GCAA
ADVISORY CIRCULAR

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SUBJECT:	**Implementation of ICAO requirement for reporting aerodrome pavement strength using Aircraft Classification Rating/Pavement Classification Rating (ACR-PCR)**	DATE INITIATED: INITIATED BY:	July 22, 2024 DIRECTOR – AVIATION SAFETY REGULATION

1. PURPOSE

1.1 This Advisory Circular (AC) provides guidance for the implementation for reporting Aerodrome pavement strength using Aircraft Classification Rating/Pavement Classification Rating (ACR-PCR)

BACKGROUND

1.2 Following ICAO's adoption of Amendment 15 to Annex 14, Volume 1, there are new provisions for reporting the strength of Aerodrome pavement intended to serve aircraft mass greater than 5,700 kg using ACR-PCR methodology which came into effect in July 2020. States are required to commence the training of technical staff and implement this new methodology by November 28th, 2024.

The objective of the new ACR-PCR methodology is to align the ACN-PCN methods with a modern method of pavement design to overcome the limitations of the current ACN-PCN system and to optimize usage of aerodrome pavements as well as improved pavement life predictability.

2. REFERENCES

2.1 Civil Aviation Requirements for Certified Aerodromes Chapter 2.6

3. APPLICABILITY

3.1 This AC is applicable to all Aerodrome Operators with an aircraft ramp mass capacity greater than 5,700 kg.

4. ACTIONS REQUIRED

4.1 All applicable Aerodrome Operators are required to implement ACR-PCR methodology by November 28th, 2024.

4.2 Identify an airport Focal Point to coordinate implementation activities.

4.3 Initiate training for all relevant airport personnel.

4.4 Conduct an airport-wide impact assessment of the changes and identify actions to address the gaps.

4.5 Develop procedures and means of compliance and submit these procedures to the Authority for review.

4.6 Carry out ACR-PCR analysis of all pavements in the movement area within the airport.

4.7 Publish coordinates, the publication of the associated PCR values in the AIP and the AOM.

4.7 Continuous improvement initiatives, share and exchange best practices with other airports/aerodromes.

4.8 Examine and analyze PCR values after any change in pavement structure or significant changes in traffic composition.

4.9 Attached herewith, are excerpts from the ICAO Aerodrome Design Manual (Doc 9157, Part 3) of the recommended steps for effective implementation of the new ACR-PCR methodology with the proposed timelines for Aerodrome Operators' adoption and necessary action.

Approved by:

DIRECTOR GENERAL GUYANA CIVIL AVIATION AUTHORITY

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Chapter 1

PROCEDURES FOR REPORTING AERODROME PAVEMENT STRENGTH

1.1 PROCEDURES FOR PAVEMENTS MEANT FOR HEAVY AIRCRAFT (AIRCRAFT CLASSIFICATION RATING — PAVEMENT CLASSIFICATION RATING (ACR-PCR) METHOD)

1.1.1 Annex 14 — *Aerodromes*, Volume I — *Aerodrome Design and Operations*, specifies that the bearing strength of a pavement intended for aircraft of a mass greater than 5 700 kg should be made available using the aircraft classification rating — pavement classification rating (ACR-PCR) method. To facilitate the proper understanding and usage of the ACR-PCR method, the following explanatory material is provided:

a) the concept of the method;

b) how the aircraft classification ratings (ACRs) of an aircraft are determined; and

c) how the pavement classification ratings (PCRs) of a pavement can be determined using the cumulative damage factor (CDF) concept.

The key parameters of the determination of the pavement classification rating (PCR) are summarized in Figure 1-1.

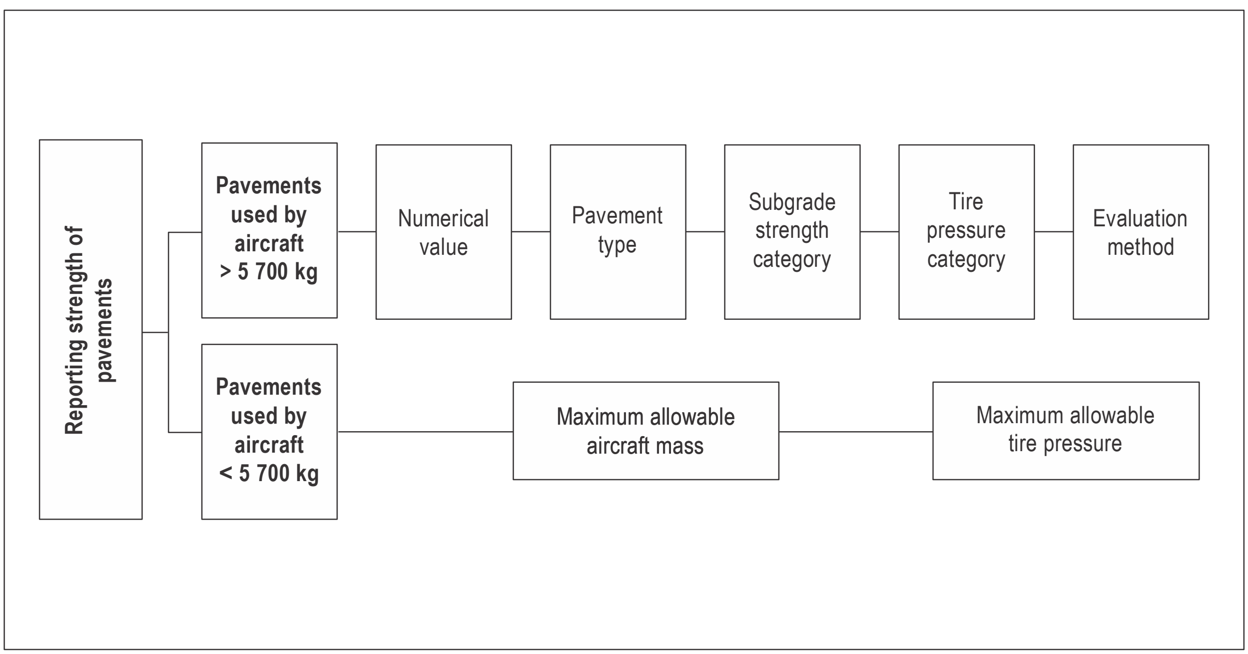

Figure 1-1. Determination of the PCR

1.1.2 Concept of the ACR-PCR method

1.1.2.1 The ACR-PCR method is meant only for the publication of pavement strength data in aeronautical information publications (AIPs). It is not intended for the design or evaluation of pavements, nor does it contemplate the use of a specific method by the aerodrome operator for either the design or evaluation of pavements. In fact, the ACR-PCR method does permit States to use any design/evaluation method of their choice. To this end, the method shifts the emphasis from the evaluation of pavements to the evaluation of the load rating of aircraft (ACR) and includes a standard procedure for the evaluation of the load rating of aircraft. The strength of a pavement is reported under the method in terms of the load rating of the aircraft, for example, that which the pavement can accept on an unrestricted basis. When referring to unrestricted operations, it does not mean unlimited operations, but refers to the relationship of the PCR to the aircraft ACR and it is permissible for an aircraft to operate without weight restrictions (subject to tire pressure limitations) when the PCR is greater than or equal to the ACR. The term unlimited operations does not take into account pavement life. The PCR to be reported is such that the pavement strength is sufficient for the current and future traffic analysed and should be re-evaluated if traffic changes significantly. A significant change in traffic would be indicated by the introduction of a new aircraft type or an increase in current aircraft traffic levels not accounted for in the original PCR analysis. The airport authority can use any method of its choice to determine the load rating of its pavement, provided it uses the CDF concept. The PCR so reported would indicate that an aircraft with an ACR equal to or less than that load rating figure can operate on the pavement, subject to any limitation on the tire pressure.

1.1.2.2 The ACR-PCR method facilitates the reporting of pavement strengths on a continuous scale. The lower end of the scale is zero and there is no upper end. Additionally, the same scale is used to measure the load ratings of both aircraft and pavements.

1.1.2.3 To facilitate the use of the method, aircraft manufacturers will publish, in the documents detailing the characteristics of their aircraft, ACRs computed at two different masses (the maximum apron mass and a representative operating mass empty) both on rigid and flexible pavements, and for the four standard subgrade strength categories. The ICAO-ACR computer programme, which is available to all stakeholders, provides any aircraft ACRs at any mass and centre of gravity (CG) position for both flexible and rigid pavement and for the four standard subgrade strength categories. It is to be noted that the mass used in the ACR calculation is a “static” mass and that no allowance is made for an increase in loading through dynamic effects.

1.1.2.4 The ACR-PCR method also envisages the reporting of the following information in respect of each pavement:

a) pavement type;

b) subgrade category;

c) maximum allowable tire pressure; and

d) pavement evaluation method used.

The data obtained from the characteristics listed above are primarily intended to enable aircraft operators to determine the permissible aircraft types and operating masses, and the aircraft manufacturers to ensure compatibility between airport pavements and aircraft under development. There is, however, no need to report the actual subgrade strength or the maximum allowable tire pressure. Consequently, the subgrade strengths and tire pressures normally encountered have been grouped into categories as indicated in 1.1.3.2. It is sufficient for the airport authority to identify the categories appropriate to its pavement (see also the examples included in Annex 14, Volume I, 2.6). The airport authority should, whenever possible, report pavement strength based on a technical evaluation of the pavement. Details of the technical evaluation process are included in 3.6. If, due to financial or engineering constraints, a technical evaluation is not feasible, then using the aircraft method must be used for reporting pavement strength. Details on the aircraft evaluation method are contained in 3.5.

1.1.2.5 The ACR-PCR method permits States to use the design/evaluation procedure of their choice when determining the PCR for their pavements. However, in many instances, the State may lack expertise in this area or wish to incorporate a standard methodology for performing the technical evaluation of their pavements. Refer to Chapter 4 for State practices.

1.1.2.6 In some cases, culverts, bridges, and other surface and subsurface structures can be the critical or limiting element necessitating the reporting of a lower PCR for the pavement. Considerations that permit the use of the ACR-PCR method to limit pavement overloading are not necessarily adequate to protect these structures. Evaluation of, and consideration for, these structures are covered in Chapter 7.

1.1.3 How ACRs are determined

1.1.3.1 ACRs of aircraft are computed under the ACR-PCR method as shown in Figure 1-2.

Relevant documents and software include the:

1) Aircraft characteristics for airport planning (published by the aircraft manufacturers).

2) ICAO-ACR computer programme (current version).

1.1.3.2 The following are standard values used in the method and include descriptions of the various terms:

Subgrade category

1.1.3.2.1 In the ACR-PCR method, four standard subgrade values (modulus values) are used, rather than a continuous scale of subgrade moduli. The grouping of subgrades with a standard value at the mid-range of each group is considered to be entirely adequate for reporting. Subgrade categories apply to both flexible and rigid pavements.

1.1.3.2.2 The subgrade categories are identified as high, medium, low and ultra-low and are assigned the following numerical values:

Code A — High strength; characterized by E = 200 MPa and representing all E values equal to or above 150 MPa, for rigid and flexible pavements.

Code B — Medium strength; characterized by E = 120 MPa and representing a range in E equal to or above 100 MPa and strictly less than 150 MPa, for rigid and flexible pavements.

Code C — Low strength; characterized by E = 80 MPa and representing a range in E equal to or above 60 MPa and strictly less than 100 MPa, for rigid and flexible pavements.

Code D — Ultra-low strength; characterized by E = 50 MPa and representing all E values strictly less than 60 MPa, for rigid and flexible pavements.

Concrete working stress for rigid pavements

1.1.3.2.3 For rigid pavements, a standard stress for reporting purposes is stipulated (σ = 2.75 MPa) only as a means of ensuring uniform reporting. The working stress to be used for the design and/or evaluation of the pavements has no relationship to the standard stress for reporting.

