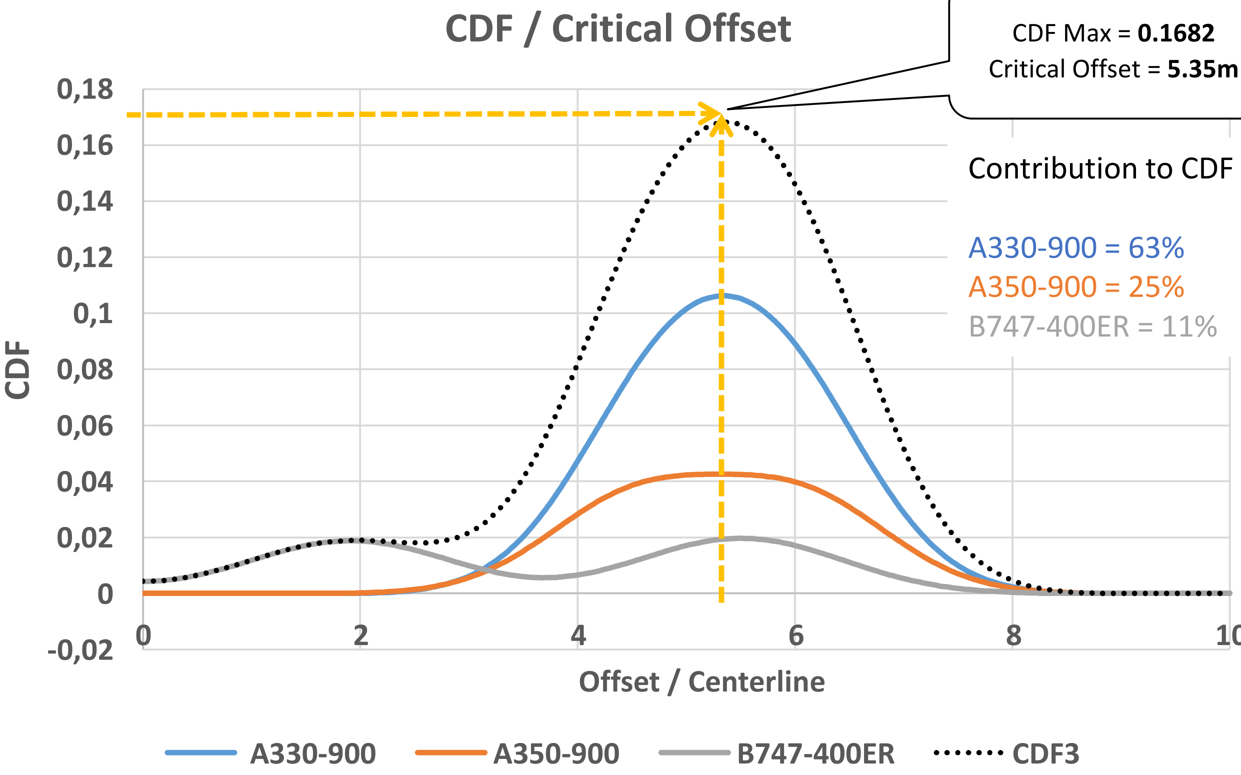
CDF Max = **0.1488**
Critical Offset = **5.35m**

Contribution to CDF max:

A330-900 = 72%
A350-900 = 28%

THE CUMULATIVE DAMAGE FACTOR (CDF)





CDF Max = **0.1682**
Critical Offset = **5.35m**

Contribution to CDF max:

