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New Alpha Factor Determination as a Function of Number of Wheels and Number of Coverages

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Final Report

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16. Abstract

A new set of Alpha Factor curves was derived for use in the CBR (California Bearing Ratio) methodology for designing flexible airport pavements. The new Alpha Factor curves are compatible with the new Alpha Factors at 10,000 coverages for four- and six-wheel gears adopted by International Civil Aviation Organization (ICAO) for calculating the Aircraft Classification Number (ACN) of airplanes operating on flexible pavements. The standard set of Alpha Factors at 10,000 coverages for 1, 2, 4, 6, 8, 12, 18, and 24 wheels, as defined in the ICAO Pavement Design Manual, have the values 0.995, 0.900, 0.825, 0.788, 0.755, 0.722, 0.700, and 0.689. These are replaced by a new set of values: 0.995, 0.900, 0.800, 0.720, 0.690, 0.660, 0.640, and 0.630. The new values for more than six wheels were derived based on maintaining a consistent ranking of ACN compared to the old values. Analytic curves are defined so that Alpha Factors can be computed at any number of coverages and for any number of wheels, up to 24. Alpha Factors computed with the analytic curves are compatible with the new ICAO values at 10,000 coverages and with existing full-scale test data. The new analytic curves are implemented in the computer program COMFAA, which may be used to compute ACN for any arbitrary gear configuration. The source code of the function routine for computing the Alpha Factor in COMFAA is included in appendix A.

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LIST OF ACRONYMS AND ABBREVIATIONS

2D	Dual tandem
3D	Triple-dual tandem
ACN	Aircraft Classification Number
AOSWG	Aerodrome Operations and Services Working Group
CBR	California Bearing Ratio
DP	Discussion Paper
ESWL	Equivalent single-wheel load
FAA	Federal Aviation Administration
ICAO	International Civil Aviation Organization
MWHGL	Multiple-wheel heavy gear load
NAPTF	National Airport Pavement Test Facility
PCN	Pavement Classification Number
R&D	Research and development
S	Single

EXECUTIVE SUMMARY

In September 2006, the Aerodrome Operations and Services Working Group (AOSWG) of the International Civil Aviation Organization (ICAO) proposed in Discussion Paper No. 21 (DP21) that the Alpha Factors at 10,000 coverages for four- and six-wheel gears be redefined for use in calculating the Aircraft Classification Number (ACN) of airplanes operating on flexible pavements. The new Alpha Factor values are 0.800 and 0.720 and the old values are 0.825 and 0.788. The new values are based on an analysis of a recently expanded set of full-scale trafficking test data for four- and six-wheel gears. With these changes, Alpha Factors at other numbers of wheels, and over the full range of coverages for design, also required redefinition to maintain consistency in the CBR (California Bearing Ratio) procedure for flexible pavement thickness design, as required for ACN calculations.

A new set of Alpha Factors at 10,000 coverages is defined based on recommendations contained in ICAO AOSWG DP21. The standard set of Alpha Factors at 10,000 coverages for 1, 2, 4, 6, 8, 12, 18, and 24 wheels is defined in a computer program listing in the ICAO Pavement Design Manual and has the values 0.995, 0.900, 0.825, 0.788, 0.755, 0.722, 0.700, and 0.689, respectively. These are replaced by a new set of values: 0.995, 0.900, 0.800, 0.720, 0.690, 0.660, 0.640, and 0.630. The new values for more than six wheels were derived based on maintaining a consistent ranking of ACN compared to the old values. Adoption of the new Alpha Factors in the standard set for computation of ACN was approved by ICAO on June 19, 2007, and formally adopted on October 16, 2007 by a letter to the member States designating the new Alpha Factors listed above as "Revised Alpha Factor Values." The letter to the member States also requested that the aircraft manufacturers "revise the ACN values for their respective aircraft types on various subgrade types, currently available as guidance material."

It is recommended in this report that the Alpha Factor for a number of wheels not contained in the standard set be obtained by linear interpolation between the two closest numbers of wheels in the standard set. A new methodology is also defined to allow the calculation of Alpha Factor over the full range of coverages expected in flexible pavement thickness design for commercial airplane operations. The new methodology defining Alpha Factor versus coverages is constrained to exactly reproduce the new Alpha Factors at 10,000 coverages over the full range of number of wheels from 1 to 24. The new methodology has been implemented in the computer program COMFAA for computing design thickness and ACN of flexible airport pavements based on the new Alpha Factors. The source code for computing Alpha Factor by the new methodology is included in appendix A.

1. INTRODUCTION.

In September 2006, the Aerodrome Operations and Services Working Group (AOSWG) of the International Civil Aviation Organization (ICAO) proposed in Discussion Paper No. 21 (DP21) that the Alpha Factors at 10,000 coverages for four- and six-wheel gears be redefined for use in calculating the Aircraft Classification Number (ACN) of airplanes operating on flexible pavements. The new Alpha Factor values are 0.800 and 0.720 and the old values are 0.825 and 0.788, with the new values being based on an analysis of a recently expanded set of full-scale trafficking test data for four- and six-wheel gears. With these changes, Alpha Factors at other numbers of wheels, and over the full range of coverages for design, also required redefinition to maintain consistency in the CBR (California Bearing Ratio) procedure for flexible pavement thickness design, as required for ACN calculations, even though additional full-scale test data is not available for other than four- and six-wheel gears.

A new set of Alpha Factors at 10,000 coverages is first defined based on recommendations contained in ICAO AOSWG DP21. A new set of functions is then defined to allow the calculation of Alpha Factor over the full range of coverages expected in flexible pavement thickness design for commercial airplane operations. The new set of functions defining Alpha Factor versus coverages is compatible with the new set of Alpha Factors at 10,000 coverages. The functions are also compatible, to the extent possible, with existing definitions of Alpha Factor versus coverages.

2. ALPHA FACTOR AT 10,000 COVERAGES VERSUS NUMBER OF WHEELS.

The Alpha Factors embedded in the ICAO pavement design manual, Computer Program No. 2 [1], for calculating flexible pavement ACN values for 1, 2, 4, 6, 8, 12, 18, and 24 wheels, are listed in table 1 and shown graphically in figure 1.

Table 1. Alpha Factors Embedded in ICAO Computer Program No. 2, Flexible Pavement ACN [1]

Number of Wheels	Alpha Factor From ICAO Computer Program No. 2	Alpha Factor From ICAO AOSWG DP21
1	0.995	
2	0.900	
4	0.825	0.800
6	0.788	0.720
8	0.755	
12	0.722	
18	0.700	
24	0.689	

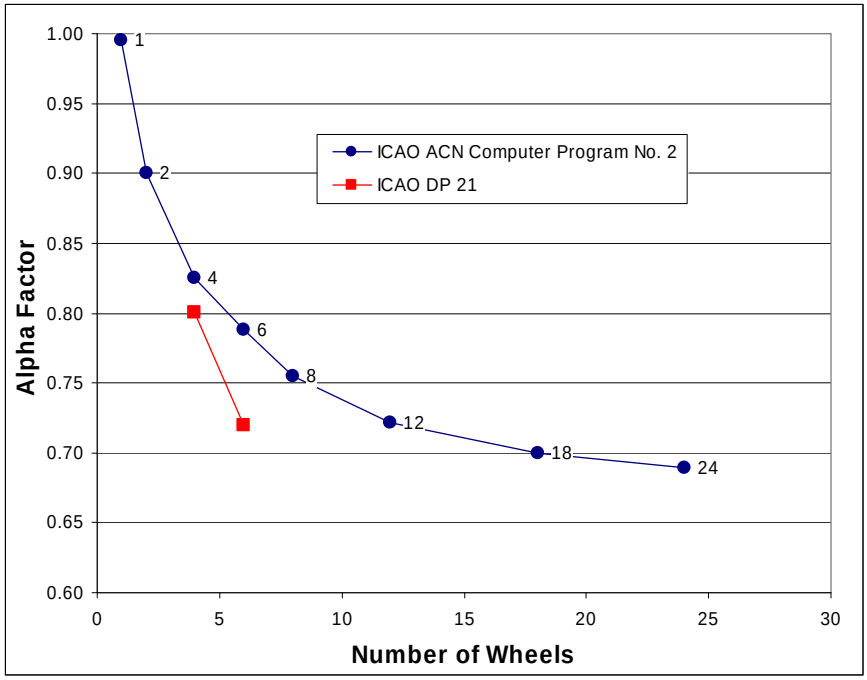

Figure 1. Alpha Factors Embedded in ICAO Computer Program No. 2, Flexible Pavement ACN [1], With Recommended Changes for Four- and Six-Wheel Airplanes

ICAO AOSWG DP21 recommends that the following change be made to the Alpha Factors for the computation of ACN values:

> "Change the Alpha Factors for all 4-wheel and 6-wheel aircraft (0.80 and ~~0.71~~/0.72), and alter the Alpha Factors for other wheel numbers so that the ranking of damaging effect is consistent. ACNs for all aircraft would change, and the Alpha Factors would be technically correct."

Table 1 and figure 1 also show the new Alpha Factors for four- and six-wheel airplanes as well as the original Alpha Factors.

The Alpha Factors in table 1 were originally derived from curves of Alpha Factor versus coverages published in references 2 and 3 for gears with 1, 2, 4, 6, 8, 12, 18, and 24 wheels. Reference 2 published the single-, 4-, and 12-wheel curves based on full-scale test data for single (S), dual tandem (2D), and two C5 six-wheel gears in tandem (for the 12-wheel gear curve). Reference 3 added the additional curves by interpolation (for 2-, 6-, and 8-wheel gears) and extrapolation (for 18- and 24-wheel gears). Extrapolation outside the range of the existing full-scale test data was necessary because the CBR design procedure, as defined in reference 4, requires that pavement thickness be computed for all combinations of wheels in the main landing gear, and that the largest of these thicknesses be used for design. Quoting the relevant passage from pages 70 and 71 in reference 4:

> "The α_i curves have been developed using the load on one landing gear assembly of an aircraft. In actual practice, designs are to be based upon the load on all main

> tires. Therefore, the α_i versus passes curves (figure 82) show the total number of aircraft main gear tires represented by the gear type. Use of the criteria, therefore, is accomplished by determining the ESWL and the α_i for all main gear tires, which generally results in maximum thickness requirements for a specific aircraft. However, where it is shown that some combination or grouping of tires other than all main gear tires will produce a greater thickness requirement, then the other combination or group will be used."

Page 27 of reference 3 contains a similar statement:

> "The number of tires used to compute the ESWL is that combination of tires which gives the greatest ESWL …"

These two statements are not necessarily consistent, but the intent is clear. In particular, the pavement thickness design charts for the B747 airplane published in Federal Aviation Administration Advisory Circular 150/5320-6C and -6D [5] are based on ESWLs computed using 16 wheels and Alpha Factor curves for 16 wheels.