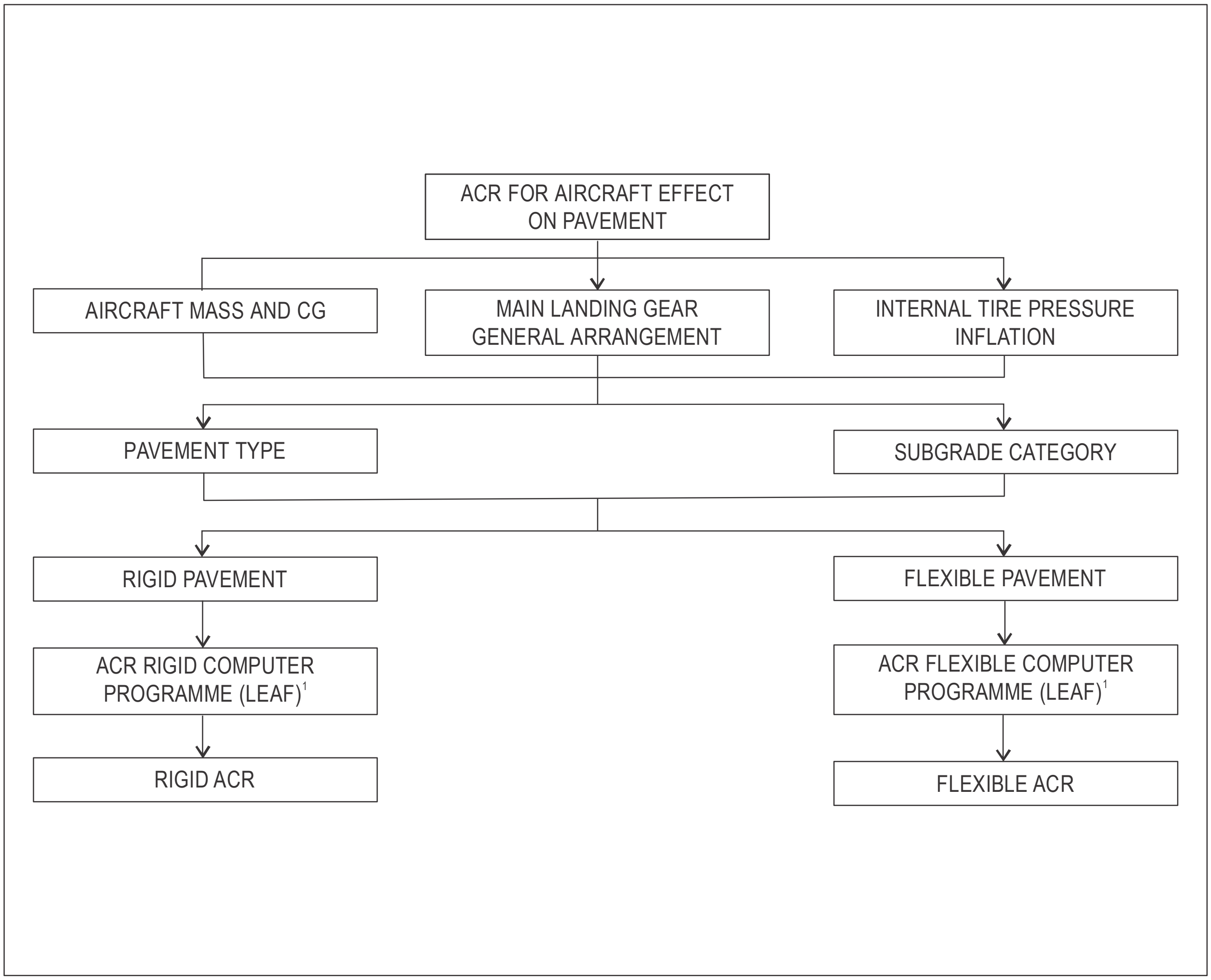

Figure 1-2. ACR Computation[1]

Mathematically derived single wheel load

1.1.3.2.4 The concept of a mathematically derived single wheel load has been employed in the ACR-PCR method as a means to define the aircraft landing gear-pavement interaction, without specifying pavement thickness as an ACR parameter. This is done by equating the thickness given by the mathematical model for an aircraft landing gear to the thickness for a single wheel at a standard tire pressure of 1.50 MPa. The single wheel load so obtained is then used without further reference to thickness; this is because the essential significance is attached to the fact of having equal thicknesses, implying "same applied stress to the pavement", rather than the magnitude of the thickness. The foregoing is in accordance with the objective of the ACR-PCR method for evaluating the relative loading effect of an aircraft on a pavement.

[1] Computer programmes are described in 1.1.3.4.

Aircraft classification rating (ACR)

1.1.3.2.5 The ACR of an aircraft is numerically defined as two times the derived single wheel load, where the derived single wheel load is expressed in hundreds of kilograms. As noted previously, single wheel tire pressure is standardized at 1.50 MPa. Additionally, the derived single wheel load is a function of the subgrade modulus. The aircraft classification rating (ACR) is defined only for the four standard subgrade categories (i.e. high, medium, low and ultra-low). The factor of two in the preceding numerical definition of ACR is used to achieve a suitable ACR versus gross mass scale, so that whole number values of ACR may be used with reasonable accuracy.

1.1.3.2.6 Because an aircraft operates at various mass and CG conditions, the following conventions have been used in ACR computations (see Figures 1-3 and 1-4):

a) the maximum ACR of an aircraft is calculated at the mass and CG that produces the highest main gear loading on the pavement (i.e. usually the maximum ramp mass and corresponding aft CG The aircraft tires are considered as inflated to the tire manufacturer's recommendation for the condition;

b) relative aircraft ACR charts and tables show the ACR as a function of aircraft gross mass with the aircraft CG as a constant value corresponding to the maximum ACR value (i.e. usually the aft CG for maximum ramp mass) and at the maximum ramp mass tire pressure; and

c) specific condition ACR values are those ACR values that are adjusted for the effects of tire pressure and/or CG location at a specified gross mass for the aircraft.

Mathematical models

1.1.3.3 The sole mathematical model used in the ACR-PCR method is the layered elastic analysis (LEA). The LEA model assumes that several homogeneous, elastic, isotropic layers arranged as a stack, whether flexible or rigid, can represent the pavement structure. Each layer in the system is characterized by an elastic modulus E_i, Poisson's ratio v_i, and a uniform layer thickness t_i. Layers are assumed to be of infinite horizontal extent and the bottom or subgrade layer is assumed to extend vertically to infinity (i.e. the subgrade is modelled as an elastic half-space). Due to the linear elastic nature of the model, individual wheel loads can be summed to obtain the combined stress and strain responses for a complex, multiple-wheel aircraft gear load. The use of the LEA model permits the maximum correlation to worldwide pavement design methods.

Computer programmes

1.1.3.4 The computer programme was developed using the above LEA mathematical model by the United States Federal Aviation Administration (FAA), named LEAF. LEAF is an open-source computer programme whose source code is available from the FAA, Airport Technology Research and Development Branch, William J. Hughes Technical Center, United States. In addition, a second LEA programme, Alizé-Aeronautique, was developed by the French Institute of Science and Technology for Transport, Development and Networks (IFSTTAR) in partnership with AIRBUS SAS, and has been found to give nearly identical results for equal inputs. The ICAO-ACR computer programme incorporates the LEAF programme and was developed to implement the ACR computational procedures for rigid and flexible pavements. ICAO-ACR is distributed in compiled form as a Visual Basic.NET dynamic-link library (DLL), and may be linked to other programmes that either compute ACR directly or that use the ACR computation to evaluate PCR. By default, the ICAO-ACR programme takes as inputs: the maximum ramp mass for ACR calculations; per cent of maximum ramp mass acting on the main gear (equivalent for this purpose to the aft CG corresponding to maximum ramp mass); the number of wheels; the geometric coordinates of all wheels; and the type of pavement (rigid or flexible). The output is the ACR at each subgrade category and the pavement reference thickness, t, corresponding to ACR at each subgrade category. Appendix 2 of this manual contains information on linking to the ICAO-ACR library.