A330-900 = 63%
A350-900 = 25%
B747-400ER = 11%

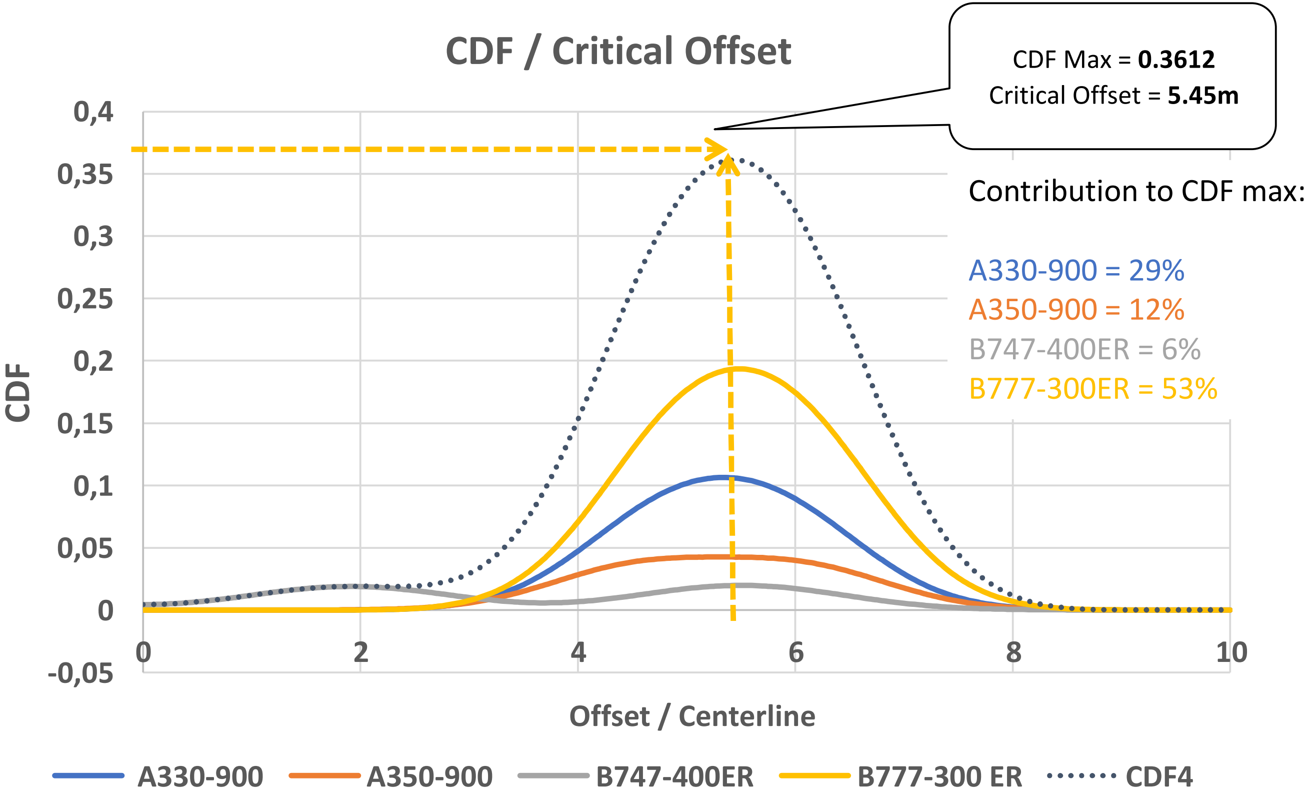
THE CUMULATIVE DAMAGE FACTOR (CDF)

15 987 passes

8 764 passes

3 650 passes

20 922 passes **B777-300ER**



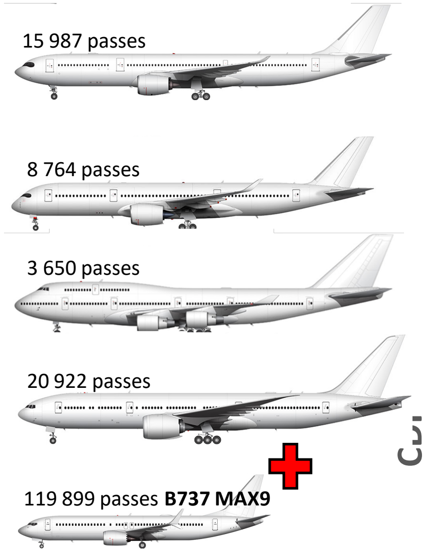
CDF / Critical Offset

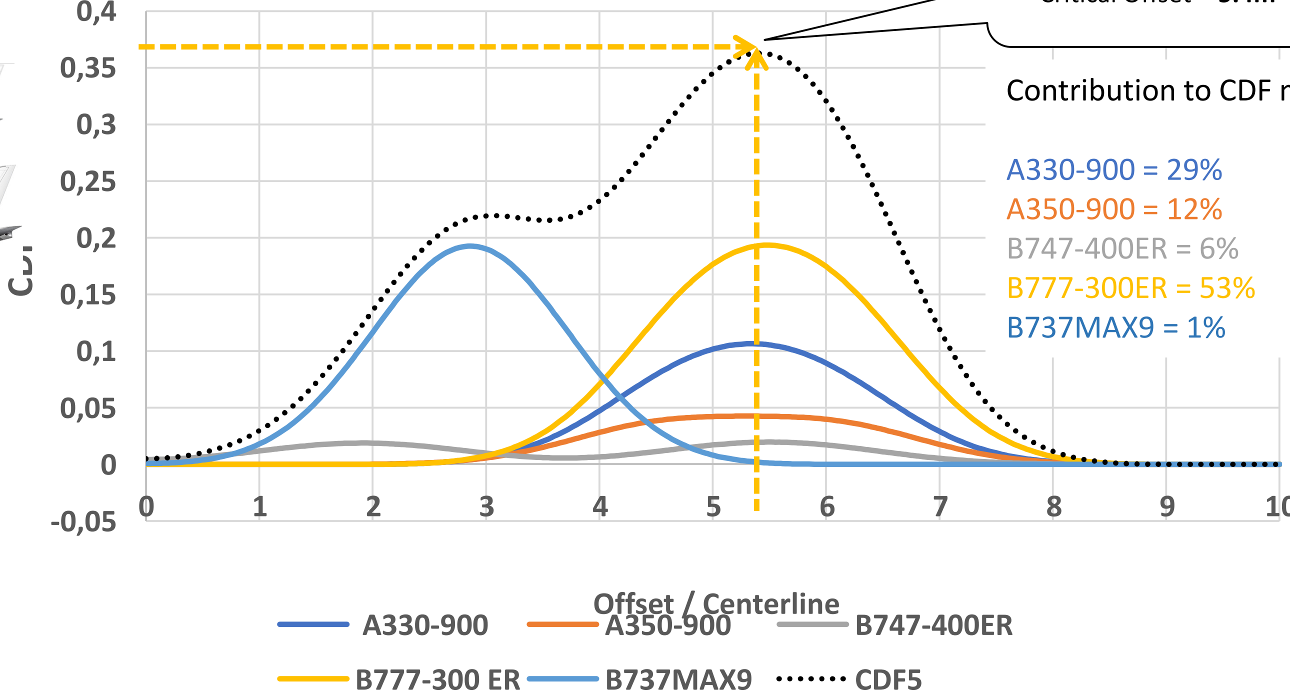
CDF Max = **0.3612**
Critical Offset = **5.45m**

