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Alpha Factor Determination Using Data Collected at the National Airport Pavement Test Facility

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16. Abstract

Full-scale test data for multiple-wheel, heavy gear load (MWHGL) loading of flexible airport pavements are summarized from three separate test series: one test series, the MWHGL tests, was conducted by the U.S. Army Corps of Engineers (USACE), and the other two series of tests were conducted by the Federal Aviation Administration (FAA) at the National Airport Pavement Test Facility (NAPTF). The MWHGL pavement structural configuration was used as the reference, and all NAPTF structures were converted to equivalent reference structures by the use of thickness equivalency factors relating the NAPTF and the MWHGL structural materials. Load repetition factors (alpha factors), required for the computation of pavement thickness by the California Bearing Ratio (CBR) design procedure for flexible airport pavements, were calculated for the NAPTF test data and plotted with the MWHGL alpha factors. Least squares quadratic curve fits were computed for the four- and six-wheel alpha factors, and the alpha factors at 10,000 coverages were computed for comparison with the International Civil Aviation Organization (ICAO) standard for computing Aircraft Classification Number (ACN). The results of the analysis are consistent with the existing alpha factor of 0.825 for four-wheel gears, but the results of the analysis are not consistent with the existing alpha factor of 0.788 for six-wheel gears. The six-wheel alpha factor at 10,000 coverages should be changed to a value approximately equal to the interim value of 0.72 adopted by the ICAO for calculating ACN for six-wheel gears.

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LIST OF ACRONYMS

AC	Advisory Circular
ACN	Aircraft classification number
BLS	Bituminous Layers Study
CA	Crushed aggregate
CBR	California Bearing Ratio
CC1	Construction cycle 1
CC3	Construction cycle 3
ESWL	Equivalent single-wheel load
FAA	Federal Aviation Administration
FSUA	Filled and stabilized uncrushed aggregate
HQS	High-quality subbase
ICAO	International Civil Aviation Organization
MWHGL	Multiple-wheel heavy gear load
NAPTF	National Airport Pavement Test Facility
R&D	Research and development
SQS	Standard quality subbase
SUA	Stabilized uncrushed aggregate
USACE	U.S. Army Corps of Engineers

EXECUTIVE SUMMARY

The purpose of the work described in this report was to recalibrate the load repetition factors (alpha factors) for four- and six-wheel landing gears in the California Bearing Ratio (CBR)-based thickness design procedure for flexible airport pavements. Full-scale traffic test data from tests run by the U.S. Army Corps of Engineers (USACE) in 1968 and 1969 and tests run by the Federal Aviation Administration (FAA) in 2000, 2001, and 2002 formed the basis for the recalibration. C5-A and Boeing 747 gear configurations were used in the USACE tests, usually referred to as the multiple-wheel heavy gear load (MWHGL) tests. Gear configurations approximating the B-777 landing gear and the B-747 landing gear were used in the FAA tests, referred to here as the National Airport Pavement Test Facility (NAPTF) tests. Since the current CBR design procedure is calibrated to the MWHGL test results, the NAPTF results were converted to equivalent MWHGL reference structures before calculating alpha factors. All MWHGL structures were of conventional construction with 3 inches (7.6 cm) of asphalt surface, 6 inches (15.2 cm) of crushed-aggregate base, and the balance of standard quality uncrushed-aggregate subbase. All NAPTF structures except one were of conventional construction with 5 inches (12.7 cm) of asphalt surface, 8 inches (20.3 cm) of crushed-aggregate base, and the balance of high-quality manufactured aggregate subbase. A test item with a stabilized base structure was also included in the NAPTF tests. The NAPTF structures were converted to MWHGL reference structures by using equivalent thickness factors relating the NAPTF materials to the MWHGL materials. Alpha factors for the NAPTF tests were computed based on the equivalent reference thicknesses, subgrade CBR values measured during the tests, and the wheel loads and gear geometries used in the individual tests. The MWHGL C5-A gear configuration was also considered to be two, six-wheel gears running in tandem rather than a single 12-wheel gear, as assumed in the original MWHGL analysis. New alpha factors were computed for the C5-A six-wheel configuration and plotted in combination with the NAPTF six-wheel alpha factors. Least squares quadratic curve fits of combined MWHGL and NAPTF alpha factors for four- and six-wheel gears were then used to compute alpha factors at 10,000 coverages for comparison with the requirements of the International Civil Aviation Authority (ICAO) standard for computing the aircraft classification number (ACN). The results of the analysis are consistent with the existing alpha factor of 0.825 for four-wheel gears, but the results of the analysis are not consistent with the existing alpha factor of 0.788 for six-wheel gears. The six-wheel alpha factor at 10,000 coverages should be changed to a value approximately equal to the interim value of 0.72 adopted by the ICAO for calculating ACN for six-wheel gears.