Looking at figure 1, it is clear that, in order to integrate the new Alpha Factors (0.8 and 0.72) into the ACN Pavement Classification Number (PCN) system, adjustments need to be made to the Alpha Factors for wheel numbers other than 4 and 6. The single-wheel Alpha Factor is based on a reasonably large set of full-scale tests [2] and there does not appear to be a compelling reason to change it. The two-wheel Alpha Factor was based on interpolation between the single- and four-wheel Alpha Factor curves, and it also seems reasonable not to change its value, although a reduction in its value proportionate to the reduction of the four-wheel value from 0.825 to 0.80 would also be reasonable. That is, a new Alpha Factor for two wheels, which has the same proportions relative to the new single- and four-wheel Alpha Factors as the old two-wheel Alpha Factor, has to the old single- and four-wheel Alpha Factors could be defined by:

$$\begin{aligned}\alpha_{2new} &= 0.995 - \frac{(0.995-0.900)\times(0.995-0.800)}{(0.995-0.825)} \\ &= 0.886\end{aligned} \tag{1}$$

The remaining Alpha Factors for 8 wheels and above have no basis in full-scale test data except that the C5 test data had originally been treated as a 12-wheel gear. This formed the basis for the old 12-wheel Alpha Factor with the old 6-wheel Alpha Factor being an interpolation between the 4- and 12-wheel values. But after test data had been collected with a triple-dual-tandem (3D) gear at higher coverage levels than the C5 tests, the C5 was recategorized as two six-wheel gears in tandem so the two data sets could be combined [6]. As stated above, ICAO AOSWG DP21 recommends that undefined Alpha Factors be altered "so that the ranking of damaging effect is consistent." The Alpha Factors for eight wheels and above have, therefore, been adjusted so that the ratio of ACN relative to the ACN for a six-wheel gear is, to a very good approximation, the same in the new system as in the old. The equation used to calculate the new Alpha Factors is:

$$\alpha_{Inew} \approx \left(\frac{\alpha_{Iold}}{\alpha_{6old}} \right) \times \alpha_{6new} \tag{2}$$

where:

α_{Iold} = old Alpha Factor for I number of wheels, as listed in table 1, for I = 8, 12, 18, and 24

α_{6old} = old Alpha Factor for six wheels = 0.788, as listed in table 1

α_{6new} = new Alpha Factor for six wheels = 0.720

Equation 2 is derived in a separate section below, where it is assumed that

$$\frac{ACN_{Inew}}{ACN_{6new}} = \frac{ACN_{Iold}}{ACN_{6old}}$$

Table 2 shows the new Alpha Factors as defined by full-scale test data (1, 2, 4, and 6 wheels) and from equation 2 (8, 12, 18, and 24 wheels). Adoption of the Alpha Factors in table 2 for computation of ACN was approved by ICAO on June 19, 2007, and formally adopted on October 16, 2007 (see State Letter AN 4/20.1-EB/07/26 in appendix B).

Table 2. New Alpha Factors at 10,000 Coverages

Number of Wheels	New Alpha Factor	Source of New Alpha Factor
1	0.995	Full-scale test data - Unchanged
2	0.900	Interpolation between 0.995 and 0.825 - Unchanged
4	0.800	ICAO AOSWG DP21
6	0.720	ICAO AOSWG DP21
8	0.690	From equation 2
12	0.660	From equation 2
18	0.640	From equation 2
24	0.630	From equation 2

To determine values of Alpha Factor for numbers of wheels other than those in table 2, a curve-fitting or interpolation scheme is needed. A curve-fitting computer program (CurveExpert 1.3) was used to find equations describing the relationship between the Alpha Factor (at 10,000 coverages) versus number of wheels. The best fit equation for the old Alpha Factors had the form

$$\alpha = a.b^{I}.I^{c} \tag{3}$$

where:

α = Alpha Factor
I = number of wheels
a, b, and c = curve-fitting coefficients

Figure 2 shows the old and new Alpha Factors with curve fits using equation 3 also shown. The curve fit for the old Alpha Factors is very good, but the curve fit for the new Alpha Factors is poor, particularly over the critical range of 2 to 12 wheels. This curve fit cannot, therefore, be used to compute Alpha Factor without either giving inaccurate values for the defined points (when the defined points are computed with the curve fit equation) or giving inaccurate relative values between undefined and defined points (when the undefined points are computed with the curve fit equation and the defined values are used for the defined points). Other equations give better correlation coefficients for the new Alpha Factors, but none satisfactorily solve the problem described in the previous sentence. A simple linear interpolation was, therefore, selected for computing the Alpha Factor values for numbers of wheels between those defined in table 2.

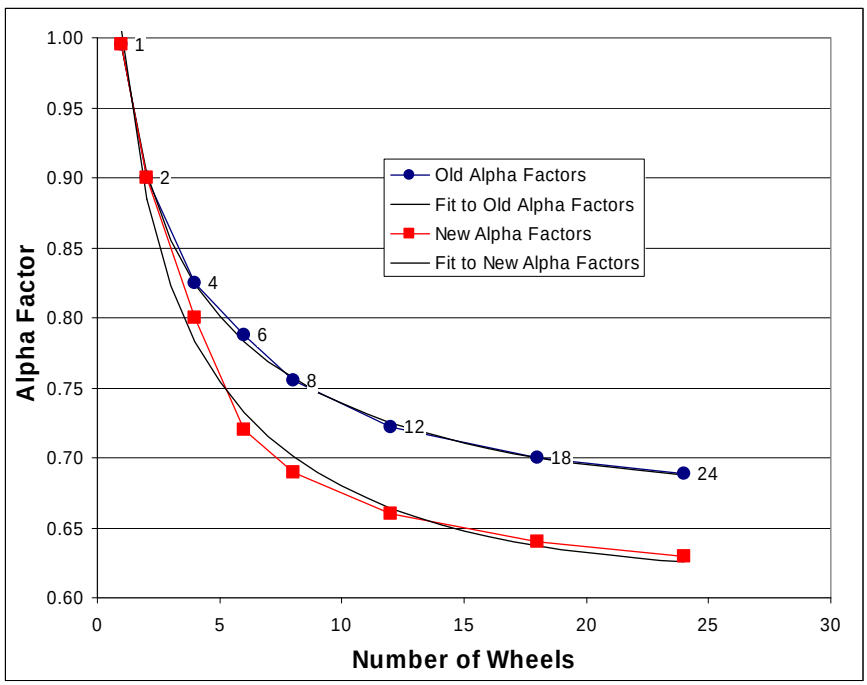

Figure 2. Old and New Alpha Factors With Curve Fits

2.1 DERIVATION OF EQUATION 2.

The equation used for thickness design of airport pavements using the CBR method (generally called the CBR equation) is:

$$t^2 = \alpha^2 \left(\frac{P}{8.1CBR} - \frac{A}{\pi} \right) = \alpha^2 \left(\frac{P.\pi - 8.1CBR.}{8.1CBR.\pi} \right) \tag{4}$$

where:

t = total pavement thickness, in.
α = load repetition factor (Alpha Factor)
CBR = subgrade strength
P = equivalent single wheel load (ESWL)
a = contact area of one tire on the gear, in.^{2}

To keep the ratio of ACN for I wheels to ACN for six wheels the same in the new system as in the old system:

$$\frac{ACN_{Inew}}{ACN_{6new}} = \frac{ACN_{Iold}}{ACN_{6old}} \tag{5}$$

The definition of ACN [1] is:

$$ACN = \frac{t_{ac}^2}{t_{ref}^2} \tag{6}$$

where:

t_{ac} = total pavement design thickness for the aircraft in question
t_{ref} = total pavement design thickness for a reference single wheel load

and therefore:

$$\frac{ACN_I}{ACN_6} = \frac{t_I^2}{t_{ref}^2} \frac{t_{ref}^2}{t_6^2} = \frac{t_I^2}{t_6^2} \tag{7}$$

Substituting for t from equation 4 (the CBR equation):

$$\begin{aligned} \frac{ACN_I}{ACN_6} &= \frac{\alpha_I^2}{\alpha_6^2} \frac{\left(P_I.\pi - 8.1CBR.A_I\right)}{8.1CBR.\pi} \frac{8.1CBR.\pi}{\left(P_6.\pi - 8.1CBR.A_6\right)} \\ &= \frac{\alpha_I^2}{\alpha_6^2} \frac{\left(P_I.\pi - 8.1CBR.A_I\right)}{\left(P_6.\pi - 8.1CBR.A_6\right)} \end{aligned} \tag{8}$$

The second terms in the parentheses are small, compared to the first terms, and:

$$\frac{ACN_I}{ACN_6} \approx \frac{\alpha_I^2}{\alpha_6^2} \frac{P_I}{P_6} \tag{9}$$

Now, from equation 5:

$$\frac{\alpha_{Inew}^2}{\alpha_{6new}^2}\frac{P_{Inew}}{P_{6new}} \approx \frac{\alpha_{Iold}^2}{\alpha_{6old}^2}\frac{P_{Iold}}{P_{6old}}$$
$$\therefore \quad \alpha_{Inew}^2 \approx \frac{\alpha_{Iold}^2}{\alpha_{6old}^2}\frac{P_{Iold}}{P_{6old}}\frac{P_{6new}}{P_{Inew}}\alpha_{6new}^2 \tag{10}$$

This equation does not have an explicit solution because P changes with pavement thickness and pavement thickness changes with the Alpha Factor. However, as is demonstrated below in a numerical example, the term $\frac{P_{Iold}}{P_{6old}}\frac{P_{6new}}{P_{Inew}}$ has a value close to one and, to a first approximation, equation 10 can be simplified to

$$\alpha_{Inew} \approx \frac{\alpha_{Iold}}{\alpha_{6old}}\alpha_{6new}$$

which is the relationship used in equation 2 to generate the new Alpha Factors listed in table 2 for 8, 12, 18, and 24 wheels.

2.2 NUMERICAL EXAMPLES.

Two numerical examples are worked through to establish how well the new Alpha Factors for 8, 12, 18, and 24 wheels maintain the same relative ACN ratios as in the old system. The first example compares two C5 airplane gear configurations. The first configuration consists of one six-wheel gear and the second configuration consists of two six-wheel gears in tandem. The 2-gear configuration is treated as a 12-wheel gear for ACN computation. The second example compares a 3D 6-wheel configuration with a 5D 10-wheel configuration. Both configurations have the same dual and tandem wheel spacing, and the 3D configuration is close to B777-300 gear geometry and wheel loading. These two examples represent two extremes of wheel configuration and wheel loading.

2.2.1 Example 1—C5 Landing Gear.

Figures 3 and 4 show screen shots from a computer program called COMFAA [7] displaying the wheel configurations for the 6- and 12-wheel cases. Gear geometry is standard, and wheel loads are 30,000 lb (133 kN). COMFAA was used to calculate ACNs with both the old and the new Alpha Factors. Tables 3 and 4 list the results for 3 CBR and 15 CBR, together with pavement thicknesses and ESWLs. The ACN ratios for old and new Alpha Factors are summarized in table 5.