Contribution to CDF max:

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

THE CUMULATIVE DAMAGE FACTOR (CDF)





CDF Max = **0.3629**
Critical Offset = **5.4m**

Contribution to CDF max:

A330-900 = 29%
A350-900 = 12%
B747-400ER = 6%
B777-300ER = 53%
B737MAX9 = 1%

THE CUMULATIVE DAMAGE FACTOR (CDF)

15 987 passes

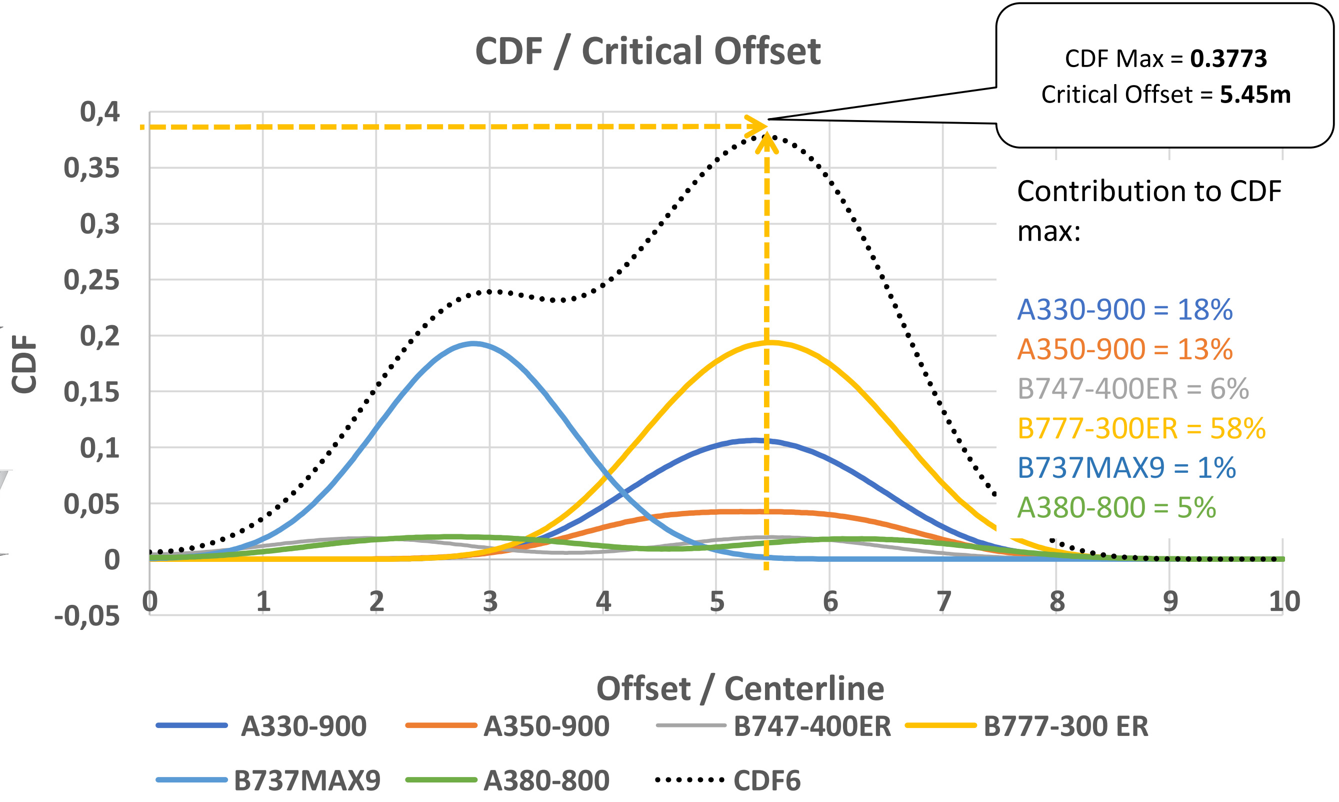