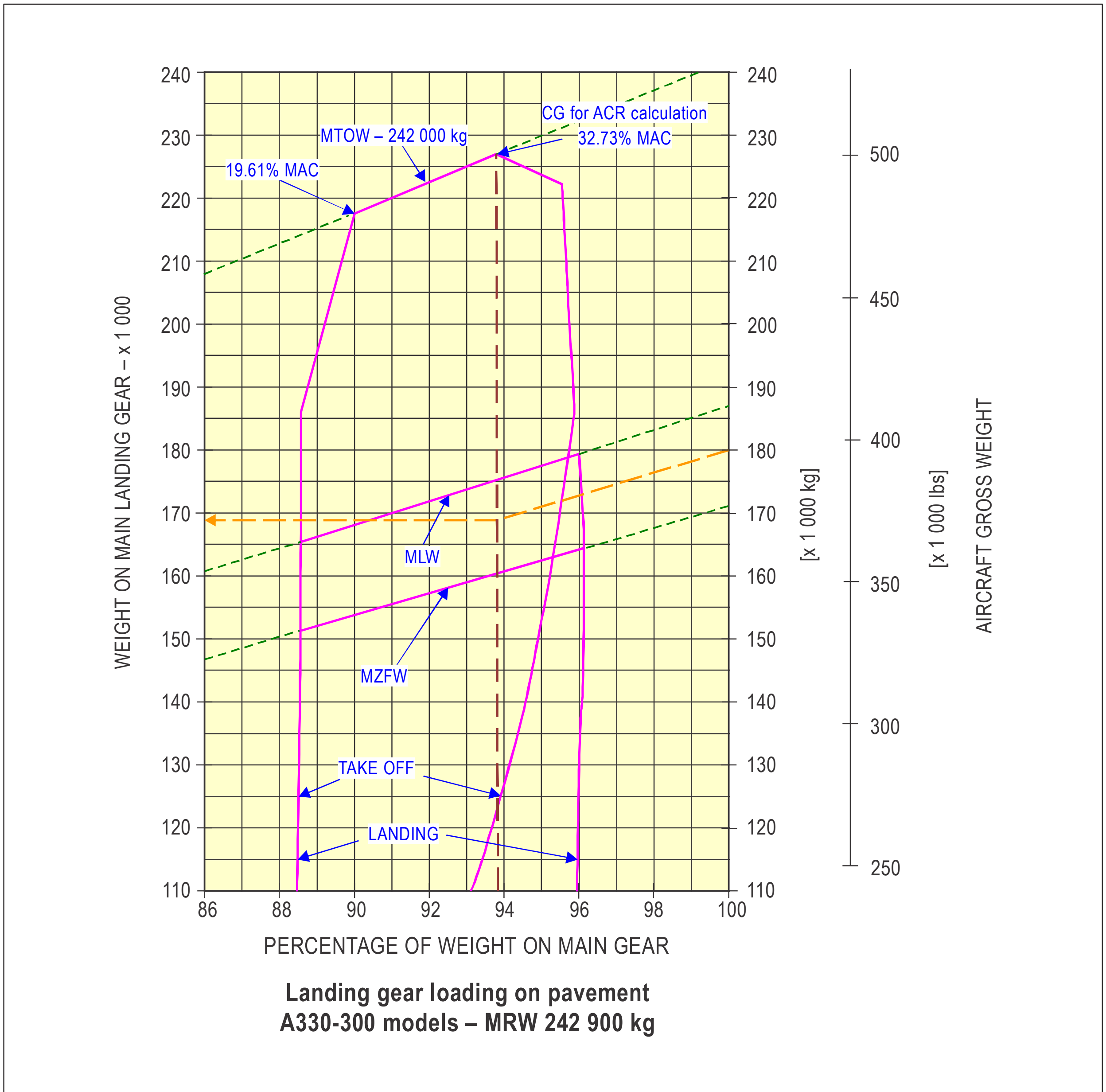

Figure 1-3. Landing gear loading on pavement — Airbus A330-300

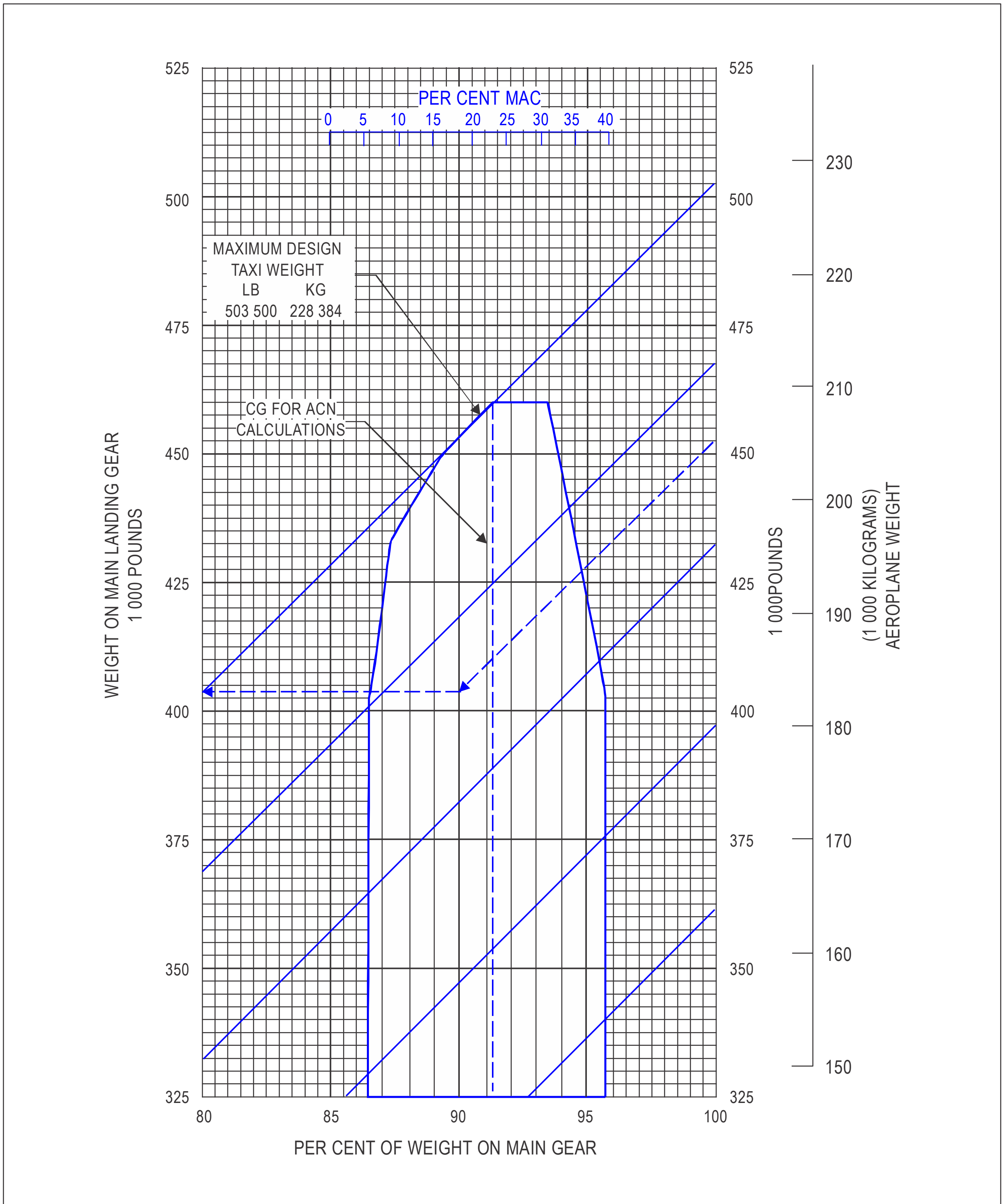

Figure 1-4. Landing gear loading on pavement — Boeing 787-8

Graphical procedures

1.1.3.5 Graphical procedures should not be used for determining the ACR. Instead, use the computer programmes as described above.

Rigid pavements

1.1.3.6 The rigid pavement ACR procedure relates the derived single wheel load at a constant tire pressure of 1.50 MPa to a reference concrete slab thickness, t. It takes into account the four subgrade categories detailed in 1.1.3.2.2, and a standard concrete stress of 2.75 MPa. Note that, because a standard concrete stress is used, no information concerning either pavement flexural strength or number of coverages is needed for the rigid ACR computation. The steps below are used to determine the rigid ACR of an aircraft.

Reference pavement structure

1.1.3.6.1 Using the aircraft data published by the manufacturer, obtain the reference thickness, t, for the given aircraft mass, E-value of the subgrade, and standard concrete stress for reporting, i.e. 2.75 MPa. For all four subgrade categories, assume the following cross-section for the LEA model (see Table 1-1):

Table 1-1. Reference pavement structure for rigid ACR

Layer description	*Designation*	*Thickness, mm*	*E, MPa*	*v*
Surface course (PCC)	Layer 1	variable	27 579	0.15
Base course (crushed aggregate)	Layer 2	200	500	0.35
Subgrade	Layer 3	infinite	See 1.1.3.2.2	0.40

The minimum allowable thickness of Layer 1 in the LEA model is 50.8 mm. LEA computations further assume that the horizontal interface between Layer 1 and Layer 2 is not bonded (full slip), and that the horizontal interface between Layer 2 and Layer 3 is full bond. Within the LEA model, stress σ is the maximum horizontal stress computed on the bottom of Layer 1 (the Portland cement concrete layer).

Evaluation gear

1.1.3.6.2 The ACR value is computed for a single truck in the main landing gear assembly (i.e. for two wheels in a dual, or D assembly, four wheels in a dual-tandem, or 2D assembly, etc.). For more complex landing gear types with more than two trucks (i.e. having a designation in FAA Order 5300.7, “Standard Naming Convention for Aircraft Landing Gear Configurations” consisting of more than two characters), the individual truck in the main gear assembly with the largest rigid ACR determines the rigid ACR for the aircraft. All trucks are evaluated at the mass and CG that produce the highest total main gear loading on the pavement.

Stress evaluation points

1.1.3.6.3 The number of LEA evaluation points is equal to the number of wheels in the evaluation gear. The evaluation points are located at the bottom of Layer 1, below the centre point of each wheel. The thickness, t, of Layer 1 is adjusted until the maximum stress evaluated over all evaluation points is equal to 2.75 MPa. The resulting t is the reference thickness for the ACR.

Derived single wheel load (DSWL) calculation

1.1.3.6.4 Using the above reference thickness and the same LEA model as in 1.1.3.6.1obtain a derived single wheel load for the selected subgrade. Maintaining the constant tire pressure of 1.50 MPa, the single wheel load magnitude is adjusted until the maximum horizontal stress at the bottom of Layer 1 is equal to 2.75 MPa. For evaluation of stresses under the single wheel load, use one evaluation point located at the bottom of Layer 1, directly below the centre of the wheel.

Modified DSWL calculation for lightweight aircraft

1.1.3.6.5 For some lightweight aircraft, the required reference thickness, t, is less than the minimum allowable thickness. Use the following modified steps to compute DSWL only when the theoretical thickness of Layer 1 that makes the maximum stress equal to 2.75 MPa is less than 50.8 mm:

a) determine the value of stress (less than 2.75 MPa) corresponding to the minimum allowable concrete thickness (50.8 mm); and

b) calculate DSWL for the selected subgrade using the minimum thickness of the reference structure. Maintaining the constant tire pressure of 1.50 MPa, the single wheel load magnitude is adjusted until the maximum horizontal stress at the bottom of Layer 1 is equal to the value determined in a) above.

ACR calculation

1.1.3.6.6 The aircraft classification rating, at the selected mass and subgrade category, is two times the derived single wheel load in hundreds of kilograms. The numerical value of ACR may be rounded to the nearest multiple of ten for reporting.

Flexible pavements

1.1.3.7 The flexible pavement ACR procedure relates the derived single wheel load at a constant tire pressure of 1.50 MPa to a reference total thickness, t, computed for 36 500 passes of the aircraft. It takes into account the four subgrade categories detailed in 1.1.3.2.2.

Reference pavement structures

1.1.3.8 The ACR-PCR system must cover a wide range of aircraft, weighing from a few to several hundreds of tons. Reference structures have been chosen to produce appropriate thicknesses for the standard subgrade categories for the range of aircraft weights used. Determining the reference structures for the flexible ACR computation consists of defining the materials and constitutive properties of the several layers. All layers are defined by: Elastic modulus E, Poisson’s ratio v, and (except for the design layer) the thickness t. LEA computations assume that all horizontal interfaces between layers are fully bonded. Tables 1-2 and 1-3 define the reference structures to be used in calculating flexible ACR.

Table 1-2. Reference structure for flexible ACR
(aircraft fitted with two or fewer wheels on all legs of the main landing gear)

Layer description	*Thickness, mm*	*E, MPa*	*v*
Surface course (asphalt)	76	1 379	0.35
Base course (crushed aggregate)	variable	See 1.1.3.10	0.35
Subgrade	infinite	See 1.1.3.2.2	0.35

Table 1-3. Reference structure for flexible ACR
(aircraft fitted with more than two wheels on any leg of the main landing gear)

Layer description	*Thickness, mm*	*E, MPa*	*v*
Surface course (asphalt)	127	1 379	0.35
Base course (crushed aggregate)	variable	See 1.1.3.10	0.35
Subgrade	infinite	See 1.1.3.2.2	0.35

1.1.3.9 In the LEA model, the minimum allowable thickness of the variable (base course) layer is 25.4 mm. Because of the intentionally limited number of reference structures, computed layer thicknesses may not be realistic at the extremes of the aircraft weight range. However, this does not invalidate the ACR concept, in which t is a relative indicator rather than the basis for a practical design.

Base layer modulus

1.1.3.10 All flexible reference pavement structures include a variable thickness layer above the subgrade, representing a crushed aggregate base layer. The modulus of the variable thickness layer is not fixed in the ACR procedure, but is a function of the thickness and of the subgrade modulus. Within the LEA model, the base layer is subdivided into smaller sublayers and a modulus value is then assigned to each sublayer using a recursive procedure as explained below. Modulus values are assigned to the sublayers following the procedure in the FAA computer programme FAARFIELD (version 1.42), for item P-209 (crushed aggregate). The steps in the procedure are as follows:

Step 1. Determine the number of sublayers *N*. If the base layer thickness t_B is less than 381 mm, then *N* = 1 and sublayering is not required. If t_B is greater than or equal to 381 mm, the number of sublayers is:

$$\boldsymbol{N = int\left(\frac{t_B}{254} + 0.5\right)}$$

where t_B is in mm, and the integer function returns the integer part of the argument (i.e. rounds down to the next whole number).

Step 2. Determine the thickness of each sublayer. If N = 1, then the sublayer thickness is equal to the base layer thickness t_B. If N > 1, then the thickness of the bottom N - 1 sublayer is 254 mm, and the thickness of the top sublayer is $t_B - (N-1) \times$ 254 mm. Note that, in general, the N sub-layers do not have equal thickness. For example, if the thickness of the base layer is 660 mm, then from Step 1, the number of sublayers is three. The bottom two sublayers are each 254 mm, while the top sublayer is660 – 2 × 254 = 152 mm.