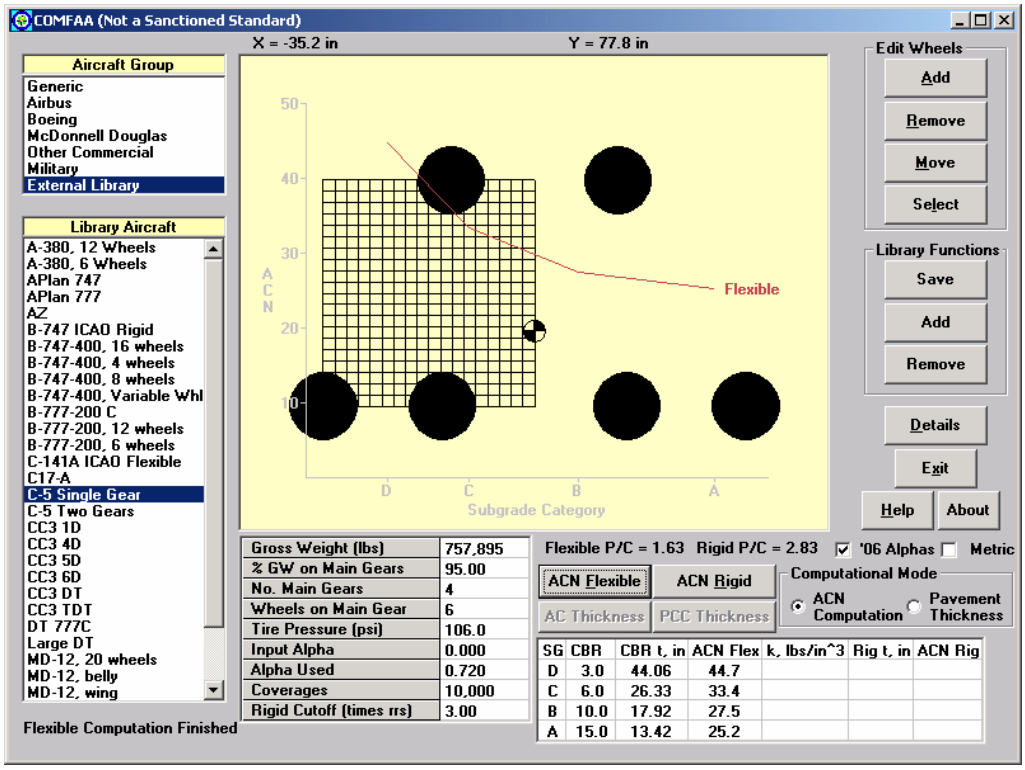

Figure 3. COMFAA Screen Shot Showing C5 Single-Gear, Six-Wheel Configuration

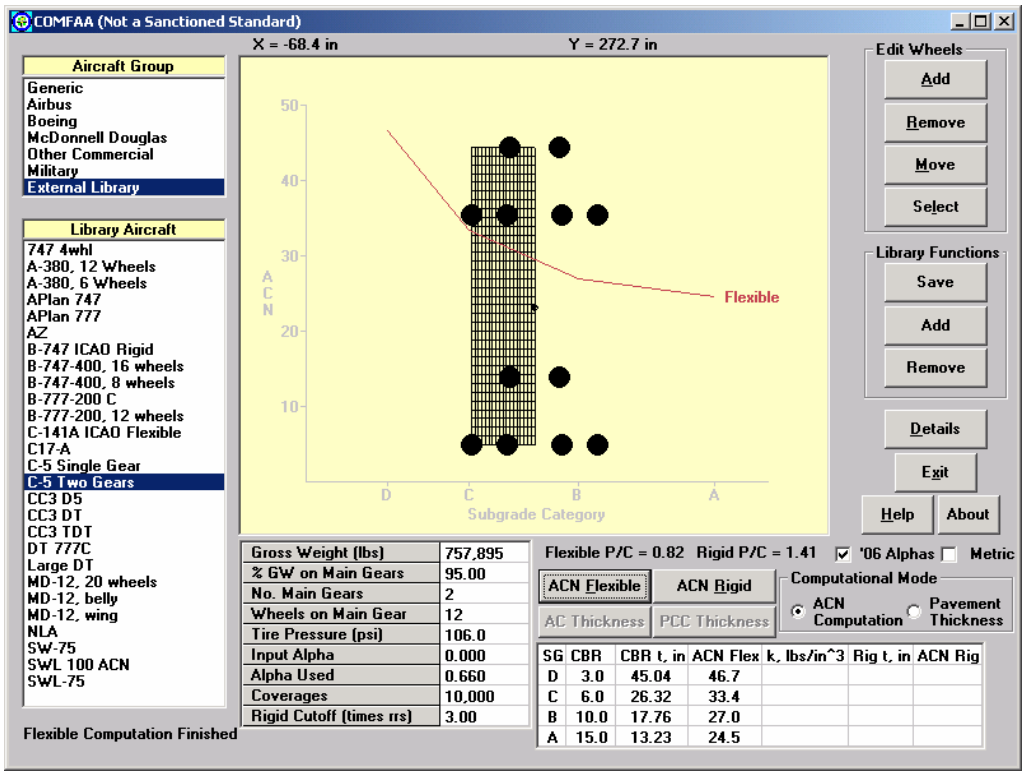

Figure 4. COMFAA Screen Shot Showing C5 Double-Gear, 12-Wheel Configuration

Table 3. The C5 ACN Results for Old Alpha Factors

Gear Configuration	CBR	ACN	Pavement Thickness (in.)	Pavement Thickness Squared ($in.^2$)	ESWL (lb)
12 Wheel	3	61.7	51.75	2678	127,111
6 Wheel	3	58.7	50.47	2547	101,903
Ratio 12Whl:6Whl		1.051	1.025	1.051	1.247
12 Wheel	15	30.9	14.84	220.2	61,702
6 Wheel	15	31.3	14.96	223.8	54,280
Ratio 12Whl:6Whl		0.987	0.992	0.984	1.137

Table 4. The C5 ACN Results for New Alpha Factors

Gear Configuration	CBR	ACN	Pavement Thickness (in.)	Pavement Thickness Squared ($in.^2$)	ESWL (lb)
12 Wheel	3	46.7	45.04	2029	115,349
6 Wheel	3	44.7	44.06	1941	93,257
Ratio 12Whl:6Whl		1.045	1.022	1.045	1.237
12 Wheel	15	24.5	13.23	175.0	59,126
6 Wheel	15	25.2	13.42	180.1	52,403
Ratio 12Whl:6Whl		0.972	0.986	0.972	1.128

Table 5. The ACN and ESWL Ratios (12whl:6whl) for C5 Gears (From tables 3 and 4)

CBR	ACN Ratio With Old Alpha Factors	ACN Ratio With New Alpha Factors	Percent Difference	$\sqrt{\frac{P_{Iold}}{P_{6old}}\frac{P_{6new}}{P_{Inew}}}$
3	1.051	1.045	0.6	1.0042
15	0.987	0.972	1.5	1.0037

2.2.2 Example 2—3D and 5D Landing Gear.

Figures 5 and 6 show the wheel configurations for the 6- and 10-wheel 3D and 5D gears. Gear geometry is 54 inches dual spacing and 57 inches tandem spacing. Wheel loads are 55,000 lb (245 kN). Tables 6 and 7 list the results for 3 CBR and 15 CBR, together with pavement

thicknesses and ESWLs. The ACN ratios for old and new Alpha Factors are summarized in table 8.

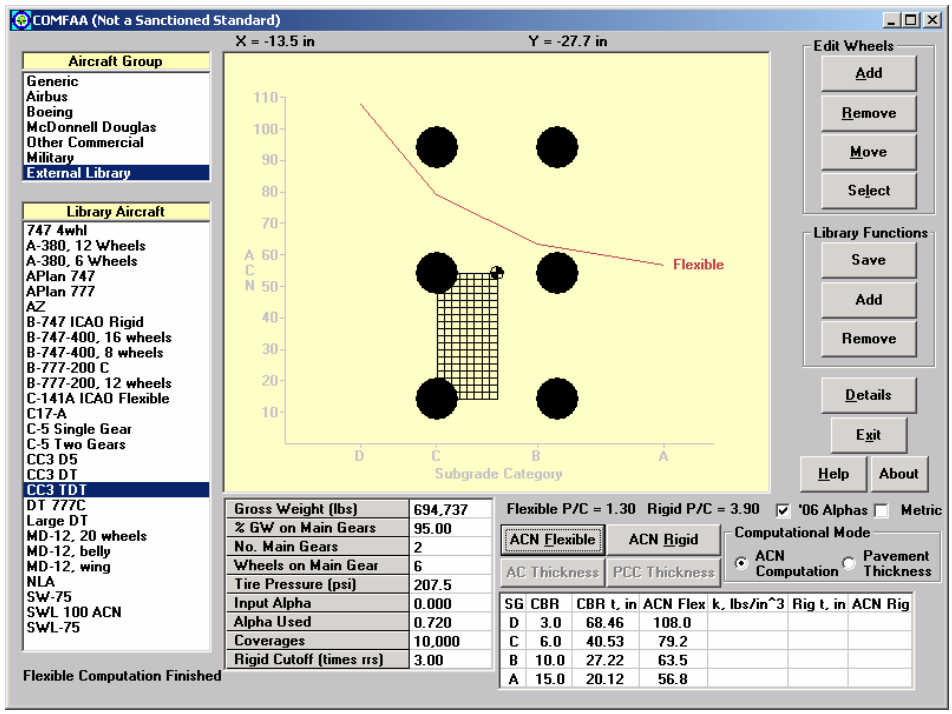

Figure 5. COMFAA Screen Shot Showing 3D Six-Wheel Gear

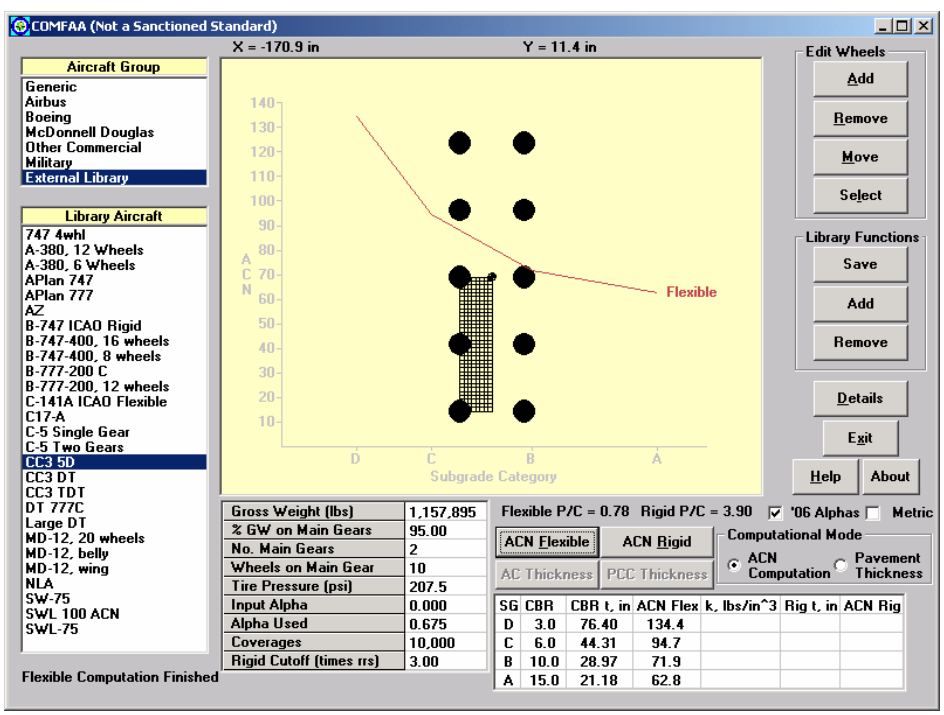

FIGURE 6. COMFAA Screen Shot Showing 5D 10-Wheel Gear

Table 6. The 3D and 5D ACN Results for Old Alpha Factors

Gear Configuration	CBR	ACN	Pavement Thickness (in.)	Pavement Thickness Squared ($in.^2$)	ESWL (lb)
10 Wheel	3	174.1	86.92	7555	338,278
6 Wheel	3	137.8	77.35	5983	235,986
Ratio 10Whl:6Whl		1.263	1.124	1.263	1.433
10 Wheel	15	81.1	24.06	578.9	139,310
6 Wheel	15	72.5	22.75	517.6	111,887
Ratio 10Whl:6Whl		1.119	1.0576	1.118	1.245

Table 7. The 3D and 5D ACN Results for New Alpha Factors

Gear Configuration	CBR	ACN	Pavement Thickness (in.)	Pavement Thickness Squared ($in.^2$)	ESWL (lb)
10 Wheel	3	134.4	76.40	5837	313,265
6 Wheel	3	108.0	68.46	4687	221,748
Ratio 10Whl:6Whl		1.244	1.116	1.245	1.413
10 Wheel	15	62.8	21.18	448.6	129,780
6 Wheel	15	56.8	20.12	404.8	105,625
Ratio 10Whl:6Whl		1.106	1.0527	1.108	1.229

Table 8. The ACN and ESWL Ratios for 3D and 5D Gears (From tables 6 and 7)

CBR	ACN Ratio With Old Alpha Factors	ACN Ratio With New Alpha Factors	Percent Difference	$\sqrt{\frac{P_{Iold}}{P_{6old}}\frac{P_{6new}}{P_{Inew}}}$
3	1.263	1.244	1.5	1.0073
15	1.119	1.106	1.2	1.0067

In both examples, the ACN ratios for the new Alpha Factors are consistently higher than those for the old Alpha Factors, but by less than 2 percent. The discrepancies are presumably due to the approximations made in deriving equation 2 and, for the second example, the linear interpolation between 8- and 12-wheel values. To determine the order of the errors in the new Alpha Factors, the new Alpha Factor for 12 wheels in example 1 was adjusted until the ACN ratio for the new Alpha Factors at 3 CBR was the same as the ACN ratio for the old Alpha

Factors at 3 CBR. This resulted in a corrected 12-wheel Alpha Factor value of 0.661 instead of the value of 0.660 from table 2. Performing the same process for example 2 resulted in a corrected 10-wheel Alpha Factor value of 0.678 instead of the value of 0.675 found by interpolating between the 8- and 12-wheel Alpha Factors in table 2. These differences are negligible and it is recommended that the values in table 2 be used for the new Alpha Factors at the indicated number of wheels and that intermediate values be found by linear interpolation.