8 764 passes

3 650 passes

20 922 passes

119 899 passes

3650 passes **A380-800**



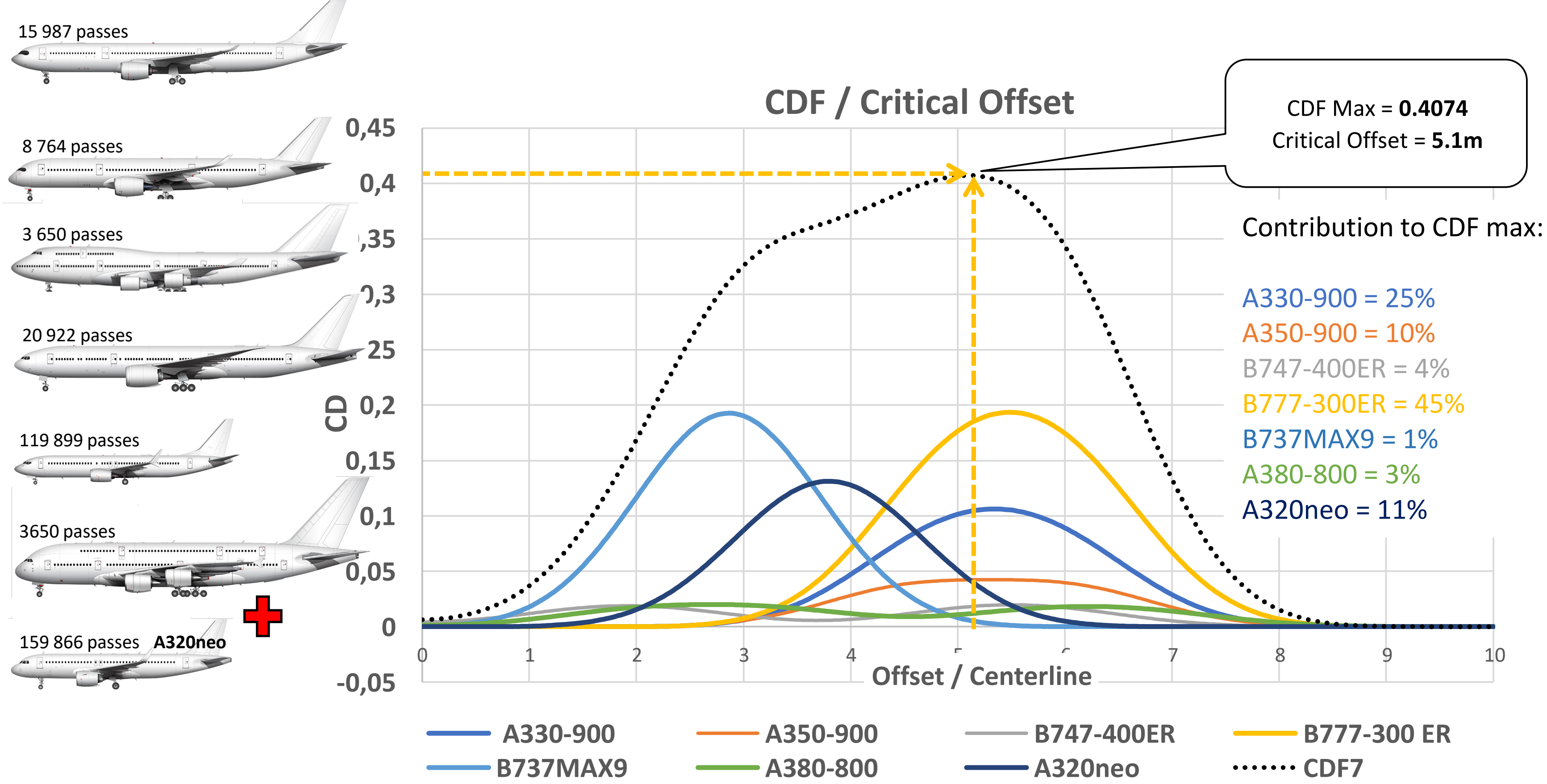
CDF / Critical Offset

CDF Max = **0.3773**
Critical Offset = **5.45m**

Contribution to CDF max:

A330-900 = 18%
A350-900 = 13%
B747-400ER = 6%
B777-300ER = 58%
B737MAX9 = 1%
A380-800 = 5%

THE CUMULATIVE DAMAGE FACTOR (CDF)