1. INTRODUCTION.

The U.S. Army Corps of Engineers (USACE) and the Federal Aviation Administration (FAA) CBR (California Bearing Ratio) thickness design procedures for flexible airport pavements are based on the CBR method originally developed for highway use and adapted for airfield use in the early 1940s. Compared to the original highway methodology, the current method for airport use has two fundamental differences: (1) the development of an explicit CBR equation relating pavement thickness to CBR, wheel load, and tire contact area for single-wheel loads; and (2) the addition of an equivalent single-wheel load (ESWL) concept for relating multiple-wheel gear loads to an equivalent single-wheel load for substitution into the CBR equation. The ESWL at a given depth is found by first computing the maximum deflection at that depth in an infinite uniform half space due to the load from the landing gear of interest. The magnitude of a single-wheel load that causes the same maximum deflection at the same depth in an infinite uniform half space is then computed. This is the ESWL at that depth.

The CBR equation contains both pavement thickness and ESWL, and, since ESWL depends on thickness, the equation cannot be used to solve directly for thickness. An iterative procedure is therefore used to find the total depth of pavement required above the top of the subgrade in order to protect the subgrade from shear failure. Because the ESWL is computed for a uniform half space, the resulting pavement thickness computed from the CBR equation is strictly valid for just one reference structure. Otherwise, over- or under-conservatism will be built into the design. For example, in the FAA CBR thickness design procedure, the reference structure is of conventional composition with asphalt surface, crushed-aggregate base, and uncrushed-aggregate subbase layers above the subgrade. If other materials are to be used in the base or subbase layers, or if additional layers are present, then thickness equivalency factors are applied to compensate for the difference in strength or load spreading capability of the substituted materials. A similar conversion should also be done even if the layer materials of the design structure are of the same composition as the reference structure, but have surface or base layers of different thickness. The equivalency factors are typically based on full-scale test data or field experience. Suitable values are published in the appropriate standards. Reference 1, Advisory Circular (AC) 150/5320-6D, gives the FAA equivalency factor requirements for design. (Also see reference 2 for a detailed description of the development of the CBR thickness design method.) Furthermore, when deriving the empirical correlation between the CBR failure model, as expressed by the CBR equation, and the ESWL response model the correlation must be done in relation to a common reference structure if more than one set of full-scale test results are included in the correlation.

During the development of the CBR design methodology, and to address the increasing weight of large aircraft and the increasing complexity of their landing gear, the USACE constructed a set of full-scale test pavements and trafficked them with Boeing 747 and C5-A landing gears. These tests became known as the multiple-wheel heavy gear load (MWHGL) tests. The MWHGL test pavements were constructed in 1968 at the Waterways Experiment Station according to the practices current at the time. Since then, the FAA has increased the minimum thickness requirements for surface and base courses for heavy commercial aircraft operation on flexible pavements. The flexible pavement test items constructed at the National Airport Pavement Test Facility (NAPTF) in 1999 and 2002, complied with the newer standards, and were therefore different structures than those used in the MWHGL tests. The relevant layer properties are summarized in table 1.