Also noted, in example 1, the ACN of the 6-wheel gear is lower than the ACN of the 12-wheel gear at 3 CBR, but not at 15 CBR. Whereas, in example 2, the ACN of the 6-wheel gear is lower than the ACN of the 10-wheel gear at both 3 and 15 CBR. Relative ACNs are therefore not consistent among different gear configurations and subgrade strengths. It would also be expected that pavement damage would always increase as the number of wheels are increased. A major difference in the examples is that the 12-wheel C5 configuration has 2 groups of 6 wheels spaced a considerable distance apart, whereas the wheels in the 10-wheel gear of example 2 all have the same tandem spacing as the wheels in the 6-wheel gear. To get a clearer picture of the variation of ACN with number of wheels, a B747 configuration was set up with 16 wheels in the main landing gear (see figure 7). The ACN was computed for the initial configuration and repeatedly after removing single wheels in the group until only one wheel remained. Wheels were removed from right to left in one case and from the left and right sides towards the center in another case. In a third case, the 5D gear in figure 6 was extended to a 6D 12-wheel gear and ACN computed as pairs of wheels were removed from one end of the gear to the other. Figures 8, 9, and 10 show the results.

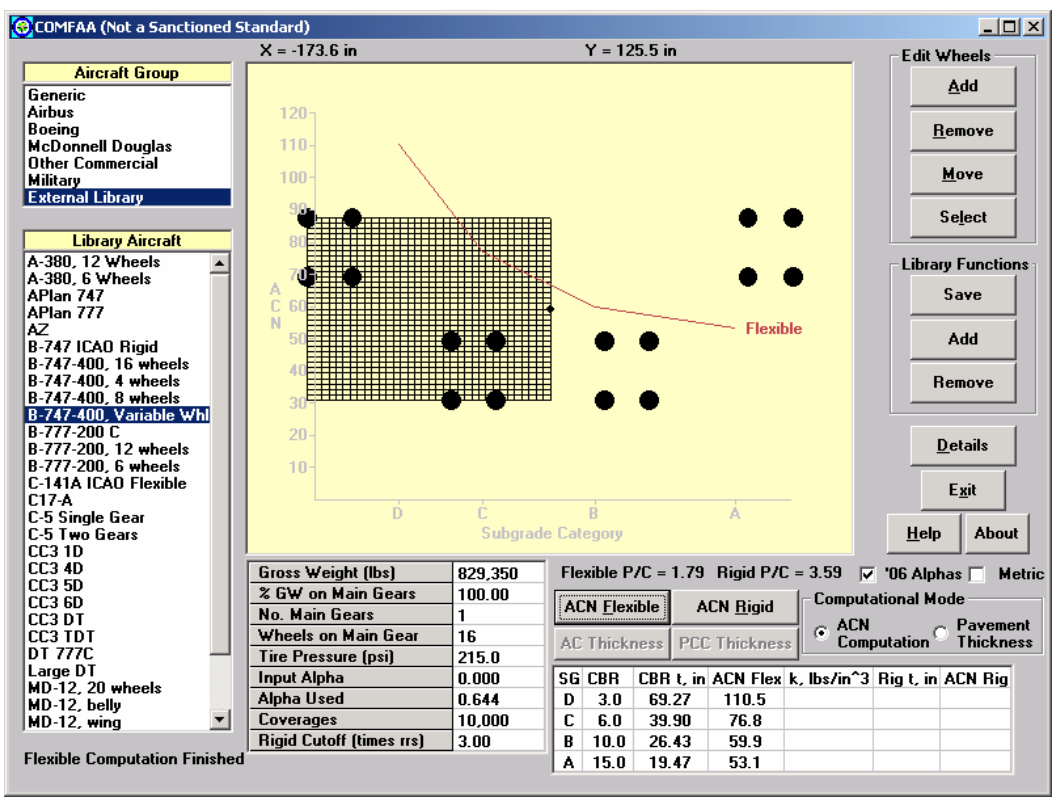

Figure 7. COMFAA Screen Shot Showing B747 16-Wheel Landing Gear

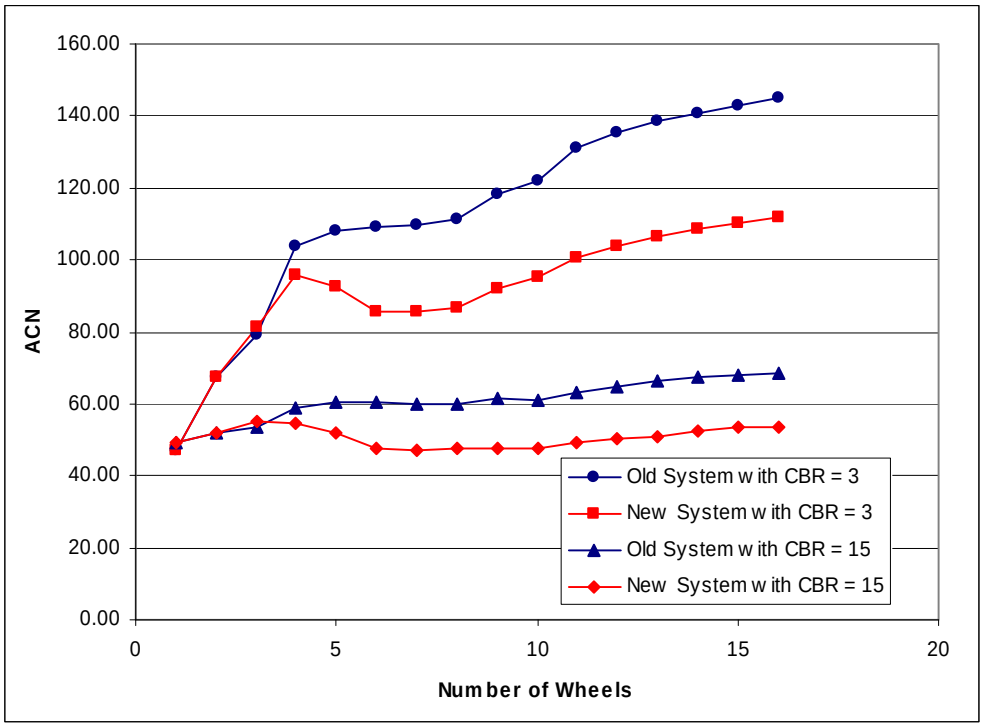

Figure 8. The ACNs for B747 Configuration—Wheels Removed From Right to Left

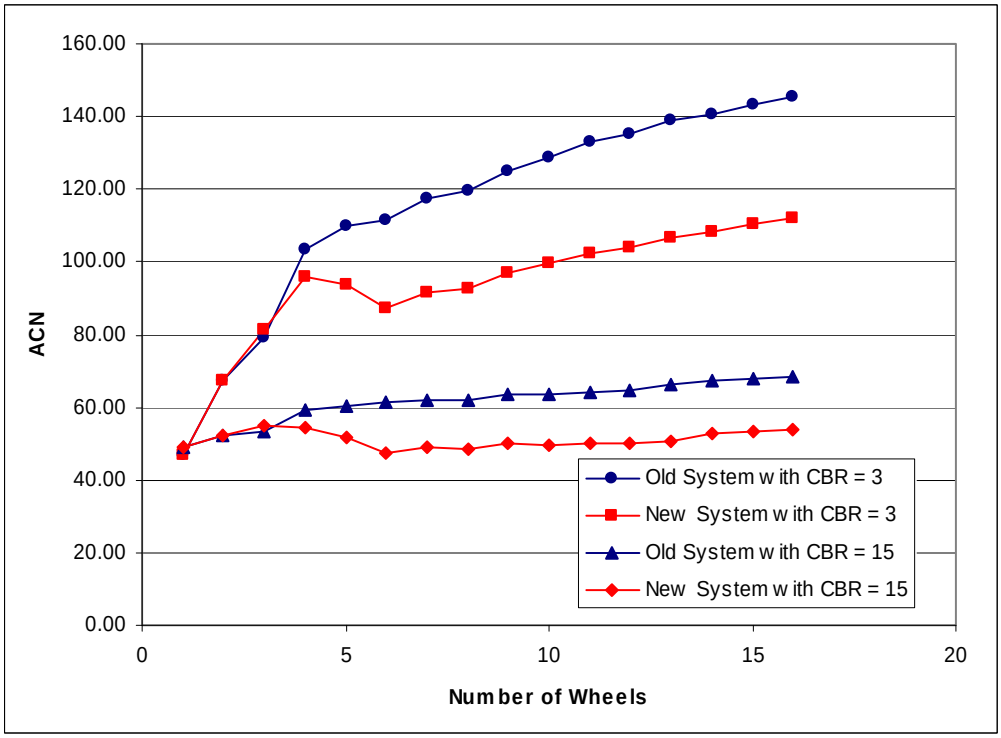

Figure 9. The ACNs for B747 Configuration—Wheels Removed From the Outside to the Center

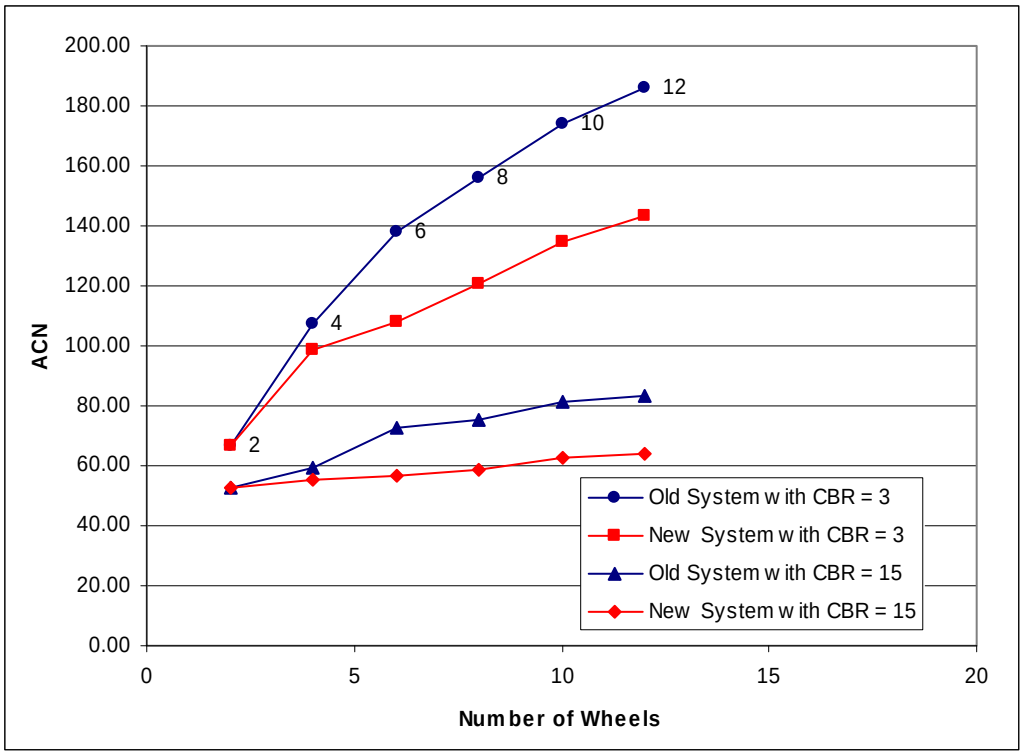

Figure 10. The ACNs for A 6D Configuration—Wheels Removed in Pairs From One End to the Other