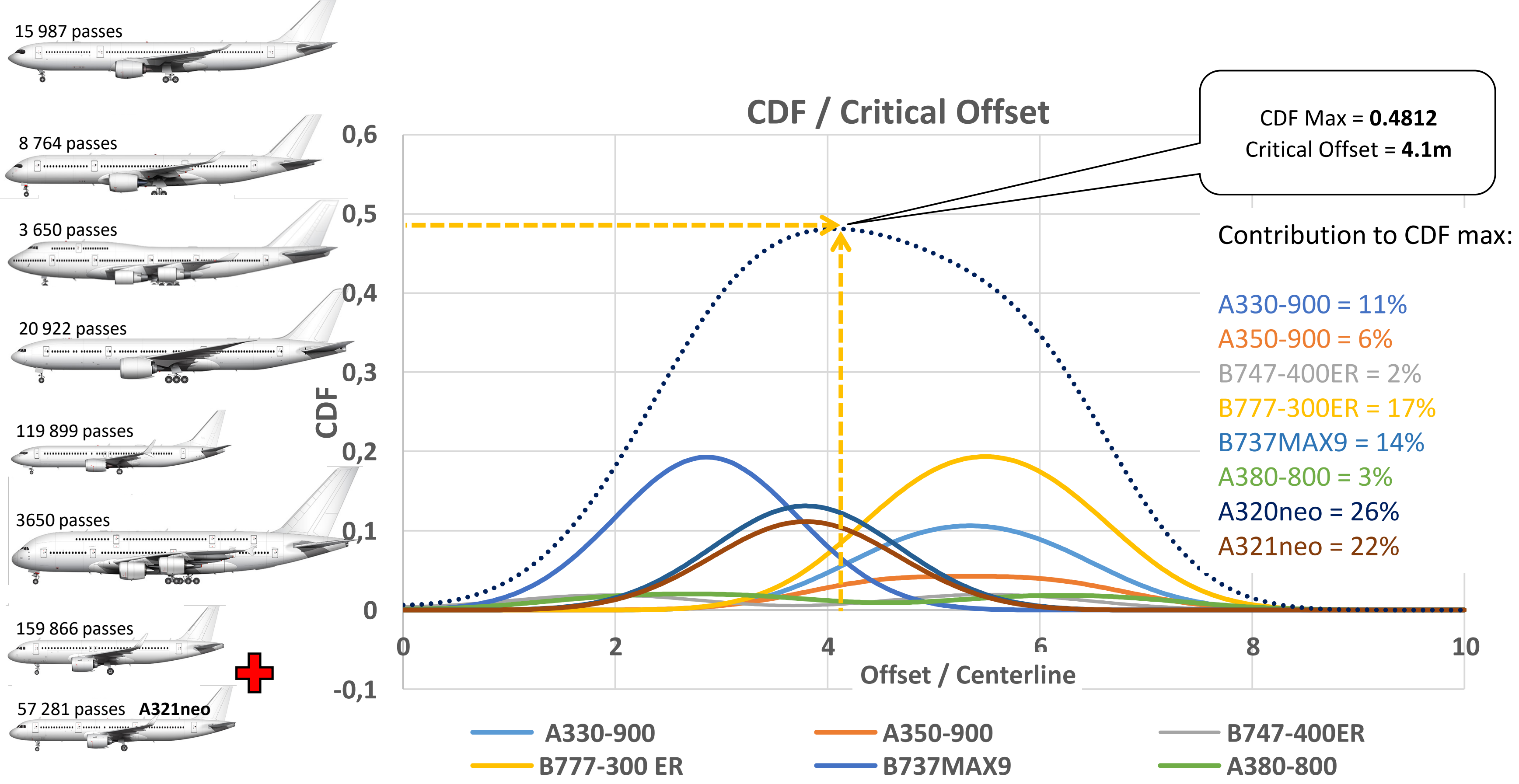


CDF Max = **0.4074**
Critical Offset = **5.1m**

Contribution to CDF max:

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

THE CUMULATIVE DAMAGE FACTOR (CDF)



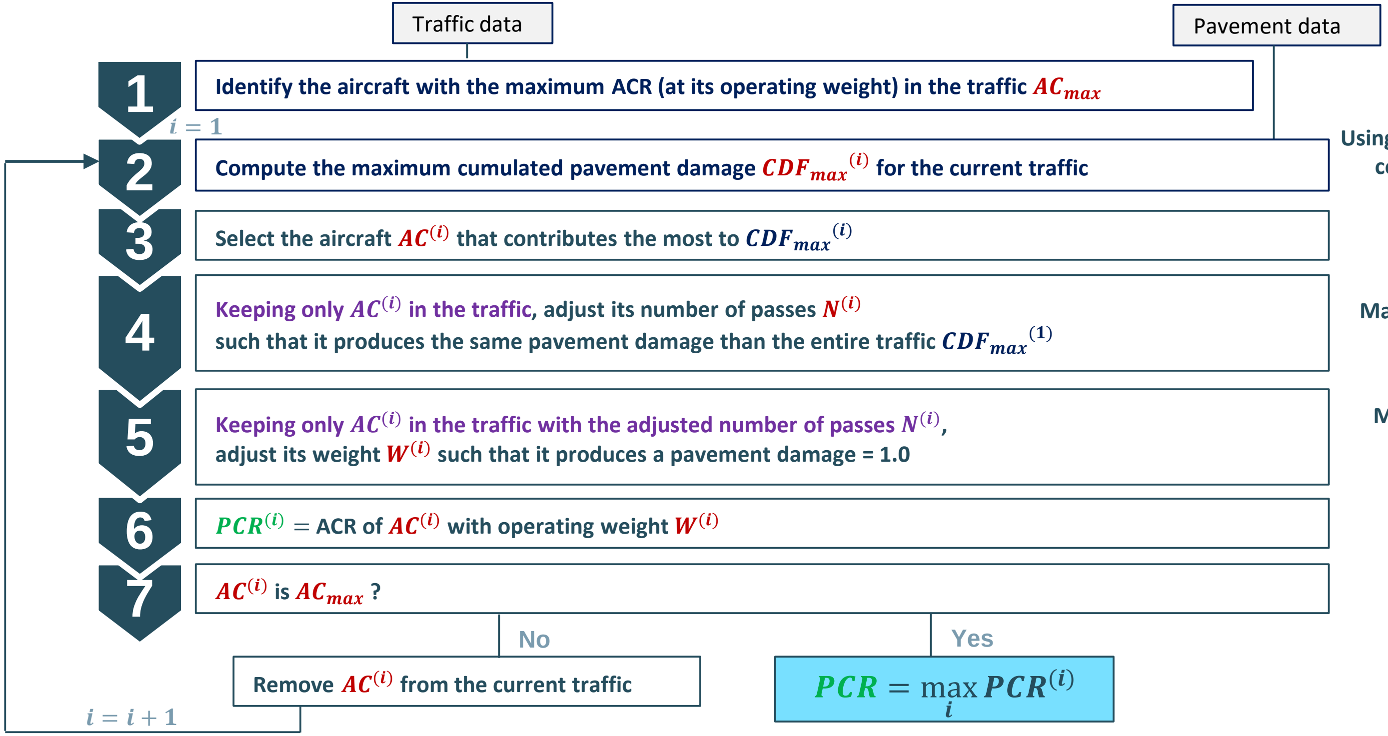
CDF Max = **0.4812**
Critical Offset = **4.1m**