TABLE 1. COMPARISON BETWEEN MWHGL AND NAPTF STRUCTURAL PROPERTIES

Layer	MWHGL Conventional Pavements			NAPTF Conventional Pavements			NAPTF Stabilized Base Pavements		
	Material	Thickness		Material	Thickness		Material	Thickness	
		in.	cm		in.	cm		in.	cm
Surface	Asphalt	3	7.6	Asphalt	5	12.7	Asphalt	5	12.7
Base	Crushed aggregate	6	15.2	Crushed aggregate	8	20.3	Asphalt	5	12.7
Subbase	Uncrushed aggregate	Variable		Crushed stone screenings	Variable		Crushed aggregate	Variable	

The purpose of the work described in this report was to combine the MWHGL and the NAPTF full-scale test data and to recalibrate the load repetition factors (alpha factors) for four- and six-wheel landing gears in the CBR-based design procedure for flexible airport pavements. Since the current CBR design procedure is calibrated to the MWHGL test results, the reference structure is the MWHGL conventional structure with 3 inches (7.6 cm) of asphalt surface, 6 inches (15.2 cm) of crushed-aggregate base, and the balance of standard quality uncrushed-aggregate subbase. The NAPTF structures were converted to reference structure properties and new alpha factors computed based on the equivalent thicknesses and the subgrade CBR values measured during the tests. The MWHGL C5-A gear configuration was also considered to be two, six-wheel gears running in tandem rather than a single 12-wheel gear. New alpha factors were computed for the six-wheel configuration and plotted in combination with the NAPTF six-wheel alpha factors. Curve fits of combined MWHGL and NAPTF alpha factors for four- and six-wheel gears were then used to compute alpha factors at 10,000 coverages for comparison with the requirements of the ICAO standard for computing the aircraft classification number (ACN) [3].

2. NAPTF TEST PAVEMENTS.

The original NAPTF test pavements, called construction cycle 1 (CC1), were constructed in 1999. The flexible test items consisted of conventional and stabilized base structures on low- and medium-strength subgrades. Structural failure occurred on the medium-strength subgrade with the premature failure in the base layer of the stabilized base test item invalidating the test result for application to alpha factor calculation. Structural failure did not occur in the test items on the low-strength subgrade, and these test items were removed and replaced by four conventional flexible test items of different thicknesses in construction cycle 3 (CC3) in 2002. Structural failure occurred in both the four- and six-wheel lanes of the two thinnest CC3 test items, with structural failure also occurring in the six-wheel lane of the next thickest test item. The four- wheel lane of the same test item showed a clear indication that it was close to meeting the structural failure criteria when trafficking was stopped. The thickest test item did not show any indication of significant structural distress when trafficking was stopped.

The naming convention for the test items was as follows: L and M refer to the low- and medium-strength subgrades, F refers to flexible pavement structure, and C and S refer to conventional and stabilized base.

3. NAPTF GEAR CONFIGURATIONS.

Each of the NAPTF test items was split into two independent loading tracks. The loading tracks were equally spaced on either side of the centerline of the test pavement with the centerlines of the landing gear wheel groups approximately 30 feet (9.1 m) apart. The total width of the test pavement was 60 feet (18.3 m). Four- and six-wheel gear configurations were run side by side in all of the tests. The six-wheel gear geometries were the same in all of the tests, but the four-wheel gear geometries were different in the CC1 and CC3 tests. The CC1 four-wheel geometry was the same as the B-747 landing gear and the CC3 four-wheel geometry was the same as the six-wheel geometry. Using the same geometries in the CC3 tests removed geometry effects from the comparative results for four- and six-wheel test data, but introduced geometry effects into the four-wheel alpha factor calculations. The effect was, however, small in comparison with typical test error. Also, the narrow dual spacing of the B-747 gear also caused interference between the tire sidewalls and the load module structure when running over deep ruts. The wider spacing used in the CC3 tests allowed a wider operating range. The geometries are summarized below and pass-to-coverage ratios are given in appendix B.

- CC1 and CC3 north track: six wheels at 54 inches (21.3 cm) dual spacing and 57 inches (22.4 cm) tandem spacing

- CC1 south track: four wheels at 44 inches (17.3 cm) dual spacing and 58 inches (22.8 cm) tandem spacing

- CC3 south track: four wheels at 54 inches (21.3 cm) dual spacing and 57 inches (22.4 cm) tandem spacing

The test speed was 5 mph (8 km/h) for the CC1 Tests and 2.5 mph (4 km/h) for the CC3 tests.