In figure 8, with the B747 wheels removed from right to left, the old system gives ACN values that decrease almost continuously from 16 wheels to 1 wheel (the curve is almost flat from 8 to 5 wheels). But with the new system, the ACN values decrease continuously from 16 to 6 wheels and then increase significantly from 6 to 4 wheels before decreasing from 4 to 1 wheel (with almost the same values as with the old system, as is to be expected). This local minimum does not make physical sense unless the procedure is considered to be exhibiting the same kind of behavior noted in reference 8, in which case reversals in pavement damage were identified being caused by reversals in the sign of computed vertical strain with distance from the point of load application. The ACN values in figure 9, with the B747 wheels removed from the outside inward, show similar trends, but are less extreme.

In figure 10, with dual wheels removed from the 6D gear from one end to the other, the old and new systems both show continuously decreasing ACN values. The old system shows a smoother curve than the new system at 3 CBR, but the reverse is the case at 15 CBR, indicating yet again that the Alpha Factor system, as implemented in the CBR design procedure, cannot account for the effects of varying gear and pavement parameters much outside the range of the full-scale test parameters. Therefore, when applying the CBR design procedure to the computation of ACN values using the new Alpha Factor system, the wheel configurations used to compute ESWLs should be as close to the wheel configurations from which the Alpha Factors were derived in full-scale tests. This means that the wheel configuration used to compute the ACN for any particular airplane should be selected on the basis of the wheels forming a recognizable group, with the spacing between adjacent wheels being about the same for all wheels in the group. With

the exception of one or two unusual and low-damage airplanes, this is the scheme that has been followed by ICAO for computing ACNs of multiple-gear airplanes, in particular, the B747 where a single group of four wheels on the same strut is used to calculate ACN. It is recommended that the same scheme be followed when computing ACNs for other large multiple-gear airplanes such as the Airbus A380.

An alternative procedure could be adopted, such as the one investigated in reference 4, in which the vertical deflection computed by elastic theory for a single-wheel load is attenuated by a factor that decreases in value with distance from the point of application of the load. The computed deflection is multiplied by the attenuation factor, which has a value of unity directly under the wheel load and a value of zero at some specified number of tire radii from the point of load application. However, such empirically derived modifications of theoretical computations are subject to the same kind of modeling constraints as discussed above for Alpha Factors, except that the empirical modification is shifted from the traffic model (in the case of the Alpha Factor model) to the response model (in the case of the attenuation model). The attenuation model was abandoned in reference 4 because: "Analysis of traffic test data with the two gear configurations [four-wheel and twelve-wheel] did not yield values of ESWL consistent with the elastic theory or any one modification thereof. The elastic theory without modification was selected as best representing the relationship of ESWL for all multiple-wheel assemblies" (reference 4, page 55). The Alpha Factor model was then adopted to account for the apparent overestimation of ESWL for multiple-wheel gears.

3. ALPHA VERSUS COVERAGES FOR THICKNESS DESIGN.

3.1 DEVELOPMENT OF NEW RELATIONSHIPS.

Computation of ACN values requires Alpha Factors defined at only 10,000 coverages. However, to determine the airplane for which ACN is to be found typically requires that pavement thickness designs be made to determine the critical airplane for a specified mix operating on the pavement of interest (references 1 and 9). This requires the definition of Alpha Factors over the full range of coverages expected at an airport. The computer program F806FAA, published by the FAA in 1989 for flexible pavement thickness design by the CBR method [10], contains the following definitions of Alpha Factor as a function of number of wheels and $\log_{10}$(Coverages) (logCov in the code below).

```
If LogCov < 1 Then                          ' Less than 10 Coverages.

  Alpha(1) = 0.405 + 0.2 * (LogCov - 1)   ' Single.
  Alpha(2) = 0.400 + 0.2 * (LogCov - 1)   ' Dual.
  Alpha(3) = 0.395 + 0.2 * (LogCov - 1)   ' Dual tandem.
  Alpha(4) = 0.390 + 0.2 * (LogCov - 1)   ' Six wheels.
  Alpha(5) = 0.380 + 0.2 * (LogCov - 1)   ' Eight wheels.
  Alpha(6) = 0.370 + 0.2 * (LogCov - 1)   ' Twelve wheels.
  Alpha(7) = 0.360 + 0.2 * (LogCov - 1)   ' Sixteen wheels.
  Alpha(8) = 0.359 + 0.2 * (LogCov - 1)   ' Twenty four wheels.

ElseIf 1 <= LogCov And LogCov <= 4 Then   ' Between 10 and 10,000 Coverages.
```

```
  Alpha(1) = 0.405 + (LogCov - 1) * _
            (0.205 + (LogCov - 2) * (-0.0025 - 0.0025000 * (LogCov - 3)))
  Alpha(2) = 0.400 + (LogCov - 1) * _
            (0.190 + (LogCov - 2) * (-0.0125 - 0.0008330 * (LogCov - 3)))
  Alpha(3) = 0.395 + (LogCov - 1) * _
            (0.180 + (LogCov - 2) * (-0.0225 + 0.0041667 * (LogCov - 3)))
  Alpha(4) = 0.390 + (LogCov - 1) * _
            (0.175 + (LogCov - 2) * (-0.0260 + 0.0048330 * (LogCov - 3)))
  Alpha(5) = 0.380 + (LogCov - 1) * _
            (0.175 + (LogCov - 2) * (-0.0375 + 0.0141667 * (LogCov - 3)))
  Alpha(6) = 0.370 + (LogCov - 1) * _
            (0.175 + (LogCov - 2) * (-0.0350 + 0.0066670 * (LogCov - 3)))
  Alpha(7) = 0.360 + (LogCov - 1) * _
            (0.175 + (LogCov - 2) * (-0.0350 + 0.0050000 * (LogCov - 3)))
  Alpha(8) = 0.359 + (LogCov - 1) * _
            (0.171 + (LogCov - 2) * (-0.0355 + 0.0035000 * (LogCov - 3)))

ElseIf LogCov > 4 Then                    ' Greater than 10,000 Coverages.

  Alpha(1) = 0.990 + 0.1700 * (LogCov - 4)
  Alpha(2) = 0.890 + 0.1250 * (LogCov - 4)
  Alpha(3) = 0.825 + 0.0875 * (LogCov - 4)
  Alpha(4) = 0.788 + 0.0800 * (LogCov - 4)
  Alpha(5) = 0.765 + 0.0700 * (LogCov - 4)
  Alpha(6) = 0.725 + 0.0500 * (LogCov - 4)
  Alpha(7) = 0.705 + 0.0375 * (LogCov - 4)
  Alpha(8) = 0.680 + 0.0200 * (LogCov - 4)
End If
```

Each curve of Alpha Factor versus coverages is divided into three separate functions that are continuous at the changeover points (10 and 10,000 coverages). Figure 11 shows the curves plotted in the range 1 to 1,000,000 coverages. The curve marked "Base" is the linear equation, $\alpha = 0.23 \times$ coverages $+ 0.15$, in use before the introduction of Alpha Factors.

The same equations were implemented in the computer program COMFAA, except that the curve for 8 wheels was deleted because it does not have the same trend as the other curves and does not fit uniformly between the 6- and 12-wheel curves. To find the Alpha Factor for a number of wheels other than those in the F806FAA set, COMFAA does a cubic spline fit through the defined Alpha Factor curve values at the $\log_{10}$(Coverages) of interest and then interpolates at the desired number of wheels. Therefore, COMFAA is compatible with the previous FAA methods for flexible pavement design by the CBR method but is applicable in a consistent manner for pavement design with any number of wheels up to a maximum of 24. With the change in the defined Alpha Factors at 10,000 coverages for ACN computation, the thickness design portion of COMFAA required modification to be compatible with the ACN portion.

As described in references 6 and 11, and from ICAO panel deliberations, the new Alpha Factors at 10,000 coverages for four- and six-wheel gears were derived from quadratic curve fits to the full-scale test data. These curve fits are only valid within the range of the test data, and an alternative procedure was developed to extrapolate outside the range of the test data in a simple and consistent manner.

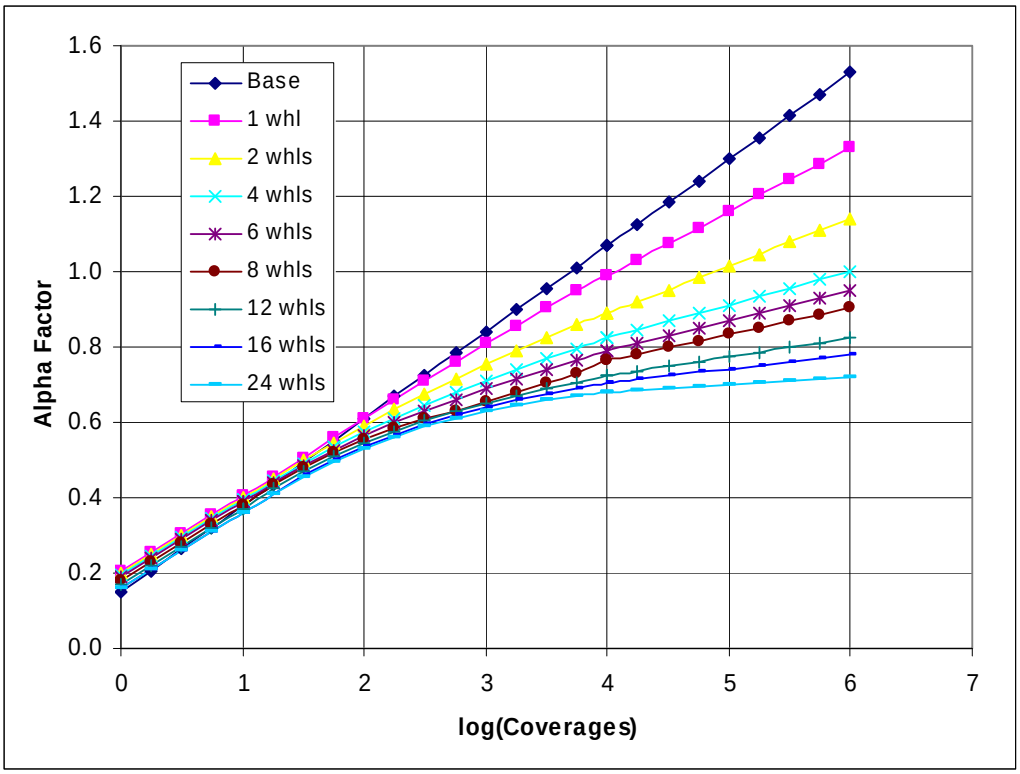

Figure 11. Alpha Factor vs $\log_{10}$(Coverages) as Implemented in Computer Program F806FAA

Tables 9 and 10 show the full-scale test data from references 4 and 11 used to determine the Alpha Factor curves for an assumed equivalency of 1.4 between standard quality base and subbase materials [11].