Step 3. Assign a modulus value E to each sublayer. Modulus values increase from bottom to top, reflecting the effect of increasing confinement of the aggregate material. Modulus values are given by the following equation:

$$E_n = E_{n-1} \times \{1 + [log_{10}(t_n) - log_{10}(25.4)] \times (c - d[log_{10}(E_{n-1}) + log_{10}(145.037)])\}$$

where E_n = the modulus of the current sublayer in MPa;

E_{n-1} = the modulus of the sublayer immediately below the current sublayer; or the modulus of the subgrade layer when the current sublayer is the bottom sublayer;

t_n = the thickness of the current sublayer in mm;

c = 10.52 (constant); and

d = 2.0 (constant).

The above equation is applied recursively beginning with the bottom sublayer.

Step 4. The modulus assignment procedure in Step 3 must be modified for the top two sublayers whenever t_B is between 127 mm and 254 mm greater than an integer multiple of 254 mm. This modification ensures that the modulus of all sublayers is a continuous function of the layer thickness, with no gaps. If N > 1 and t_B exceeds an integer multiple of 254 mm by more than 127 mm, but less than 254 mm, then:

a) The top sub-layer (sub-layer N) is between 127 mm and 254 mm thick, and all sublayers below it (sublayers 1 to N-1) are 254 mm thick.

b) Using the equation in Step 3, compute the modulus E_{254} that would be obtained for sublayer N for an assumed top sublayer thickness t_n equal to 254 mm.

c) Compute the modulus of sublayer N-1 (i.e. the sublayer immediately below the top su-layer) using the equation in Step 3, but substituting t_n = 508 mm – t_N, where t_N is the actual thickness of the top sublayer in mm.

d) Compute the modulus of sublayer N by linear interpolation between E_{N-1} (the modulus of sublayer N-1) and E_{254}:

$$E_N = E_{N-1} + t_N \times \frac{E_{254} - E_{N-1}}{254}$$

Evaluation gear

1.1.3.11 The ACR value is computed using all wheels in the main landing gear (wheels in the nose landing gear are not included). Main landing gears are evaluated at the mass and CG that produces the highest total main gear loading on the pavement.

Strain evaluation points

1.1.3.12 Within the LEA model, strain ε is the maximum vertical strain computed on the top surface of the subgrade (lowest) layer. In the ICAO-ACR computer programme, strains are computed at specific evaluation points based on the geometry of the evaluation gear. Evaluation points are placed directly below the centre point of each wheel, and at the points defined by a regular rectangular grid spaced at 10-cm intervals, and oriented parallel to the principal axes of the gear.

1.1.3.12.1 For simple main landing gears consisting of two trucks (i.e. for two wheels in a dual, or D assembly, four wheels in a dual-tandem, or 2D assembly, etc.), the grid origin is set at the geometric centre of one truck. The limits of the grid extend 30 cm beyond the maximum wheel coordinates on all sides of the truck (Figure 1-5).

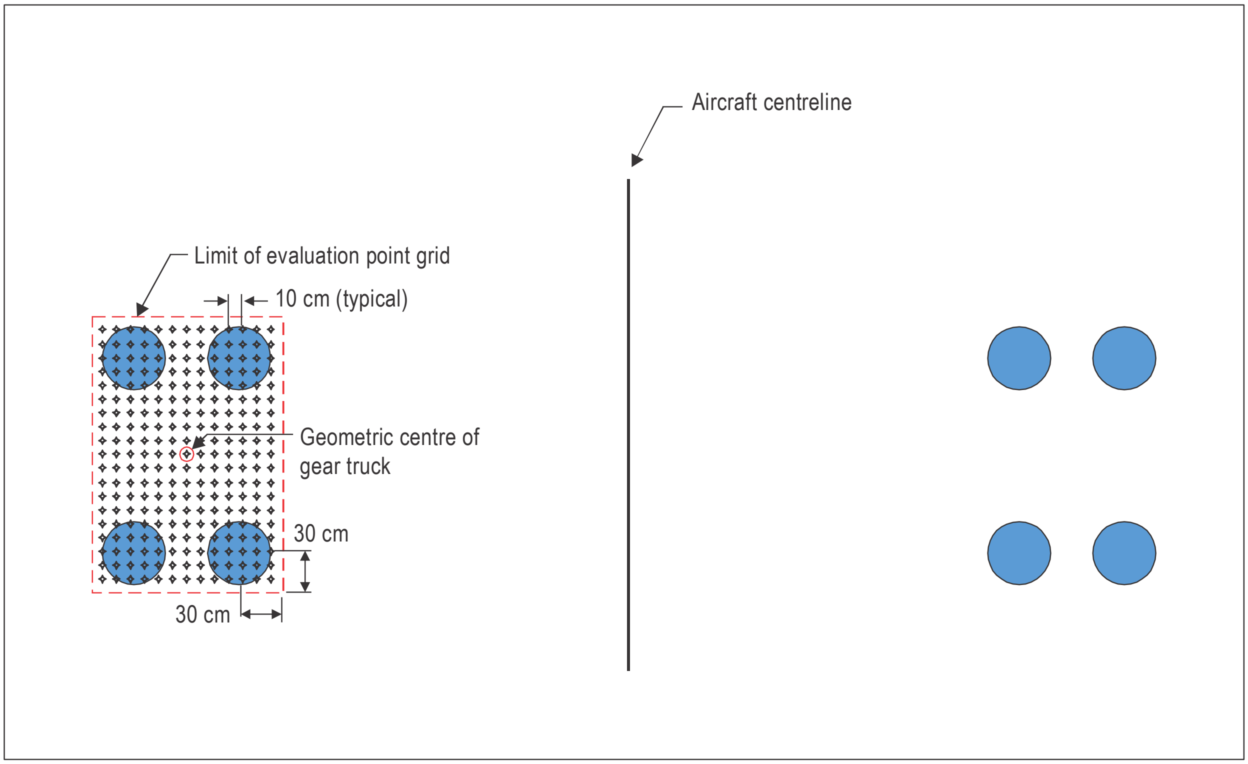

Figure 1-5. Grid definition for simple main landing gear arrangement

1.1.3.12.2 For more complex gear types with more than two trucks comprising the main landing gear assembly (i.e. all aircraft whose gear designation consists of more than two characters in FAA Order 5300.7, "Standard Naming Convention for Aircraft Landing Gear Configurations"), the origin of the grid is at the geometric centre of the entire landing gear assembly. The limits of the grid extend 30 cm beyond the maximum wheel coordinates on all sides (see Figure 1-6). For the purpose of computing the geometric centre coordinates, all included wheels should be weighted equally, regardless of different wheel loads or tire pressures.

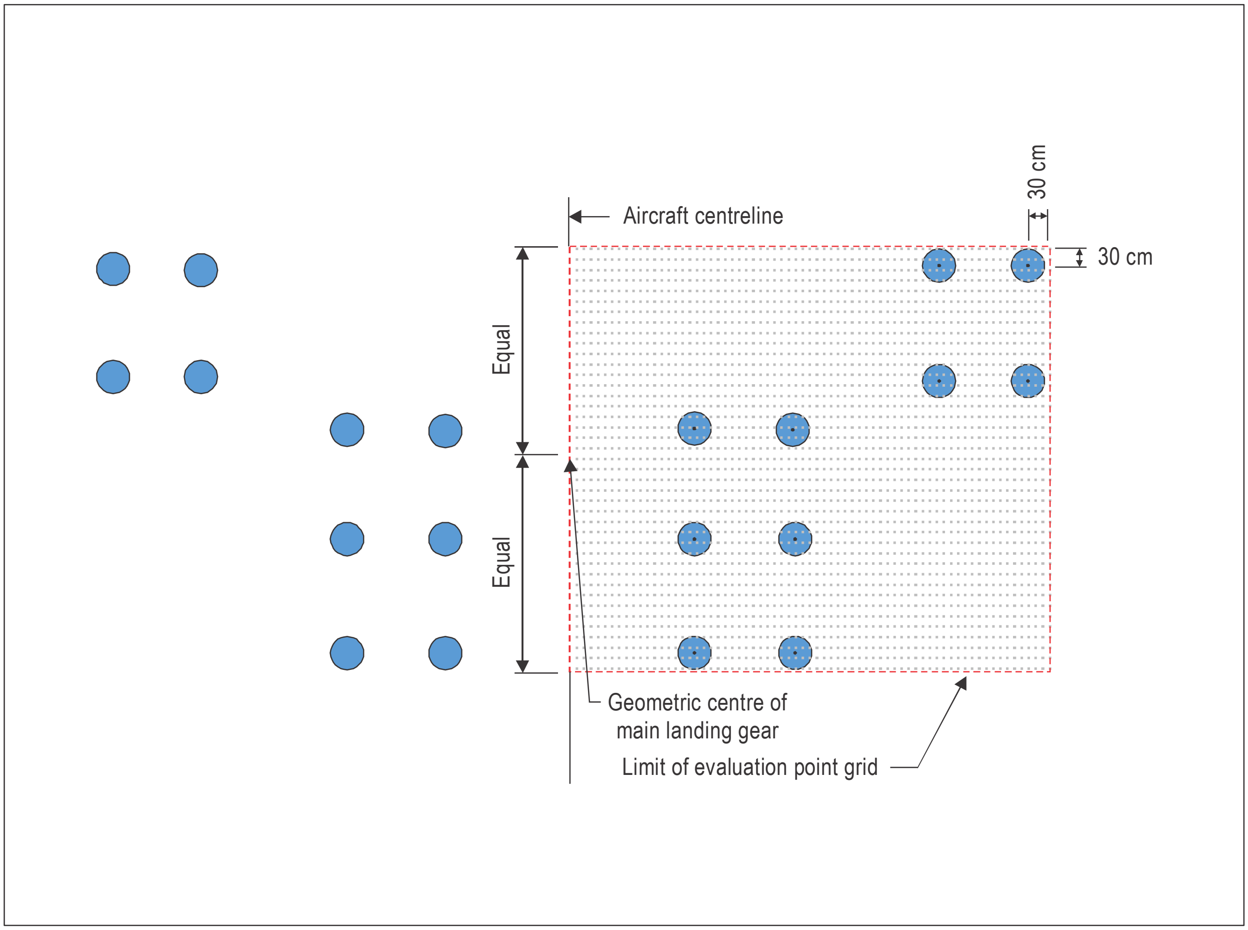

Figure 1-6. Grid definition for complex aircraft main landing gear

1.1.3.12.3 Strain ε is the maximum of the strains computed for all evaluation points.

Note.— ICAO-ACR automatically detects symmetries within the evaluation point grid to reduce the number of required computations. In the case of the B787-9, only one half of the evaluation point grid may actually be computed due to the transverse symmetry.

Damage model

1.1.3.13 The flexible ACR procedure relies on the subgrade failure criterion associated with the elementary damage law:

$$D_e(\varepsilon) = \frac{1}{C_e(\varepsilon)}$$

This elementary damage law is based on the notion of loading cycle (single-peak strain profile with maximum value ε), which cannot be applied to arrangements with axles in tandem producing complex strain profiles, possibly with multiple strain peaks and no return to zero-strain between peaks. Therefore, the elementary damage law is extended to a continuous integral form:

$$D = \int_{x=-\infty}^{x=+\infty} < \frac{dD_e(x)}{dx} > dx$$

where *x* refers to the longitudinal position along the landing gear and <y> to the positive part of y. Details of the integral formulation are described in Appendix 3.

DSWL calculation

1.1.3.14 Using the pavement requirement data published by the manufacturer, calculate the reference thickness, t, for the given aircraft mass, E-value of the subgrade, and 36 500 passes of the aircraft. Use the appropriate reference pavement structure from 1.1.3.8 with evaluation points as described in 1.1.3.12. The thickness of the variable (design) layer is adjusted until the damage as computed from 1.1.3.13 is equal to 1.0. The resulting thickness, t, is the reference thickness for ACR.