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%

ACR-PCR

GENERIC PCR COMPUTATION PROCEDURE



Traffic data

Pavement data

1. Identify the aircraft with the maximum ACR (at its operating weight) in the traffic AC_{max}

$i = 1$

2. Compute the maximum cumulated pavement damage $CDF_{max}{}^{(i)}$ for the current traffic

Using subgrade failure model consistent with design parameters

3. Select the aircraft $AC^{(i)}$ that contributes the most to $CDF_{max}{}^{(i)}$

4. Keeping only $AC^{(i)}$ in the traffic, adjust its number of passes $N^{(i)}$ such that it produces the same pavement damage than the entire traffic $CDF_{max}{}^{(1)}$

Make aircraft equivalent to the entire traffic

5. Keeping only $AC^{(i)}$ in the traffic with the adjusted number of passes $N^{(i)}$, adjust its weight $W^{(i)}$ such that it produces a pavement damage = 1.0

Make equivalent aircraft compatible with the pavement

6. $PCR^{(i)}$ = ACR of $AC^{(i)}$ with operating weight $W^{(i)}$

7. $AC^{(i)}$ is AC_{max} ?

No

Remove $AC^{(i)}$ from the current traffic

$i = i + 1$

Yes

$$PCR = \max_i PCR^{(i)}$$

ACR-PCR

PCR DETERMINATION AND PUBLICATION – EXAMPLE 1.1

- A (new) flexible runway is designed according to the French rational design method.
- The subgrade modulus is estimated as: $E = 80\ MPa$ ⇨ subgrade category C
- The surface layer is made of asphalt concrete able to withstand the highest tire pressures ⇨ tire pressure category W
- The damage model for the PCR evaluation is the same than used for pavement design (French DGAC-STAC damage model)

EB-BBA2 **Wearing course**	$E = 5500\ MPa$	$\nu = 0.35$	$t = 6\ cm$
EB-GB3 **Base course**	$E = 14000\ MPa$	$\nu = 0.35$	$t = 13\ cm$
GNT1 **Sub-base**	$E = 450\ MPa$	$\nu = 0.35$	$t = 25\ cm$
Subgrade	$E = 80\ MPa$	$\nu = 0.35$	$t = \infty$

ACR-PCR

PCR DETERMINATION AND PUBLICATION – EXAMPLE 1.2

- Traffic forecasted over the 10-year pavement life

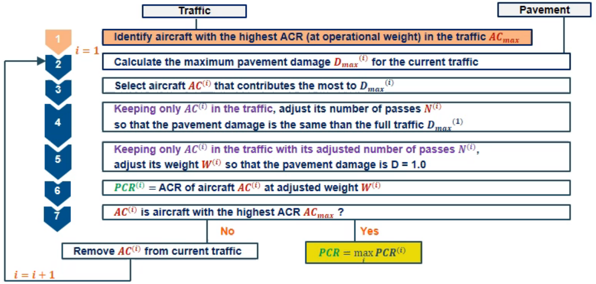
Aircraft	Operating weight (t)	Passes
A319neo	75.9	258 542
A320neo	79.4	232 094
A321neo	97.4	210 424
A330-200	233.9	51 405
A330-300	233.9	19 396
A350-900	268.9	8 971
A380-800	571.0	29 123

Aircraft	Operating weight (t)	Passes
737-800	79.2	98 433
757-200	116.1	4 352
767-300	163.8	17 094
767-400ER	204.6	3 415
787-8	228.4	10 885
787-9	254.7	16 045
777-200	248.1	40 378
777-300ER	352.4	37 842

- Aircraft wander is considered as per the French rational design method for flexible runways (Gaussian distribution, σ = 75 cm = 29.53 in)