Table 9. Alpha Factor vs Coverages From Four-Wheel Full-Scale Test Data

Test Series	Coverages to Failure	$\log_{10}$(Coverages)	Alpha Factor
MWHGL, 4-Whl	40	1.602	0.524
MWHGL, 4-Whl	40	1.602	0.538
NAPTF, 4-Whl	55.9	1.747	0.634
MWHGL, 4-Whl	280	2.447	0.621
NAPTF, 4-Whl	1,258	3.100	0.745
NAPTF, 4-Whl	5,825	3.765	0.818
NAPTF, 4-Whl	9,223	3.965	0.774
NAPTF, 4-Whl	16,949	4.229	0.803

Table 10. Alpha Factor vs Coverages From Six-Wheel Full-Scale Test Data

Test Series	Coverages to Failure	$\log_{10}$(Coverages)	Alpha Factor
MWHGL, 6-Whl	8	0.903	0.362
NAPTF, 6-Whl	57.3	1.758	0.517
MWHGL, 6-Whl	104	2.017	0.572
NAPTF, 6-Whl	1,009	3.004	0.645
MWHGL, 6-Whl	1,500	3.176	0.667
MWHGL, 6-Whl	1,500	3.176	0.684
NAPTF, 6-Whl	8,280	3.918	0.736
NAPTF, 6-Whl	12,739	4.105	0.693

The curve-fitting computer program CurveExpert 1.3 was used to select the best-fitting function in terms of goodness of fit and applicability to representing Alpha Factor as a function of $\log_{10}$(Coverages) for pavement design. The function selected is called Exponential Association (3) in the CurveExpert program and is defined by equation 11.

$$\alpha = a\left(b - e^{-c.\log(\text{Coverages})}\right) \tag{11}$$

Figures 12 and 13 show screen shots of the output from the program. The coefficients a, b, and c corresponding to figures 12 and 13 are listed in table 11.

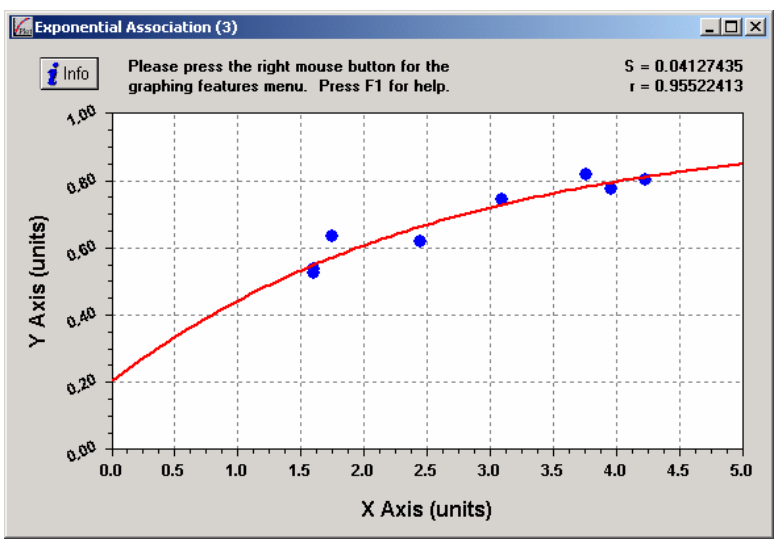

Figure 12. Four-Wheel Alpha Factor vs $\log_{10}$(Coverages) From Curve Fit Program for the Exponential Association (3) Function

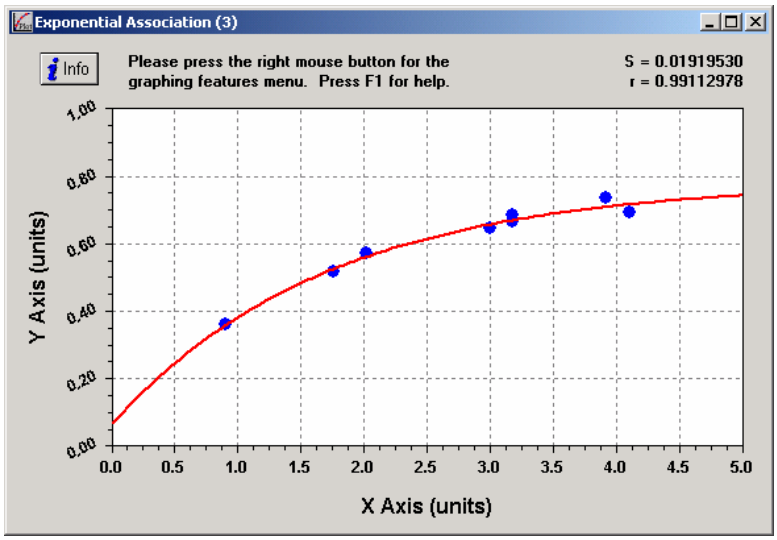

Figure 13. Six-Wheel Alpha Factor vs $\log_{10}$(Coverages) From Curve Fit Program for the Exponential Association (3) Function

Table 11. Coefficients for the Exponential Association (3) Function Curve Fits in Figures 12 and 13

Coefficient	Four-Wheel Data	Six-Wheel Data
a	0.759554	0.714537
b	1.269902	1.093644
c	0.378882	0.586352

Figure 14 shows the two curves plotted on the same graph together with the base curve from figure 11 and the quadratic curves from reference 11. It can be seen that the exponential association curves agree very well with the quadratic curves over the range of the full-scale test data (about 10 to 15,000 coverages, or 1 to 4.2 $\log_{10}$(Coverages)). But, outside the range of the test data, the two sets of curves diverge significantly. Coverage levels below 10 are of relatively little interest, particularly for commercial operations. Coverage levels from 15,000 to 100,000 and higher are, however, well within normal commercial operations at large airports. Figure 14 demonstrates clearly that the quadratic curves are not suitable for extrapolation outside the range of the test data. The design program F806FAA extrapolates outside the range of the test data with linear functions of $\log_{10}$(Coverages), and it is considered that this is a reasonable strategy at low coverage levels. However, at high coverage levels, it seems more reasonable to continue the curved characteristic evident within the range of the test data, as long as the slope does not become negative, as can happen with the quadratic curves. The exponential association curve has a very simple and well-defined characteristic at all coverage levels beyond 10,000 when constrained to pass through a defined Alpha Factor at 10,000 coverages. On this basis, and considering that it appears to be a physically reasonable continuation of the existing test data, the exponential association curve was selected for extrapolation at high coverage levels.

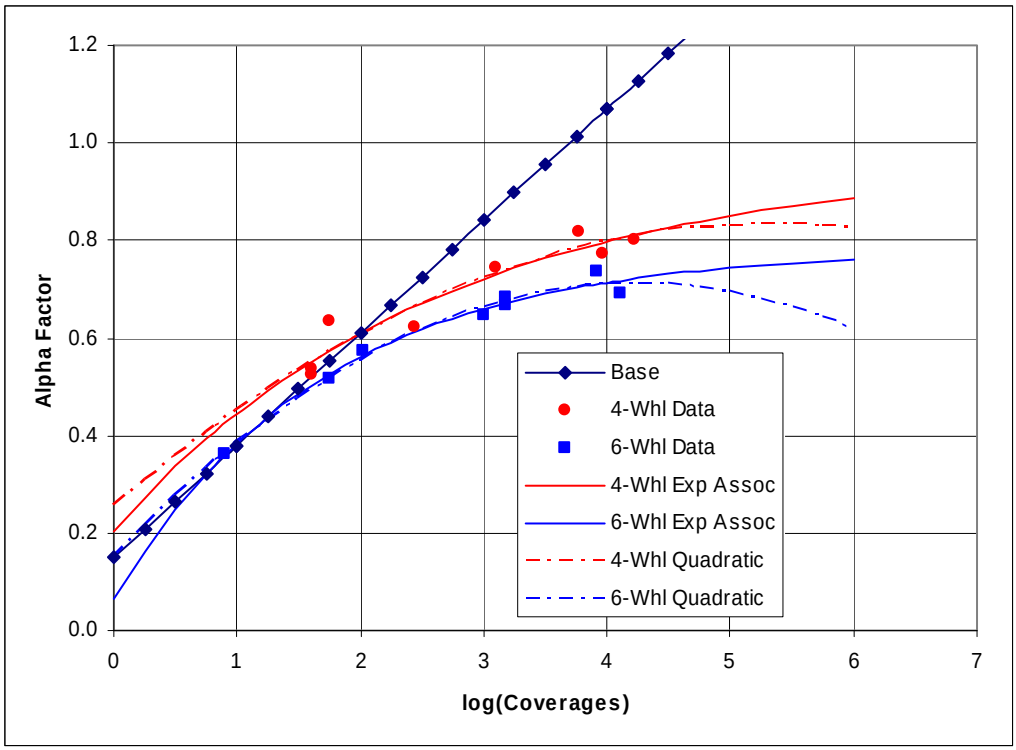

Figure 14. Four- and Six-Wheel Alpha Factor vs $\log_{10}$(Coverages) Showing Raw Data and Quadratic and Exponential Association (3) Curves

To make the COMFAA thickness designs compatible with the Alpha Factor values at 10,000 coverages of table 2, the exponential association curve for any number of wheels is constrained to pass through the point defined by the Alpha Factor value in the table (or linearly interpolated from the values in the table) and $\log_{10}$(Coverages) = 4.0. At the low end, the curves for all numbers of wheels are constrained to pass through the points $\log_{10}$(Coverages) = 0.0, Alpha Factor = 0.1; and $\log_{10}$(Coverages) = 1.0, Alpha Factor = 0.38.

3.2 DERIVATION OF THE CONSTRAINT EQUATIONS.

The Alpha Factor versus coverages curve is defined by:

$$\alpha = a\left(b - e^{-c.LogCov}\right) \tag{12}$$

where:

α = Alpha Factor
A, *b*, and *c* = curve fitting coefficients
LogCov = $\log_{10}$(Coverages)

When coverages = 1.0, *LogCov* = 0.0, $\alpha_0 = a(b - 1)$, and

$$a.b = \alpha_0 + a \tag{13}$$

When coverages = 10, *LogCov* = 1.0, and

$$\alpha_1 = a\left(b - e^{-c}\right) \tag{14}$$

When coverages = 10,000, *LogCov* = 4.0, and

$$\alpha_4 = a\left(b - e^{-4c}\right) \tag{15}$$

where α_4 is found from table 2 for the number of wheels of interest.

Rearranging equation 14 and substituting for *a.b* from equation 13 gives:

$$e^{-c} = \frac{\alpha_0 + a - \alpha_1}{a}$$

and

$$-c = \ln\left(\frac{\alpha_0 + a - \alpha_1}{a}\right) \tag{16}$$

Rearranging equation 15 and substituting for *a.b* from equation 13 gives:

$$e^{-4c} = \frac{\alpha_0 + a - \alpha_4}{a}$$

and

$$-c = \frac{1}{4}\ln\left(\frac{\alpha_0 + a - \alpha_4}{a}\right) \tag{17}$$

Subtracting equation 17 from equation 16 gives:

$$\ln\left(\frac{\alpha_0 + a - \alpha_4}{a}\right) - \frac{1}{4}\ln\left(\frac{\alpha_0 + a - \alpha_4}{a}\right) = 0 \tag{18}$$

Equation 18 can be solved iteratively for the coefficient *a*. Coefficient *b* is then found from equation 13, *c* is found from equation 16 or 17, and the Alpha Factor for the number of wheels of interest at *LogCov* ($\log_{10}$(Coverages)) is found from equation 12. A Microsoft® Visual Basic® function routine implementing this procedure is listed in appendix A.