1.1.3.15 Using the above reference thickness and the same LEA model as in 1.1.3.13, obtain a derived single wheel load for the selected subgrade. Maintaining the constant tire pressure of 1.50 MPa, the single wheel load magnitude is adjusted until the damage is equal to 1.0 for 36 500 passes. For evaluation of strains under the single wheel load, use one evaluation point located at the top of the subgrade, directly below the centre of the wheel.

Modified DSWL calculation for lightweight aircraft

1.1.3.16 For some lightweight aircraft, the required reference thickness, t, is less than the minimum allowable thickness. Use the following modified steps to compute DSWL only when the theoretical thickness of the variable design layer that makes the damage equal to 1.0 for 36 500 aircraft passes is less than 25.4 mm:

a) determine the value of maximum vertical strain at the top of the subgrade corresponding to the minimum allowable variable design layer thickness (25.4 mm); and

b) calculate DSWL for the selected subgrade using the minimum thickness of the reference structure. Maintaining the constant tire pressure of 1.50 MPa, the single wheel load magnitude is adjusted until the maximum vertical strain at the top of the subgrade is equal to the value determined in a) above.

ACR calculation

1.1.3.17 The aircraft classification rating, at the selected mass and subgrade category is two times the derived single wheel load in hundreds of kilograms. The numerical value of ACR may be rounded to the nearest multiple of ten for reporting.

Tire pressure adjustment to ACR

1.1.3.18 Aircraft normally have their tires inflated to the pressure corresponding to the maximum gross mass without engine thrust, and maintain this pressure regardless of the variation in take-off masses. There are times, however, when operations at reduced masses, modified CG and/or reduced tire pressures are productive and reduced ACRs need to be calculated. To calculate the ACR for these conditions, the adjusted tire inflation pressure should be entered in the ICAO-ACR dedicated input field.

1.1.3.19 Examples of these calculations are as follows:

Example 1: Find the ACR of a B747-400 at 397 800 kg on a rigid pavement, resting on a medium-strength subgrade. The tire pressure of the main wheels is 1.38 MPa. From the manufacturer's data, it is known that, at the aft CG for maximum ramp mass, 93.33 per cent of the aircraft mass is on the main gear.

Solution: The ACR is found based on steps as described in 1.1.3.6. These steps are automatically implemented in the ICAO-ACR programme referenced in 1.1.3.4.

Step 1. Use the main gear characteristics and the standard rigid pavement structure to determine the reference ACR thickness *t*. Compute ACR for one four-wheel truck of the 16-wheel B747-400 main gear. All trucks in the B747-400 main gear have the same load, tire pressure and wheel configuration; therefore, the selection of the single truck to be used for evaluation is arbitrary. The LEAF programme described in 1.1.3.4 was used to determine stresses at evaluation points at the bottom of the concrete layer under each of the four wheels in one truck. The LEAF input data for the B747-400 aircraft are shown in Figure 1-7. In Figure 1-7, the force acting on the single truck, 910.22 kN, is the gross weight of the aircraft times 93.33 per cent, divided by four. From this analysis, for the given load and gear geometry, a concrete thickness of 381 mm produces a maximum horizontal concrete stress of 2.75 MPa. Due to symmetry, the maximum horizontal stress under all four wheels is the same. Therefore, the reference thickness, t, is 381 mm.

Step 2. Determine the derived single wheel load corresponding to the reference ACR thickness *t*. Use the same layered elastic structure as in Step 1 with Layer 1 thickness equal to 381 mm. Apply a single wheel load with constant tire pressure P_s equal to 1.50 MPa. Vary the magnitude of the derived single wheel load until the horizontal stress computed at a single evaluation point located at the bottom of the concrete layer is 2.75 MPa. Figure 1-8 shows the LEAF programme output for this case. From Figure 1-8, the tire load producing the standard stress σ = 2.75 MPa at the standard tire pressure = 1.50 MPa is 336.17 kN, corresponding to a single wheel load of 34 280 kg.

Step 3. The numerical value of ACR is two times the single wheel load in kg determined in Step 2, divided by 100. Therefore, the ACR on medium-strength ("B") subgrade is 2 × 343 = 686. The ACR on subgrade category "B" will be reported as 690.

Layer No.	Thickness, mm	Elasticity Modulus, MPa	Poisson's Ratio	Interface Condition
1	381.00	27,579.03	0.1500	0.0000
2	200.00	500.00	0.3500	1.0000
3	0.00	120.00	0.4000	1.0000

Aircraft No. 1 B–747–Wing :
Aircraft design load : Not Applicable
Fraction of load on main gear : 100.0
Gear load, KN : 910.22
Number of tires : 4

Tire No.	Radius (mm)	Cont.Area (sq.mm)	Cont.Press (MPa)	Tire Load (kiloNewtons)	X-Coord (mm)	Y-Coord (mm)
1	229	165,021	1.38	227.56	–559	0
2	229	165,021	1.38	227.56	–559	0
3	229	165,021	1.38	227.56	–559	1,473
4	229	165,021	1.38	227.56	–559	1,473

Figure 1-7. Input data for B747-400 evaluation aircraft in programme LEAF in ACR example 1

Layer No.	Thickness mm	Elasticity Modulus, MPa	Poisson's Ratio	Interface Condition
1	381.00	27,579.03	0.1500	0.0000
2	200.00	500.00	0.3500	1.0000
3	0.00	120.00	0.4000	1.0000

Aircraft No. 1 SWL–ACR :
Aircraft design load : Not Applicable
Fraction of load on main gear : 100.0
Gear load, KN : 336.17
Number of tires : 1

Tire No.	Radius (mm)	Cont.Area (sq.mm)	Cont.Press (MPa)	Tire Load (kiloNewtons)	X-Coord (mm)	Y-Coord (mm)
1	267	224,114	1.50	336.17	0	0

Eval point = 1 Layer No. = 1
X-Coord. = 0.000 Y-Coord. = 0.000 Z–Depth = 380.9900

	VERT STR	HOR Y STR	HOR X STR	XZ SHEAR	YZ SHEAR	XY SHEAR
Stress	–5.036809E–002	2.747433E+000	2.747433E+000	0.000000E+000	0.000000E+000	0.000000E+000
Strain	–3.171243E–005	8.495126E–005	8.495126E–005	0.000000E+000	0.000000E+000	0.000000E+000
Displt	7.395790E–001	0.000000E+000	0.000000E+000			

	PRIN 1	PRIN 2	PRIN 3	MAX SHEAR	OCT NORMAL	OCT SHEAR
Stress	2.747441E+000	2.747425E+000	–5.036809E–002	1.398904E+000	1.814833E+000	1.318896E+000
Strain	8.495158E–005	8.495094E–005	–3.171243E–005			

Figure 1-8. Data for derived single wheel load in programme LEAF in ACR example 1 (stresses are in MPa)

Example 2: Find the ACR of B787-9 at 254 692 kg on a flexible pavement resting on a low-strength subgrade. The tire pressure of the main wheels is 1.56 MPa. From the manufacturer's data, it is known that, at the aft CGfor maximum ramp mass, 92.46 per cent of the aircraft mass is on the main gear.

Solution: The ACR is found using the steps as described in 1.1.3.7. These steps are automatically implemented in the ICAO-ACR programme referenced in 1.1.3.4.

Step 1. Use the main gear characteristics and the standard flexible pavement structure for aircraft with more than two wheels to determine the reference ACR thickness *t*. From FAA Order 5300.7, "Standard Naming Convention for Aircraft Landing Gear Configurations", the B787-9 has main gear designation 2D. As a simple landing gear (the gear designation does not exceed two characters), the strain evaluation points for ACR are based on a single truck. Use the ICAO-ACR programme to find the reference thickness *t* = 796 mm for 36 500 passes of the evaluated aircraft. The layered elastic structure for subgrade category C (low-strength) with moduli assigned according to 1.1.3.10 is:

Layer	*Thickness, mm*	*E, MPa*	*v*
Asphalt	127	1 379	0.35
Sublayer 3	161	769.52	0.35
Sublayer 2	254	680.85	0.35
Sublayer 1	254	271.27	0.35
Subgrade	infinite	80	0.35

Step 2. Determine the DSWL corresponding to the reference ACR thickness *t*. Use the same layered elastic structure as in Step 1. Apply a single wheel load with constant tire pressure P_s equal to 1.50 MPa. Vary the magnitude of the DSWL until damage is 1.0 for 36 500 passes. From the ICAO-ACR programme, the computed value of the DSWL is 37 522.2 kg, corresponding to a maximum vertical strain on the top of the subgrade of 0.001325. Note that for the single wheel load there is no multi-axle effect, therefore the maximum strain can be found directly by substituting 36 500 passes in the elementary damage law equation in Appendix 3, Section 1.

Step 3. The numerical value of ACR is two times the single wheel load in kg determined in Step 3, divided by 100. Therefore, the ACR on low-strength ("C") subgrade is 2 × 375 = 750. The ACR on subgrade category "C" will be reported as 750.

Example 3: Find the ACR of A380-800 at 562 000 kg on a flexible pavement resting on a medium-strength subgrade. The tire pressure of the main wheels is 1.50 MPa. From the manufacturer's data, it is known that, at the aft CG for maximum ramp mass, 95.13 per cent of the aircraft mass is on the main gear (57.08 per cent on the body landing gear and 38.05 per cent on the wing landing gear).

Solution: The ACR is found using the steps as described in 1.1.3.7. These steps are automatically implemented in the ICAO-ACR programme referenced in 1.1.3.4.

Step 1. Use the main gear characteristics and the standard flexible pavement structure for aircraft with more than two wheels to determine the reference ACR thickness *t*. From FAA Order 5300.7, "Standard Naming Convention for Aircraft Landing Gear Configurations", the A380-800 has main gear designation 2D/3D2. As a complex landing gear (the gear designation exceeds two characters), the strain evaluation points for ACR are based on the entire landing gear assembly. Use the ICAO-ACR programme to find the reference thickness *t* = 616 mm. The layered elastic structure for subgrade category B (medium-strength) with moduli assigned according to 1.1.3.10 is:

Layer	*Thickness, mm*	*E, MPa*	*v*
Asphalt	127	1379	0.35
Sublayer 2	235	698.75	0.35
Sublayer 1	254	372.29	0.35
Subgrade	infinite	120	0.35

Step 2. Determine the DSWL corresponding to the reference ACR thickness *t*. Use the same layered elastic structure as in Step 1. Apply a single wheel load with constant tire pressure P_s equal to 1.50 MPa. Vary the magnitude of the DSWL until CDF = 1.0 for 36 500 passes. From the ICAO-ACR programme, the computed value of the DSWL is 28 902.4 kg, corresponding to a maximum vertical strain on the top of the subgrade of 0.001325. Note that for the single wheel load there is no multi-axle effect, therefore the maximum strain can be found directly by substituting 36 500 passes in the elementary damage law equation in Appendix 3, Section 1.

Step 3. The numerical value of the ACR is two times the single wheel load in kg determined in Step 3, divided by 100. Therefore, the ACR on low-strength ("B") subgrade is 2 × 289 = 578. The ACR on subgrade category "B" will be reported as 580.

1.1.4 How PCRs are determined

1.1.4.1 This section is intended to provide a model procedure for PCR determination and publication, using the CDF concept. States may develop their own methods for PCR determination, consistent with the overall parameters of the ACR-PCR method.

1.1.4.2 CDF concept

1.1.4.2.1 The CDF is the amount of the structural fatigue life of a pavement that has been used up. It is expressed as the ratio of applied load repetitions to allowable load repetitions to failure, or, for one aircraft and constant annual departures where a coverage is one application of the maximum strain or stress due to load on a given point in the pavement structure:

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

Note 1.— When CDF = 1, the pavement subgrade will have used all of its fatigue life.