ACR-PCR

PCR DETERMINATION AND PUBLICATION – EXAMPLE 1.3



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 $D_{max}{}^{(i)}$ 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 $D_{max}{}^{(1)}$

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

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

$i = i + 1$

Yes: $PCR = \max_i PCR^{(i)}$

ACR-PCR

PCR DETERMINATION AND PUBLICATION – EXAMPLE 1.4

- The PCR should be reported as **800 F/C/W/T**

⚠

- The PCR would have been reported as 590 /F/C/W/T based on the A321neo if only the most contributing aircraft is considered
- This would have lead to weight restrictions for most of the long-range aircraft, despite the pavement being properly designed for the entire traffic

ACR-PCR

PCR DETERMINATION AND PUBLICATION – EXAMPLE 2.1

Pavement structure (Design life = 10 years)

Surface course EB-BBSG3	$E = f(\theta, freq)$	$\nu = 0.35$	$t = 6\ cm$
Base course EB-GB3	$E = f(\theta, freq)$	$\nu = 0.35$	$t = 18\ cm$
Subbase 1 GNT1	$E = 600\ MPa$	$\nu = 0.35$	$t = 12\ cm$
Subbase 1 GNT1	$E = 240\ MPa$	$\nu = 0.35$	$t = 25\ cm$
Subgrade	$E = 80\ MPa$ (CAT C)	$\nu = 0.35$	$t = \infty$

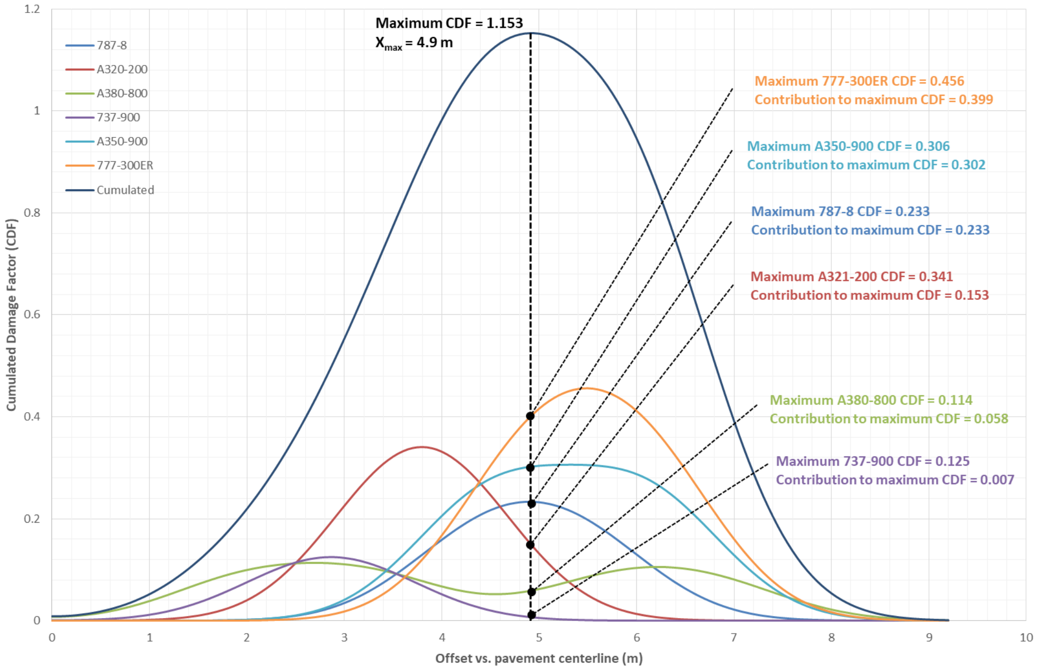
Traffic (simplified)

#	Aircraft model	Operating weight (t)	Annual departures	ACR @ operating weight
1	A321-200	93.9	14600	550
2	A350-900	268.9	5475	720
3	A380-800	571.0	1825	650
4	B737-900	79.2	10950	450
5	B787-8	228.4	3650	680
6	B777-300ER	352.4	4380	780

① The 777-300ER is the aircraft with the maximum ACR (AC_{max})

ACR-PCR

PCR DETERMINATION AND PUBLICATION – EXAMPLE 2.2



② The maximum CDF is $CDF_{max}^{(1)} = 1.153$

③ The 777-300ER is the aircraft contributing the most to $CDF_{max}^{(1)}$

④ When considered alone, the 4380 annual departures of the 777-300ER produces a CDF of 0.456.
The annual departures to produce $CDF_{max}^{(1)}$ are: $N^{(1)} = 4380\frac{1.153}{0.456} = 11073$

⑤ In order to reach a maximum CDF = 1.00, the 777-300ER weight must be reduced from 352.4 t to $W^{(1)} = 341.1\ t$

⑥ $PCR^{(1)}$ = ACR of 777-300ER at $W^{(1)} = 740\ FC$

⑦ Since the 777-300ER is AC_{max}, no additional iteration is required

ACR-PCR

PCR DETERMINATION AND PUBLICATION – EXAMPLE 2.3

- Using design parameters different of those used for pavement design lead to inconsistent PCR determination.
- From the previous aircraft mix and pavement characteristics, see below examples using different design parameters