Figure 15 shows the new Alpha Factor curves versus $\log_{10}$(Coverages) for four- and six-wheel gears. The raw data for the single-wheel test data from reference 2 has also been included in the figure (see table 12) and extrapolation below $\log_{10}$(Coverages) = 1.0 is along the base curve. In comparison with the best fit curves of figure 14, the six-wheel curve in figure 15 is almost identical with that of figure 14. The four-wheel curves in figures 14 and 15 correspond closely above 1000 coverages, but diverge below that value. The four-wheel curve in figure 15 could be made to match better with that in figure 14, below 1000 coverages, by making α_1 a function of the number of wheels to provide a spread in the curves similar to that shown in figure 11.

However, this would probably be an unnecessary complication. Quoting again from reference 4, page 71:

> "The unique limiting curve shown [in figure 82] from 1 to 100 passes represents a composite of the single, twin-tandem, and 12-wheel curves shown in figure 80. Actually, the composite curve for the very low operational level is used for convenience because there is such a small difference in repetitions effect and because it is difficult to differentiate failure at a low operational level."

The wide scatter of the single-wheel raw data shown in figure 15 at low coverages supports these comments.

Figure 16 shows Alpha Factor versus $\log_{10}$(Coverages) for constrained exponential association (3) curves and the corresponding curves from the F806 program (see figure 11). Curves are shown only for the single- and four-wheel gears because the new and old curves for six wheels and higher diverge too much at 10,000 coverages for the shape comparison to have any real meaning. The single-wheel curves are almost identical below 10,000 coverages and show minimal divergence at higher coverage levels, with the new curve being less conservative than the old curve for thickness design. The four-wheel curves show a similar correspondence, except that the divergence above 10,000 coverages is exaggerated by the enforced difference of 0.25 at 10,000 coverages.

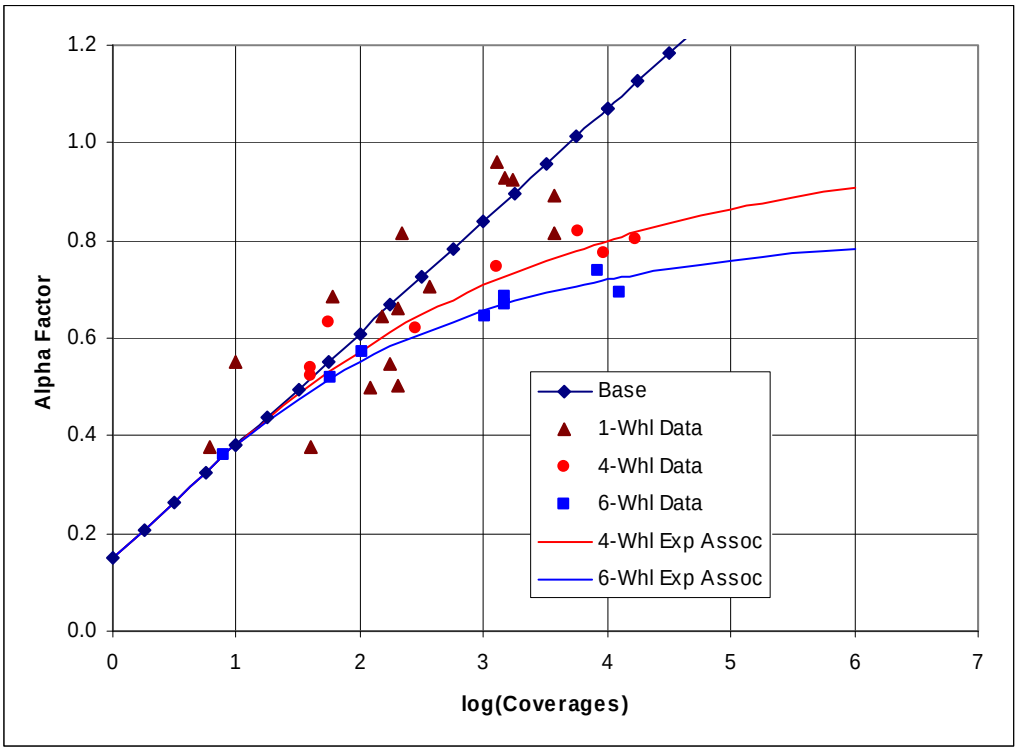

Figure 15. Four- and Six-Wheel Alpha Factor vs $\log_{10}$(Coverages) Showing Raw Data and Constrained Exponential Association (3) Curves

Table 12. Alpha Factors vs Coverages From Single-Wheel Full-Scale Test Data [2]

Wheel Load, (kips)	Subgrade CBR	Coverages to Failure	$\log_{10}$(Coverages)	Alpha Factor
200	6.0	150	2.176	0.646
200	9.0	1700	3.230	0.924
200	16.0	10	1.000	0.550
200	18.0	60	1.778	0.686
200	15.5	360	2.556	0.704
200	17.5	1500	3.176	0.930
200	8.0	1300	3.114	0.959
15	8.0	3760	3.575	0.813
15	9.0	3760	3.575	0.893
50	3.7	6	0.778	0.378
50	4.4	200	2.301	0.662
30	3.7	120	2.079	0.497
30	14.0	216	2.334	0.816
30	7.0	178	2.250	0.548
30	6.0	203	2.307	0.502
10	6.0	40	1.602	0.376

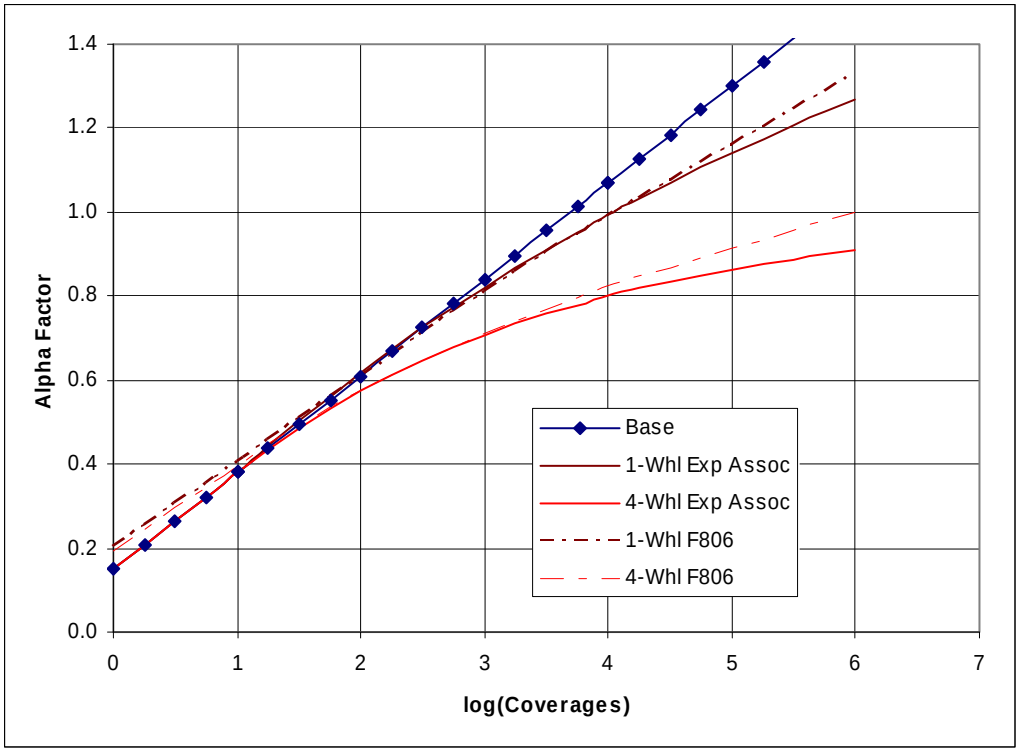

Figure 16. Single- and Four-Wheel Alpha Factor vs $\log_{10}$(Coverages) Showing Constrained Exponential Association (3) Curves and the Corresponding Curves From the F806 Program

Finally, figure 17 shows the family of new Alpha Factor constrained exponential association curves corresponding to the old F806FAA curves shown in figure 11. Curves for any other number of wheels can be found by linear interpolation between the values of Alpha Factor given in table 2 and the application of equation 11 as described above.

For thickness design of flexible pavements, it is recommended that the design be based on the number of wheels that gives the thickest pavement out of all combinations of wheels from the complete main landing gear group. This will maintain compatibility with the CBR flexible pavement thickness design procedure as specified in reference 4.

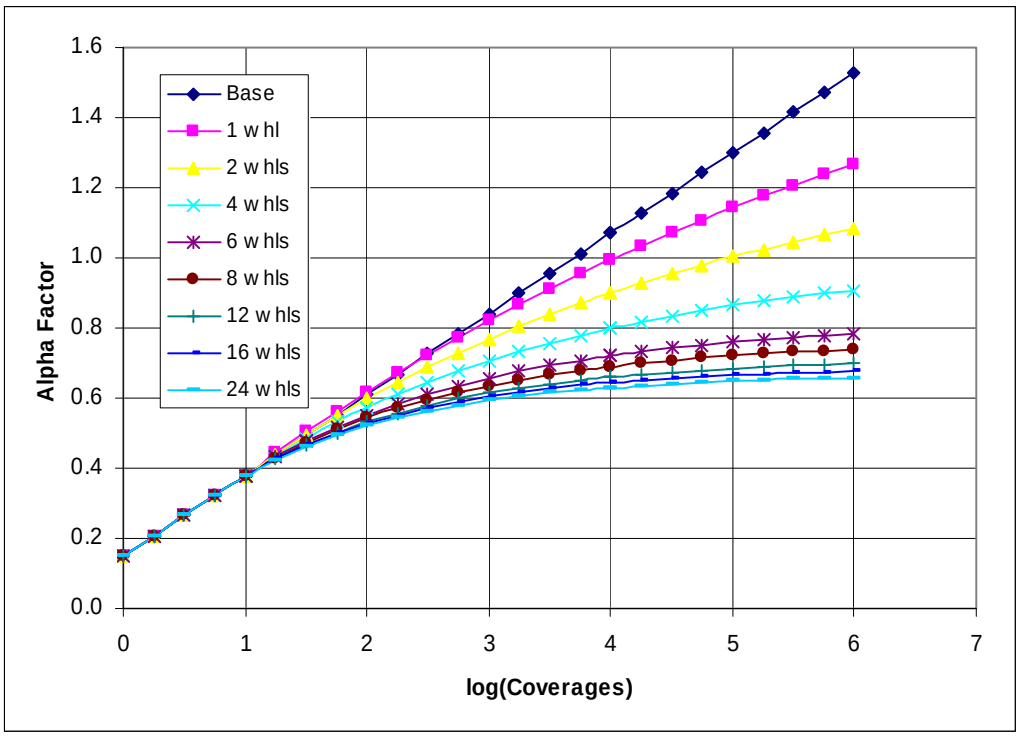

Figure 17. Family of Constrained Exponential Association (3) Alpha Factor vs $\log_{10}$(Coverages) Curves for Use in COMFAA

4. SUMMARY.

ICAO proposed that new Alpha Factors for four- and six-wheel gears at 10,000 coverages be defined for use in calculating the ACN of airplanes operating on flexible pavements. The new Alpha Factors are 0.800 and 0.720, replacing the old values of 0.825 and 0.788. The new values are based on an analysis of an expanded set of full-scale test data for four- and six-wheel traffic. With these changes, Alpha Factors at other numbers of wheels, and over the full range of coverages for design, required redefinition to maintain consistency in the CBR procedure for flexible pavement thickness design, as required for ACN calculations, even though additional full-scale test data is only available for four- and six-wheel gears. In fact, full-scale test data is not available at all for gears with more than six wheels. The Alpha Factors have been redefined as follows:

1. The standard set of Alpha Factors at 10,000 coverages for 1, 2, 4, 6, 8, 12, 18, and 24 wheels have the new values 0.995, 0.900, 0.800, 0.720, 0.690, 0.660, 0.640, and 0.630. The values for one and two wheels are unchanged from the old set because the old values were based on existing full-scale test data. The values for more than six wheels were derived based on maintaining a consistent ranking of damaging effect, as recommended in ICAO AOSWG Discussion Paper No. 21. This was done by making the ratio of ACN for the higher numbers of wheels to ACN for six wheels in the new set of values approximately the same as in the old set of values. Adoption of these new Alpha Factors for computation of ACN was approved by ICAO on June 19, 2007, and formally adopted on October 16, 2007 (see appendix B).