Note 2.— When CDF < 1, the pavement subgrade will have some remaining life and the value of CDF will give the fraction of the life used.

Note 3.— When CDF > 1, all of the fatigue life will have been used and the pavement subgrade will have failed.

1.1.4.2.2 In these definitions, failure means failure according to the assumptions and definitions on which the design procedures are based. A value of CDF greater than one does not mean that the pavement will no longer support traffic, but that it will have failed according to the definition of failure used in the design procedure. The thickness design is based on the assumption that failure occurs when CDF = 1.

1.1.4.2.3 Multiple aircraft types are accounted for using Miner's Rule:

$$CDF = CDF_1 + CDF_2 + \cdots + CDF_N$$

where CDF_i is the CDF for each aircraft in the traffic mix and N is the number of aircrafts in the mix.

1.1.4.2.4 Since the PCR relates to the structural pavement life, the CDF is based on the subgrade failure mode.

1.1.4.3 Lateral wander

1.1.4.3.1 The distribution of aircraft passes for a given aircraft type over the life of the pavement is described by a Gaussian (or normal) distribution function, with a standard deviation s that depends on several factors: the type of aircraft, its ground speed, and the manoeuvring area. Another term that is frequently used is the amplitude of lateral wander, which is twice the standard deviation.

1.1.4.3.2 High-speed sections (e.g. runways) are associated with higher values of s than moderate-speed sections (e.g. taxiways), while wander may be considered negligible ($s \cong 0$) on low-speed sections (e.g. aprons).

1.1.4.3.3 The following values of standard deviation may be used independently of the type of aircraft:

Pavement section	*Standard deviation s (metres)*
High-speed sections (runway, rapid exit taxiway)	0.75
Moderate-speed sections (taxiways)	0.5
Aprons and low-speed sections	0

1.1.4.3.4 The FAA design procedure assumes s = 0.776 metres (30.54 inches) independently of the type of aircraft or feature.

1.1.4.3.5 The effect of lateral wander may be considered indirectly by computing a pass-to-coverage (P/C) ratio from the normal aircraft distribution. Alternatively, the distribution function can be discretized (mapped to a calculation grid) and the wandered damage computed numerically. A more closely spaced grid results in higher calculation times but greater accuracy. A grid spacing of 5 cm has been found to give good results. Discretization on a grid with transverse pitch Δy results in the distribution of the paths on *nw* lines y_w of the grid, which are associated with percentages of the traffic P_w.

1.1.4.3.6 The effect of including lateral wander is to reduce the theoretical damage that would be caused by having all aircraft traverse a single path, i.e. $D_{wander} < D_{zero\ wander}$. Zero wander implies that the number of passes equals the number of coverages (P/C = 1).

Calculation of damage assuming lateral wander

1.1.4.3.7 When the grid method is used, it is necessary to obtain the total damage (for one aircraft) by summing the individual damage contributions from each of the *nw* profiles. This step consists of adding up the damage profiles $D_{no\ wander}(y, z)$, offset by the value y_w and weighted by probability of occurrence P_w in the lateral wander law:

$$D_{wander}(y, z) = \sum_{w=1}^{nw} P_w \times D_{no\ wander}(y - y_w, z)$$

where nw = total number of damage profiles.

Determination of the cumulative damage for a traffic mix

1.1.4.3.8 The cumulative damage for all aircraft comprising an aircraft mix is given by the following equation, which treats the additive effect of damage according to Miner's Rule:

$$CDF(y_j, z) = \sum_{i=1}^{m} N_i \times (D_{wander})_i(y_j, z)$$

where m = total number of aircraft in the traffic mix; i = aircraft within the aircraft mix; and N_i = number of aircraft passes.

1.1.4.3.9 The resulting curve represents the variation of the CDF in the transverse direction (relative to the longitudinal centreline).

1.1.4.3.10 If the P/C ratio is computed for each aircraft i, an equivalent expression giving CDF at lateral offset j is:

$$CDF(y_j, z) = \sum_{i=1}^{m} \frac{N_i}{(P/C)_j^i} \times D_i(z)$$

where D_i is the damage contributed by a pass of aircraft i, including any effects of interaction between wheels in tandem.

1.1.4.4 Pavement strength reporting

1.1.4.4.1 PCR shall be reported using the following codes:

a) Rigid pavement = R

b) Flexible pavement = F

Note.— If the actual pavement construction is composite or non-standard, include a note to that effect.

1.1.4.4.2 *Subgrade category*

1.1.4.4.3 The subgrade categories are:

a) High strength: Characterized by E = 200 MPa, and representing all E values equal to or above 150 MPa for rigid and flexible pavements = Code A.

b) Medium strength: Characterized by E = 120 MPa and representing a range in E equals to or above 100 and strictly less than 150 MPa, for rigid and flexible pavements = Code B.

c) Low strength: Characterized by E = 80 MPa and representing a range in E equals to or above 60 and strictly less than 100 MPa, for rigid and flexible pavements = Code C.

d) Ultra-low strength: Characterized by E = 50 MPa and representing all E values strictly less than 60 MPa, for rigid and flexible pavements = Code D.

1.1.4.4.4 For existing pavements initially designed with the California bearing radio (CBR) design procedure, subgrade modulus values can be determined in a number of ways. The procedure that will be applicable in most cases is to use available CBR values and substitute the relationship:

E = 1 500 × CBR (E in psi) or 10 x CBR (E in MPa)

1.1.4.4.5 This method provides designs compatible with the earlier flexible design procedure based on subgrade CBR, but other accepted equivalencies can also be used (Shell method, Airport Pavement Design System Knowledge Base (APSDS) method, etc.). Subgrade modulus values for PCR determination may also be determined from direct soil testing (e.g. lightweight deflectometer, plate test).

1.1.4.4.6 Similarly, for rigid pavement design, the foundation modulus can be expressed as the modulus of subgrade reaction k or as the elastic (Young's) modulus E. However, all structural computations are performed using the elastic modulus E. If the foundation modulus is input as a k value it can be converted to the equivalent E value using the following equations:

$E_{SG}=20.15\times k^{1.284}$

where E_{SG} = Elastic (Young's) modulus of the subgrade, pounds per square inch (psi); and K = Modulus of subgrade reaction, pounds per cubic inch (pci).

1.1.4.4.7 For new pavement construction, the subgrade modulus value for PCR determination should be the same value used for pavement thickness design.

1.1.4.4.8 The maximum allowable tire pressure categories are:

a) Unlimited: no pressure limit = Code W.

b) High: pressure limited to 1.75 MPa = Code X.

c) Medium: pressure limited to 1.25 MPa = Code Y.

d) Low: pressure limited to 0.5 MPa = Code Z.

1.1.4.4.9 There are two types of evaluation methods, mainly:

a) Technical evaluation: representing a specific study of the pavement characteristics and its capability of supporting the aircraft mix that is intended to serve, using the CDF concept through a mechanistic design/evaluation method calibrated against observed pavement behaviour = Code T

b) Using aircraft experience: representing a knowledge of the specific type and mass of aircraft satisfactorily being supported under regular use = Code U

1.1.4.5 PCR recommended procedure for technical evaluation (T)

1.1.4.5.1 The following recommended PCR procedure reduces to the computation of an aircraft ACR. The steps below can be used to convert the mix of using aircraft traffic to an equivalent critical, or reference aircraft at maximum allowable gross weight, which will then produce a CDF of 1.0 on the evaluated pavement. The ACR calculation follows the ACR procedure described in 1.1.3.

1,1,4.5.2 The PCR procedure considers the actual pavement characteristics at the time of the evaluation — considering the existing pavement structure, and the aircraft traffic forecast to use the pavement over its design structural life (for new pavement construction) or estimated remaining structural life (for in service pavements). The PCR should be valid only for this usage period. In case of major pavement rehabilitation or significant traffic changes compared to the initial traffic, a new evaluation should be performed.

1.1.4.5.3 The PCR procedure involves the following steps:

1) collect all relevant pavement data (layer thicknesses, elastic moduli and Poisson's ratio of all layers, using projected aircraft traffic) using the best available sources;

2) define the aircraft mix by aircraft type, number of departures (or operations consistent with pavement design practices), and aircraft weight that the evaluated pavement is expected to experience over its design or estimated remaining structural life (according to the manoeuvre area (runway, taxiway, apron, ramp), the traffic can be assigned a lateral wander characterized by a standard deviation as detailed in 1.1.4.2.1);

3) compute the ACRs for each aircraft in the aircraft mix at its operating weight and record the maximum ACR aircraft (ACR computations must follow the procedure in 1.1.3);

4) compute the maximum CDF of the aircraft mix and record the value (the CDF is computed with any damage/failure model consistent with the procedure used for pavement design);

5) select the aircraft with the highest contribution to the maximum CDF as the critical aircraft. This aircraft is designated AC(i), where i is an index value with an initial value 1. Remove all aircraft other than the current critical aircraft AC(i) from the traffic list;

6) adjust the number of departures of the critical aircraft until the maximum aircraft CDF is equal to the value recorded in step 4). Record the equivalent number of departures of the critical aircraft;

7) adjust the critical aircraft weight to obtain a maximum CDF of 1.0 for the number of departures obtained at step 6). This is the maximum allowable gross weight (MAGW) for the critical aircraft;

8) compute the ACR of the critical aircraft at its MAGW. The value obtained is designated as PCR(i). (ACR computations must follow the procedure in 1.1.3);

9) if AC(i) is the maximum ACR aircraft from step 3) above, then skip to step 13);

10) remove the current critical aircraft AC(i) from the traffic list and re-introduce the other aircraft not previously considered as critical aircraft. The new aircraft list, which does not contain any of the previous critical aircraft, is referred to as the reduced aircraft list. Increment the index value ($i = i+1$);

11) compute the maximum CDF of the reduced aircraft list and select the new critical aircraft AC(i);

12) repeat steps 5-9 for AC(i). In step 6, use the same maximum CDF as computed for the initial aircraft mix to compute the equivalent number of departures for the reduced list; and

13) the PCR to be reported is the maximum value of all computed PCR(i). The critical aircraft is the aircraft associated with this maximum value of PCR(i).

1.1.4.5.4 A flowchart of the above procedure is shown in Figure 1-9. The purpose of steps 10 to 13 is to account for certain cases with a large number of departures of a short/medium-range aircraft (such as the B737) and a relatively small number of departures of a long-range aircraft (e.g. the A350). Without these steps, the smaller aircraft would generally be identified as critical, with the result that the PCR would require unreasonable operating weight restrictions on larger aircraft (unreasonable because the design traffic already included the large aircraft). Note that if the initial critical aircraft is also the aircraft in the list with the maximum ACR at operating weight, then the procedure is completed in one iteration, with no subsequent reduction to the traffic list.

1.1.4.5.5 The above procedure returns a uniquely determined PCR numerical value based on the identified critical aircraft.

1.1.4.6 Applicability

1.1.4.6.1 The technical evaluation should be used when pavement characteristics and aircraft mix are consistently known and documented.

1.1.4.6.2 The PCR procedure does not dictate the use of a preferred subgrade failure/damage model or a method for treating the multi-axle loading. Therefore, States can use their existing pavement design and evaluation methodologies. The use of the initial pavement design parameters will ensure consistency between what the actual pavement is able to withstand and the PCR assignment.

PCR procedure — Using aircraft experience (U)

1.1.4.6.3 Whenever possible, reported pavement strength should be based on a “technical evaluation”. When, for economic or other reasons a technical evaluation is not feasible, evaluation can be based on experience with “using aircraft”. A pavement satisfactorily supporting aircraft using it, can accept other aircraft if they are no more demanding than the using aircraft. This can be the basis for an evaluation.