Subgrade Failure model	Wheels in tandem (multi-axle wheels)	CDF Max.	PCR	Comment
WÖLHER	**Integral form**	**1,15**	**740 FCXT**	**Match design parameters**
WÖLHER	TGF (longitudinal P-to-C ratio)	1,81	622 FCXT	Inconsistency
BLEASDALE	Integral form	0,2	900 FCXT	Inconsistency
BLEASDALE	TGF (longitudinal P-to-C retio)	0,55	823 FCXT	Inconsistency

ACR-PCR

CONSEQUENCES OF PCR INACCURACIES

Under-estimated PCR (overestimated CDF)

- ➔ Aircraft weight / annual departure restrictions or operations not granted
- ➔ Pavement usage not optimized, **loss of airport revenues**

Over-estimated PCR (underestimated CDF)

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

ACR-PCR

OVERLOAD OPERATIONS

- For flexible and rigid pavements, occasional movements by aircraft with ACR not exceeding 10% of the reported PCR should not adversely affect the pavement
- The annual number of overload movements should not exceed approximately 5% of the total annual movements excluding light aircraft

- Overload operations in excess of 10% may be considered on a case by case basis when supported by a detailed technical analysis
- The technical analysis should assess how the overload operations actually contribute to the pavement damage when integrated to the existing traffic, which could be done using the same framework than for the PCR computation

ACR-PCR

OVERLOAD OPERATIONS - EXAMPLE

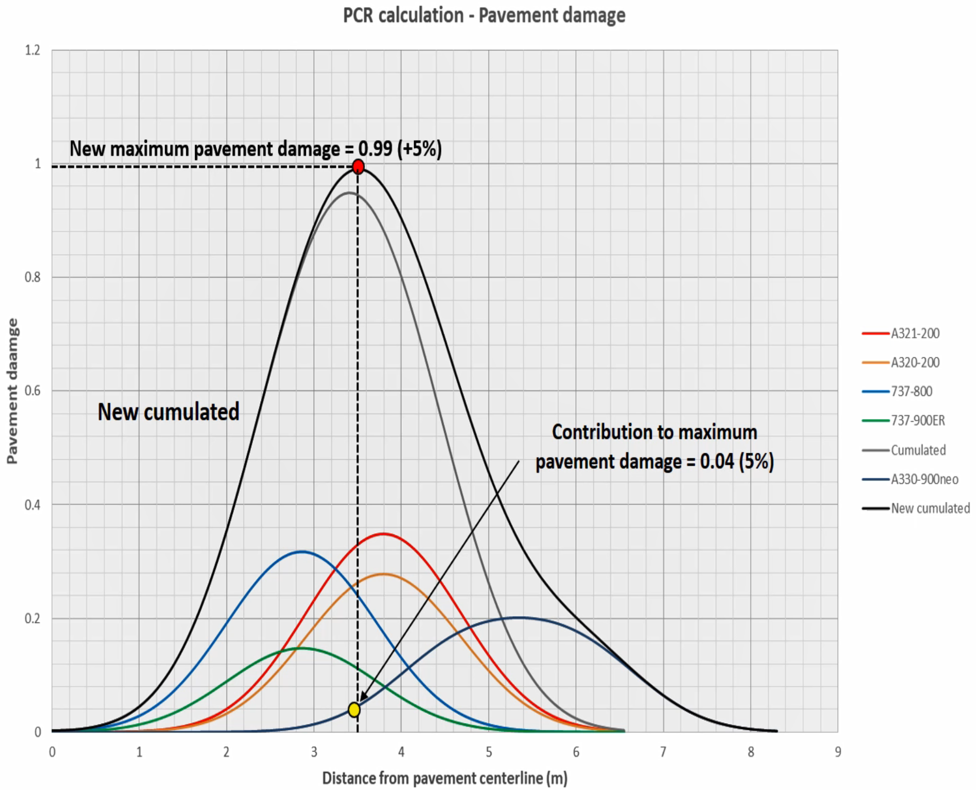
- The PCR also provides a damage-based approach for assessing overload operations

- Example: PCR for the previous all-SA traffic (~25 mvts/days) computed as **560 F/C**

- Airport wants to assess whether it can accept 1 daily operation of A330-900neo (ACR = **710 F/C**)

- ACR/PCR overload is significant (> 25%)
- But actual impact on pavement damage is limited to 5%

⇨ Airport may allow the overload operations



ACR-PCR

BENEFITS OF THE ACR-PCR METHOD

- Overcomes the identified limitations of the current ACN-PCN system and allows a full consideration of the latest evolutions in the field

- Provides several benefits to airport owners
  - Optimized usage of their pavements
  - Improved pavement life predictability
  - Availability of a generic PCR computation procedure
  - Unified soil characterization for both flexible and rigid pavements

- Benefits to airlines and the whole air transport community by allowing optimized operating weights and frequencies without over-conservatism

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