2. Alpha Factors at 10,000 coverages for numbers of wheels other than those in the standard set (in item 1 above) should be found by linear interpolation between the two closest numbers of wheels in the standard set.

3. It is recommended that the wheel configuration used to compute the ACN for any particular airplane should be selected on the basis of the wheels used in the computation forming a recognizable group, with the spacing between adjacent wheels being about the same for all wheels in the group. This is compatible with current ICAO ACN calculations for multiple-gear airplanes.

4. A new set of functions was established for describing the variation of Alpha Factor with coverages over the full range of 1 to 24 wheels. The functions are defined by an exponential equation constrained to pass through the points:

   a. Alpha Factor as defined in items 1 and 2 above and coverages = 10,000.
   b. Alpha Factor = 0.38 and coverages = 10.
   c. Alpha Factor = 0.1 and coverages = 0.

5. If the new set of functions is to be used for flexible pavement thickness design, it is recommended that the design be based on the number of wheels that gives the thickest pavement out of all combinations of wheels from the complete main landing gear group. This is compatible with the CBR flexible pavement thickness design procedure as recommended by the U.S. Army Corps of Engineers and as implemented by the FAA for multiple-gear airplanes.

6. The methodology for defining, and computing, Alpha Factors at any level of coverages and for any number of wheels, up to 24, described by items 1, 2, and 4 above, was implemented in the computer program COMFAA. The program computes thickness and ACN for flexible pavements based on the new Alpha Factors.

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3. Pereira, A. Taboza, Instruction Report S-77-1, "Procedures for Development of CBR Design Curves," U.S. Army Engineer Waterways Experiment Station, CE, June 1977.

4. Ahlvin, R.G., Ulery, H.H., Hutchinson, R.L., and Rice, J.L., Technical Report S-71-17, "Multiple-Wheel Heavy Gear Load Pavement Tests, Vol. 1, Basic Report," U.S. Army Engineer Waterways Experiment Station, CE, June 1971.

5. FAA Advisory Circular 150/5320-6C and -6D, "Airport Pavement Design and Evaluation."

6. Hayhoe, Gordon F., "Alpha Factor Determination Using Data Collected at the National Airport Pavement Test Facility," FAA report DOT/FAA/AR-06/7, March 2006.

7. Kawa, Izydor and Hayhoe, Gordon F., "Development of a Computer Program to Compute Pavement Thickness and Strength," in Proceedings of the 2002 FAA Worldwide Airport Technology Transfer Conference, Atlantic City, New Jersey, May 2002.

8. Rodway, Bruce, Wardle, Leigh, J, and Wickham, Gary, "Interaction Between Wheels and Wheel Groups of New Large Aircraft," 1999 FAA Airport Technology Transfer Conference, Atlantic City, New Jersey, April 1999.

9. FAA Advisory Circular 150/5335-5A, "Standardized Method of Reporting Airport Pavement Strength – PCN."

10. FAA Engineering Brief No. 43, "Computerized Pavement Design," FAA Engineering Specifications Division, AAS-200, April 1989.

11. Hayhoe, Gordon F., "Subgrade CBR Values for Alpha Factor Determination Using Data Collected at the National Airport Pavement Test Facility," FAA report DOT/FAA/TN-07/14, April 2007.

APPENDIX A—VISUAL BASIC FUNCTION ROUTINE FOR COMPUTING ALPHA FACTOR

```
Function New06AlphaFactorFromCurve(NW As Integer, Coverages As Double) As Double

' NW = number of wheels.
  Dim I As Long
  Dim A As Double, B As Double, C As Double
  Dim A0 As Double, A1 As Double, A4 As Double
  Dim LogCovA0 As Double, LogCovA1 As Double, LogCovA4 As Double
  Dim A4define() As Double, NWA4define() As Long, NA4define As Long
  Dim Resid As Double, ResidM1 As Double, DelA As Double, Slope As Double

' Fixed points to define alpha versus log(coverages) curves.
' log(coverage) values.
  LogCovA0 = 0:  LogCovA1 = 1:  LogCovA4 = 4
' Alphas at log(coverages)
  A0 = 0.1:  A1 = 0.38  ' A4 = derived from new set of alphas at 10,000 coverages.

' Incremental damage relative to six-wheels the same as old alphas for higher than 6-
wheels.
  NA4define = 8 ' Number of defined values of alpha at 10,000 coverages.
' NWA4define() = number of wheels. A4define = alpha for NWA4define wheels.
  ReDim NWA4define(NA4define), A4define(NA4define)
  NWA4define(1) = 1:     NWA4define(2) = 2:     NWA4define(3) = 4
  NWA4define(4) = 6:     NWA4define(5) = 8:     NWA4define(6) = 12
  NWA4define(7) = 18:    NWA4define(8) = 24
    A4define(1) = 0.995:   A4define(2) = 0.9:     A4define(3) = 0.8
    A4define(4) = 0.72:    A4define(5) = 0.69:    A4define(6) = 0.66
    A4define(7) = 0.64:    A4define(8) = 0.63

  If NW < NWA4define(1) Then ' Should never happen. Would be an error.
    New06AlphaFactorFromCurve = A4define(1)
    Exit Function
  End If

  If Coverages < 10 Then ' Lower end of curves is independent of number of wheels.
    New06AlphaFactorFromCurve = 0.15 + 0.23 * Log10(Coverages)
    Exit Function
  End If

' Linear interpolation for undefined alpha factors at 10,000 coverages.
  For I = 1 To NA4define - 1
    If NW < NWA4define(I + 1) Then
      Slope = (A4define(I + 1) - A4define(I)) / _
               CDbl(NWA4define(I + 1) - NWA4define(I))
      A4 = A4define(I) + Slope * CDbl(NW - NWA4define(I))
      Exit For
    Else
      A4 = A4define(NA4define)
    End If
  Next I

' Find the coefficients of the defining exponential association (3) curve
' Alpha = A * (B - e^(-C * log10(Coverages))), (see CurveExpert program).
' Solve for Resid function (below) by Newton's method.
  A = A4 - A0 + 0.1 ' The second log argument is -ve if A < A4 - A0.
  DelA = A / 1000

  ResidM1 = Log((A0 + A - A1) / A) / LogCovA1 - Log((A0 + A - A4) / A) / LogCovA4
  Do
    A = A + DelA
```

```
    Resid = Log((A0 + A - A1) / A) / LogCovA1 - Log((A0 + A - A4) / A) / LogCovA4
    A = A - Resid * DelA / (Resid - ResidM1)
    If A < A4 - A0 + 0.001 Then
      A = A4 - A0 + 0.001 ' Jumped too far because of nonlinearity.
    End If
    ResidM1 = Log((A0 + A - A1) / A) / LogCovA1 - Log((A0 + A - A4) / A) / LogCovA4
    DoEvents ' In case the iteration does not terminate. Allows interruption.
  Loop Until Abs(ResidM1) < 0.000001

  B = A0 / A + 1
  C = -Log((A0 + A - A4) / A) / LogCovA4

  New06AlphaFactorFromCurve = A * (B - Exp(-C * Log10(Coverages)))

End Function
```

APPENDIX B—THE ICAO STATE LETTER ADOPTING THE NEW ALPHA FACTORS

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Ref.: AN 4/20.1-EB/07/26 16 October 2007

Subject: Revised alpha factor values for the computation of Aircraft Classification Number (ACN) on flexible pavements

Action required: a) States to note; and b) Aircraft manufacturers to revise ACN values in Table A5-1, *Aerodrome Design Manual*, Part 3 — *Pavements* (Doc 9157)

Sir/Madam,

1. I have the honour to inform you that the Air Navigation Commission, during the fourteenth meeting of its 175th Session held on 19 June 2007, approved Recommendation 4/3 developed by the first meeting of the Aerodromes Panel (AP/1) concerning revised alpha factor values for the computation of Aircraft Classification Number (ACN) and authorized their transmittal to States and international organizations.

2. Currently ICAO Annex 14 — *Aerodromes*, Volume I — *Aerodrome Design and Operations*, paragraph 2.6.4 specifies that the ACN of an aircraft shall be determined in accordance with the standard procedures associated with the Aircraft Classification Number – Pavement Classification Number (ACN-PCN) method. Guidance for determining the ACN of an aircraft can be found in *Aerodrome Design Manual,* Part 3 — *Pavements* (Doc 9157).

3. The alpha factor, or pavement thickness reduction factor, is used to take into account the effect of gear geometry in computing pavement design curves for flexible pavements. The original deflection-based design method overstated the damage caused by multi-wheel gears and this was later corrected by introducing the alpha factor.

4. Studies undertaken in some States had indicated that the classical pavement design theories could not correctly predict the behaviour of soils under the pavement when the design curves for dual-tandem landing gears were extrapolated for main landing gears with six wheels. Additionally, there was a lack of data points on the original alpha factor curve and any extrapolation results in a higher value

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of the alpha factor, thus predicting higher stresses in the pavement, whereas the additional set of wheels were intended to distribute the load better.

5. In order to resolve the above technical anomaly, some States had decided to carry out full scale pavement tests. In the meantime, an interim alpha factor of 0.72 for six-wheels per main landing gear would be used by aircraft manufacturers, until such time the results of the tests were available.

6. Recent findings of full scale pavement tests conducted by one State had been reviewed by the Aerodromes Panel. The Commission, based on advice of the panel, agreed to the following revisions concerning the alpha factor values:

a) change the alpha factor value for all four-wheels per main landing gear from the current 0.825 to 0.80;

b) retain the alpha factor value for six-wheels per main landing gear at 0.72; and

c) change the alpha factors for other main landing gears so that the ranking of the damaging effect remains consistent.

7. In light of the above, a table of revised alpha factor values is attached to this State letter. Aircraft manufacturers are requested to revise the ACN values for their respective aircraft types on various subgrade categories, currently available as guidance material in Doc 9157, Part 3, Table A5-1.

Accept, Sir/Madam, the assurances of my highest consideration.

Taïeb Chérif
Secretary General

Enclosure:
Revised alpha factor values

ATTACHMENT to State letter AN 4/20.1-EB/07/26

REVISED ALPHA FACTOR VALUES

Number of Wheels	Current Alpha Factor	Revised Alpha Factor
1	0.995	0.995
2	0.900	0.900
4	0.825	0.800
6	0.788	0.720
8	0.755	0.690
12	0.722	0.660
18	0.700	0.640
24	0.689	0.630

— END —