1.1.4.6.4 Techniques for “using aircraft” evaluation are given in 3.5.

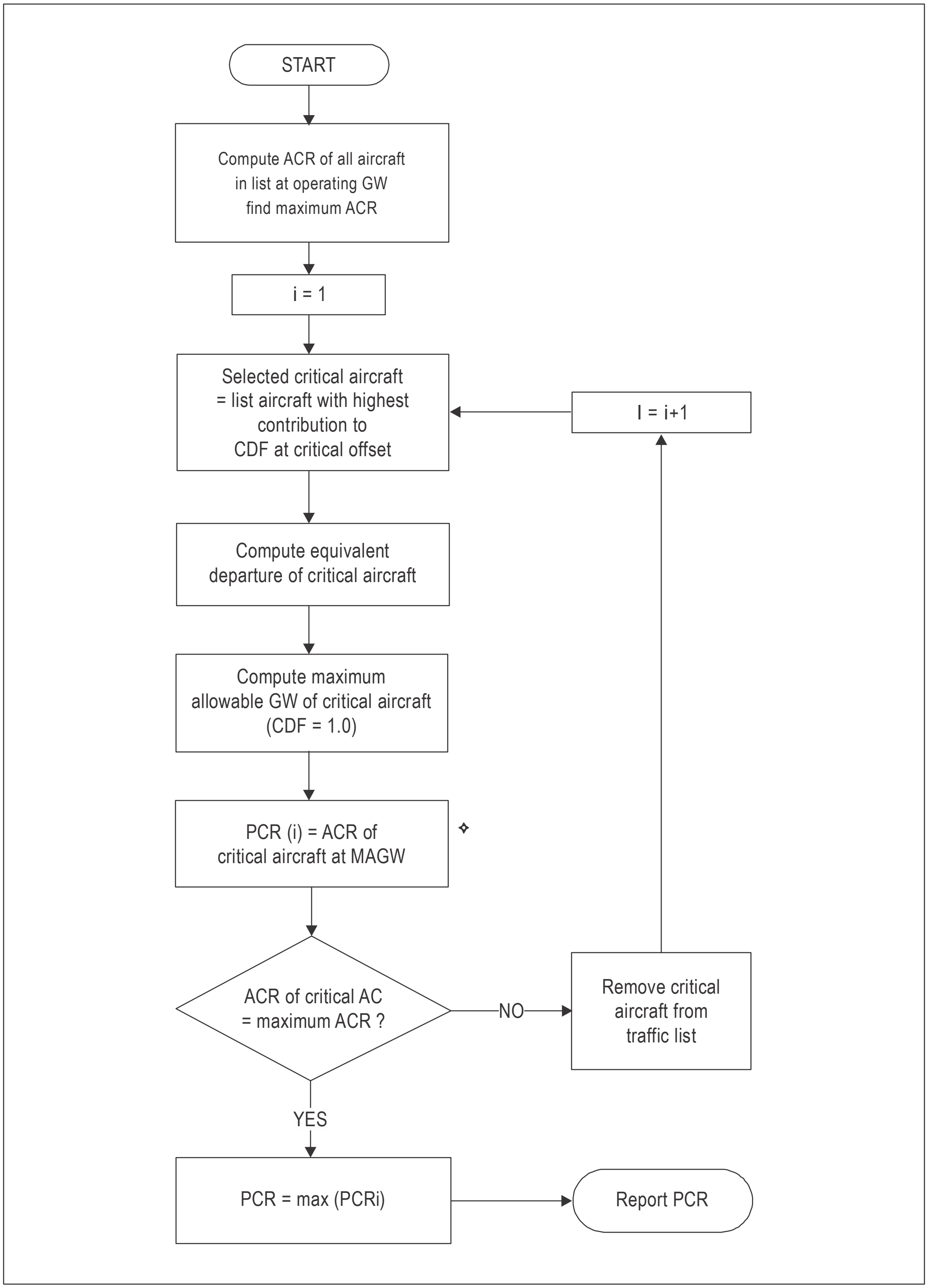

Figure 1-9. Flowchart of recommended PCR computation procedure

1.1.4.6.5 Worked examples:

Example 1 (Flexible)

Steps 1 and 2: Data collection:

a) Pavement characteristics

The pavement description consists of providing for each layer its thickness, modulus of elasticity (E) and Poisson's ratio (ν). For new pavement construction, the data should be those which served for the pavement design.

For in-service pavement, it may be necessary to determine these input values by non-destructive testing (core sampling, heavy-weight deflectometer, etc.). Due to loading or environmental conditions, the pavement material characteristics may change over time. In the following example, the pavement was designed according to the French pavement design procedure, using standard French material specifications found in NF EN 13 108-1, for a period of usage of ten years. For PCR consistency, and to determine precisely the individual contribution of each aircraft in the mix to the maximum CDF, the same parameters that were used for the original pavement design (subgrade failure model, treatment of multi-axle loads, etc.) are also used to determine PCR. The evaluated pavement is a runway.

PAVEMENT CHARACTERISTICS				
Layers	*Designation*	*E-Modulus (MPa)*	*Poisson's ratio*	*Thickness (cm)*
Surface course	EB-BBSG3	E=f (θ, freq.)	0.35	6
Base course	EB-GB3	E=f (θ, freq.)	0.35	18
Sub-base (1)	GNT1	600	0.35	12
Sub-base (2)	GNT1	240	0.35	25
Subgrade		80	0.35	∞

b) Aircraft mix data

For new pavement construction, the aircraft mix for PCR determination is the same aircraft list used for the pavement design.

For in-service pavement, the PCR analysis considers aircraft usage over the remaining pavement (structural) life. If the mixture of aircraft types using the pavement is known to have changed significantly from the design forecast, an updated aircraft list should be used. This example uses the following list of aircraft with maximum operating weights and annual departures:

AIRCRAFT MIX ANALYSED			
No.	*Aircraft model*	*Maximum taxi weight (t)*	*Annual departures*
1	A321-200	93.9	14 600
2	A350-900	268.9	5 475
3	A380-800	571	1 825
4	B737-900	79.2	10 950
5	B787-8	228.4	3 650
6	B777-300ER	352.4	4 380

Note.— The evaluated pavement is a runway; each aircraft is assigned a lateral wander of 1.5 m (standard deviation of 0.75 m). Each aircraft is centred on the pavement centreline and modelled with its real main landing gear coordinates.

Step 3: Aircraft ACR at operating weight:

	B777-300ER	A321-200	A350-900	B787-8	B737-9	A380-800
Operating weight (t)	352.4	93.9	268.9	228.4	79.2	571
ACR	790	550	720	680	450	650

Step 4: CDF of the entire aircraft mix:

The CDF is computed for the entire fleet by summing the individual aircraft CDF contributions along a transverse axis perpendicular to the runway centreline. Figure 1-10 shows the individual aircraft contributions to CDF and the resulting total CDF of the mix. The maximum value of CDF is 1.153, located at an offset 4.9 m from the runway centreline. The contribution of each aircraft in the mix to the maximum CDF is plotted in Figure 1-10.

The maximum CDF is greater than 1.0, indicating that the pavement is under-designed for the traffic analysed.

Note.— It is important to distinguish the CDF contributions of each aircraft to the maximum CDF at the critical offset from the maximum damage due to individual aircraft (which may or may not occur at the critical offset). For instance, the A321-200 damage contribution to the maximum CDF at the critical offset is 0.153 while its maximum damage is equal to 0.341. Similarly, the A350-900 produces a maximum damage of 0.306, lower than the A321, but its contribution to the maximum CDF is of 0.302, higher than the A321 contribution. The difference is due to different track dimensions (distance of the landing gear from the centreline) of the various aircraft.

The aircraft with the highest CDF contribution (to the maximum CDF) becomes the most demanding aircraft within the mix. In this example, the highest contribution to the maximum CDF (0.399 — see Figure 1-10) is produced by the B777-300ER.

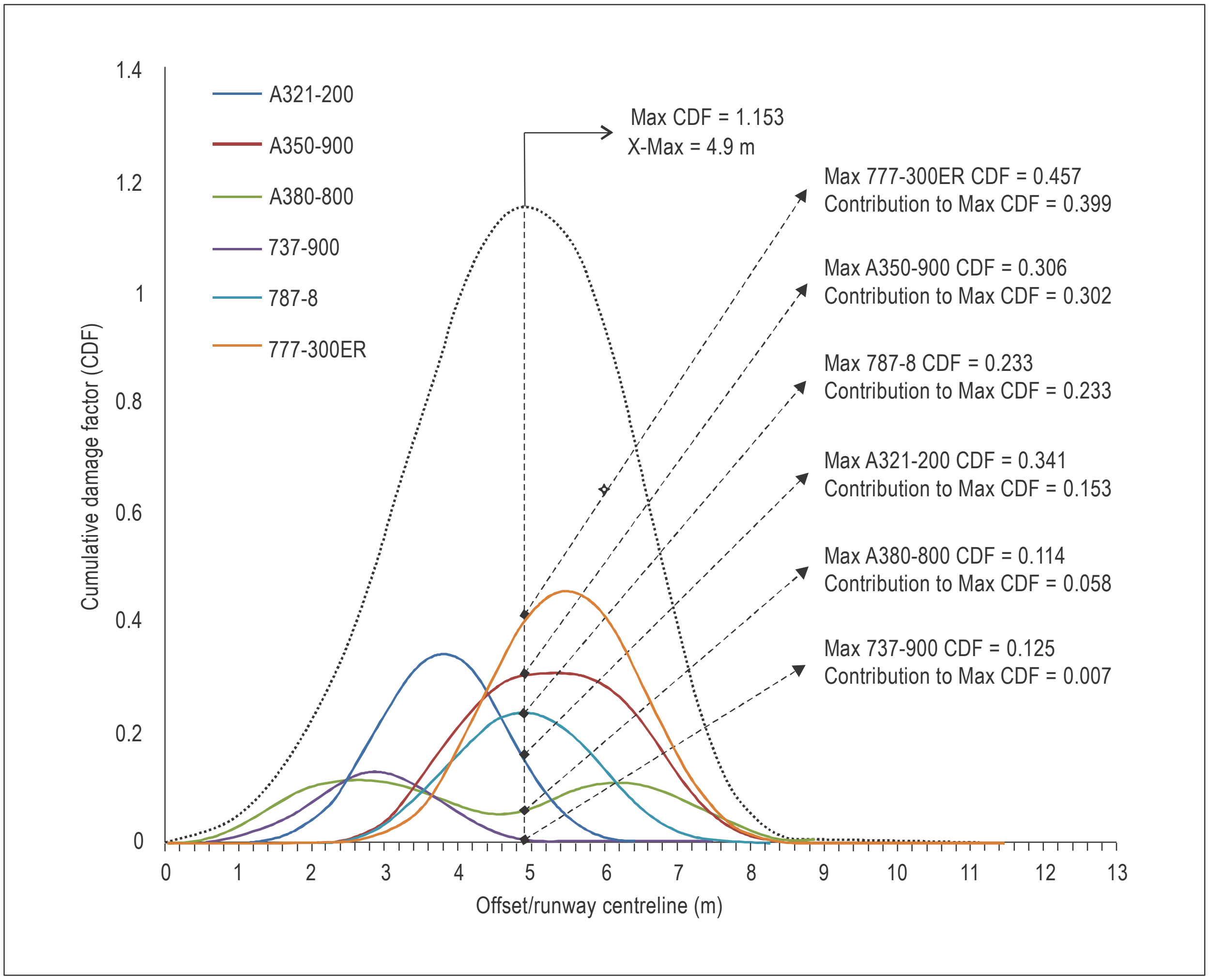

Figure 1-10. Aircraft CDF, total CDF and aircraft contribution to the maximum CDF

Step 5: The B777-300ER is selected as the most contributing aircraft to the maximum CDF. All other aircraft are removed.

Step 6: The contribution of the B777-300ER to the maximum CDF at its initial annual departure level is 0.457. The number of annual departures is adjusted until CDF equals 1.153. This step is performed by simple linear extrapolation, giving 11 050 equivalent annual departures of the B777-300ER (110 500 total departures).

Step 7: The gross weight of the B777-300ER is adjusted to obtain a maximum CDF of 1.0. In other words, the pavement is now correctly designed to accommodate the single equivalent aircraft at its adjusted weight and equivalent annual departure level. The MAGW is 341.3t.

Step 8: The B777-300ER ACR at its MAGW is 740/F/C.

Step 9: Checking against the list in Step 3, the B777-300ER is the maximum ACR aircraft. Therefore, the procedure is stopped. The PCR to be reported is equal to the B777-300ER ACR at its MAGW:

PCR 740 FCWT.

For the tire pressure code, the letter W is selected since the evaluated pavement is new construction, and the surface asphalt mix has been designed to resist the imposed tire pressures.

Example 2 (Flexible)

Steps 1 and 2: Data collection:

a) Pavement characteristics

In this example, a flexible runway was designed according to the FAA pavement design procedure, using standard material specifications found in the United States FAA AC 150/5370-10. For PCR consistency, and to determine precisely the individual contribution of each aircraft in the mix to the maximum CDF, the procedure should consider the design parameters that served the original pavement design (subgrade failure model, treatment of multi-axle loadings, etc.). This is achieved in accordance with FAA AC 150/5320-6F, Airport Pavement Design and Evaluation.

PAVEMENT CHARACTERISTICS				
Layers	*Designation*	*E-Modulus (MPa)*	*Poisson's ratio*	*Thickness (cm)*
Surface course	P-401/P-403 HMA Surface	1379	0.35	10.2
Base course	P-401/P-403 (flex)	2758	0.35	12.7
Sub-base	P-209	467	0.35	17.5
Subgrade		200	0.35	infinite

b) Aircraft mix data

In this example, the traffic data represent a regional hub, in which there is a large number of departures of mid-range jet aircraft (A320, A321, B737) combined with a smaller number of operations of long-range or large aircraft (A330, B777 and A380). The design life is 20 years.

AIRCRAFT MIX			
No.	*Aircraft model*	*Maximum taxi weight (t)*	*Annual departures*
1	A330-300	233.9	52
2	B777-300ER	352.4	52
3	A380-800	571	52
4	B737-900ER	85.4	109 50
5	A320-200	77.4	10 950
6	A321-200	93.9	1 560

Note.— Consistent with FAA design standards, the assumed standard deviation of aircraft wander is 0.776 metres (30.54 inches).

Step 3: Aircraft ACR at operating weight:

	A321-200	B737-900ER	B777-300ER	A320-200	A330-300	A380-800
Operating weight (t)	93.9	85.4	352.4	77.4	233.9	571
ACR	460	420	570	360	570	550

Step 4: CDF of the entire aircraft mix:

The CDF is computed for the entire fleet by summing the individual aircraft CDF contributions along a transverse axis perpendicular to the runway centreline. In this example, the computation was done using the FAA programme FAARFIELD 1.42.

Figure 1-11 shows the individual aircraft CDF and the resulting total CDF for the design. The maximum CDF is 0.99, located at a lateral offset 3.7 m from the runway centreline. The contribution of each aircraft in the mix to the maximum CDF is plotted in Figure 1-11. Note that the CDF values plotted in Figure 1-11 are based on aircraft characteristics for thickness design, according to which 95 per cent of the aircraft gross weight acts on the main gear. The maximum CDF is slightly less than 1.0, indicating that the pavement thickness is properly designed for the traffic analysed. When the characteristics are adjusted to reflect the mass and CG values that produce the highest main gear loads on each aircraft (see 1.1.3.2.6, then the maximum CDF is reduced to 0.898; however, the relative contributions of the aircraft are the same. In contrast to Example 1, the maximum CDF is concentrated around single-aisle aircraft, while the contribution of the long-range aircraft is less, due to the small number of annual departures.

Step 5: Based on Figure 1-11, the B737-900ER is selected as the most contributing aircraft to the maximum CDF. All other aircraft are removed.

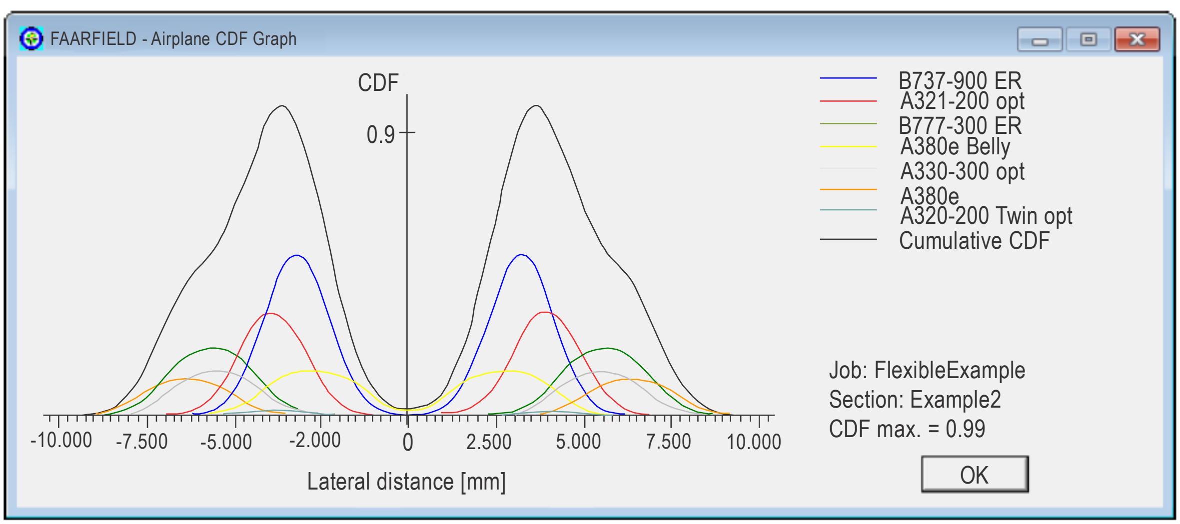

Figure 1-11. Aircraft CDF, total CDF and aircraft contribution to the maximum CDF

Step 6: The contribution of the B737-900ER to the maximum CDF at its initial annual departure level is 0.405. The programme adjusts the number of annual departures iteratively until CDF equals 0.898, giving 21 837 equivalent annual departures of the B737-900ER.

Step 7: The gross weight of the B737-900ER is adjusted to obtain a maximum CDF of 1.0. The pavement is now correctly designed to accommodate the single equivalent aircraft at its adjusted weight and equivalent annual departure level. The MAGW is 85.77 t.

Step 8: The ACR of the B737-900ER at its MAGW is 425 FA = PCR1.

Step 9: Checking against the table in Step 3, it is found that the B737-900ER is not the maximum ACR aircraft. Therefore, the procedure continues to Step 10.

Step 10: The B737-900ER is removed from the aircraft list, and all other aircraft are reintroduced.

Step 11: In the reduced aircraft mix, the most contributing aircraft is the A321-200, since the location of the maximum CDF has now changed by removing the B737-900ER.

Step 12: Steps 5 to 9 are repeated until the aircraft that is the highest contributor to CDF at the critical offset is also the maximum ACR aircraft.

In this example, the recursive procedure is stopped at the third potential critical aircraft. The resulting PCRi values are:

a) PCR1 425 FAWT (first critical aircraft, B737-900ER)

b) PCR2 465 FAWT (second critical aircraft of the reduced aircraft mix, A321-200)

c) PCR3 580 FAWT (third critical aircraft and maximum ACR aircraft, B777-300ER)

Retained PCR = maximum (PCR1, PCR2, PCR3) = 580 FAWT

Because the reported PCR is higher than the maximum operating weight ACR of any of the mix aircraft, there are no operating weight restrictions.

<u>Example 3 (Rigid)</u>

Steps 1 and 2: Data collection:

a) Pavement characteristics

In this example, a rigid taxiway is evaluated for PCR reporting. Material properties are assigned to layers following standard the material specifications found in FAA AC 150/5370-10 and FAA AC 150/5320-6F. For this example, assume that, based on laboratory tests, the flexural strength of the concrete is 4.5 MPa.

PAVEMENT CHARACTERISTICS				
Layers	*Designation*	*E-Modulus (MPa)*	*Poisson's ratio*	*Thickness (cm)*
Surface course	P-501 Portland cement concrete	27 579	0.15	45.0
Base course	P-401/P-403 (flexible)	2 758	0.35	12.5
Sub-base	P-209	311	0.35	30.0
Subgrade	P-152	90	0.40	infinite

b) Aircraft mix data

The applied traffic for this example is given in the table below. The design life is 20 years. For this traffic mix, the FAA standard thickness design requirement (FAARFIELD 1.42) is 45.6 cm of concrete. Therefore, the existing pavement thickness is slightly under-designed for the given traffic, consequently operating weight restrictions may be required for some of the heavier aircraft.

AIRCRAFT MIX ANALYSED				
No.	Aircraft model	Maximum taxi weight (t)	Per cent weight on main gear	Annual departures
1	B747-8	440.0	94.7	365
2	A350-900	268.9	94.8	5 475
3	B787-8	228.4	91.3	3 650
4	A321-200	93.9	94.6	14 600
5	B737-900	79.2	94.6	10 950
6	EMB-190	48.0	95.0	10 950

Note.— Consistent with FAA design standards, the assumed standard deviation of aircraft wander is 0.776 metres (30.54 inches).

Step 3: Aircraft ACR at operating weight:

	B747-8	A350-900	B787-8	A321-200	B737-900	EMB-190
Operating weight (t)	440.0	268.9	228.4	93.9	79.2	48.0
ACR/R/C	910	920	870	660	550	290

Step 4: CDF of the entire aircraft mix:

The CDF is computed for the entire fleet by summing the individual aircraft CDF contributions along a transverse axis perpendicular to the runway centreline. In this example, the computation was done using the FAA programme FAARFIELD 1.42.

Using the aircraft data in Step 2, the maximum CDF for the given traffic mix is found to be 1.24, which is higher than the design target value 1.0. The maximum CDF is located at a lateral offset 4.7 m from the runway centreline. The aircraft that is the largest contributor to CDF at this critical offset is the A350-900.

Aircraft contribution to CDF at critical offset (4.7 m)	
Aircraft	CDF
B747-8 (Wing Gear)	0.023
B747-8 (Body Gear)	0.001
A350-900	**0.935**
B787-8	0.158
A321-200	0.124
B737-900	0.001
EMB-190	0.000
Total	1.242

Step 5: The A350-900 is selected as the most contributing aircraft to the maximum CDF. All other aircraft are removed.

Step 6: The contribution of the A350-900 to the maximum CDF at its initial annual departure level is 0.935. The programme adjusts the number of annual departures iteratively until CDF equals 1.24, giving 7 227 equivalent annual departures of the A350-900.

Step 7: The gross weight of the A350-900 is adjusted to obtain a maximum CDF of 1.0 for 7 227 annual departures. The MAGW is 270.4 t.

Step 8: The ACR of the A350-900 at its MAGW is 906/R/C = PCR1.

Step 9: Checking against the table in Step 3, it is found that the A350-900 is also the maximum ACR aircraft. Therefore, the procedure jumps to Step 13 (end). Rounding the PCR numerical value to the nearest multiple of 10, the PCR to be reported is 910/R/C/W/T.

If the airport publishes this PCR, then minor operating weight restrictions will be required on the A350-900. Alternatively, the A350-900 could be allowed to operate under the overload provisions (see 2.1.1), as its ACR exceeds the PCR by less than the 10 per cent allowance.