4. EQUIVALENT THICKNESS OF NAPTF STRUCTURES.

The asphalt (FAA Item P-401) and crushed-aggregate (FAA Item P-209) materials used in the NAPTF pavements were considered to be of the same quality as the asphalt and crushed-aggregate materials used in the MWHGL pavements. (Specifications for FAA requirements for construction of airport pavements can be found in reference 4.) However, the different surface and base thicknesses required conversion of the NAPTF layers to make them equivalent to the MWHGL structures. Also, the P-209 base material used in CC3 was from a different supplier than the material used in CC1. The two materials had different gradations at the coarse end of the curve and, due to uncertainty in the selection of a suitable thickness equivalency factor, two different equivalency factors were used in the conversion of base material to subbase. This shows the effect of using different factors on the final results and provides a measure of the sensitivity of the analysis procedure to variations in the equivalency factors. A value of 1.6 was initially selected because, from experience in the use of the recommendations in AC 150/5320-6D [1] and comparisons with layered elastic-based designs, it was felt that this value was the most appropriate conversion factor for this exercise. However, there was some uncertainty regarding exact factors for the conversion because of the use of two different base materials and the fact that the preferred value of 1.6 was 0.1 higher than the median value of the acceptable range given in reference 1. It therefore was felt to be appropriate to also compare the results using an equivalency factor of 0.1 below the median. This would provide an acceptable range of possible results while remaining near the middle of the established range.

The MWHGL subbase material was an uncrushed gravelly river sand and the NAPTF subbase material was crushed argillite screenings. The NAPTF subbase material was considered to be of higher quality than the MWHGL subbase material and a conversion was made to increase the thickness of the NAPTF subbase for substitution in the equivalent reference structure. Tables 2 and 3 show the as-constructed CBR values for the subbase materials. The NAPTF material shows 2.7 times the strength of the MWHGL material based on the average CBR values. Subbase CBR values measured after traffic are given in appendix A, where a similar difference in strength was seen.

TABLE 2. MWHGL SUBBASE CBR, AS-CONSTRUCTED

Test Item	Total Design Thickness		Subbase CBR As-Constructed
	in.	cm	
1	15	38.1	13
2	24	61.0	12
3	33	83.8	13
4	33	83.8	15
5	42	106.7	15
Average			13.6

(From table 1, MWHGL report, vol. 1, page 169.)

TABLE 3. NAPTF SUBBASE CBR, AS-CONSTRUCTED

Test Item	Total Design Thickness		Number of CBR Tests	Average Subbase CBR As-Constructed	Standard Deviation of Subbase CBR As-Constructed
	in.	cm			
CC1-LFC	49	124.5	10	40.6	10.4
CC1-MFC	25	63.5	9	33.1	6.4
Total			19	37.0	

(CBR was not measured on the subbase of CC3 test items during construction. Each CBR test consisted of three penetrations.)

Table 4 gives material designations used to identify the various materials, and table 5 gives the equivalency factors used in the thickness conversions. Appendix A discusses the selection of the equivalency factors and presents independent test data showing the effect of subbase material quality on the life of a flexible pavement.

TABLE 4. LEGEND FOR MATERIAL IDENTIFICATION

Identifier	Definition
AC	Asphaltic concrete MWHGL and NAPTF (P-401) surface course material
CA	Crushed aggregate MWHGL and NAPTF (P-209) base course material
SQS	Standard quality subbase MWHGL subbase course material
HQS	High-quality subbase NAPTF (P-154) subbase course material

TABLE 5. LAYER THICKNESS EQUIVALENCY FACTORS

Identifier	Definition
CA	1.6 × AC
SQS	1.4 × CA and 1.6 × CA
SQS	1.2 × HQS

The procedure for converting an NAPTF conventional structure to the equivalent reference structure is illustrated in figure 1 using the thinnest of the NAPTF structures (CC3-LFC1) as an example and using SQS = 1.6 × CA. Figure 1(a) is the original structure and figure 1(f) is the equivalent reference structure.

Specific steps in the procedure are as follows:

1. Convert 2 inches (5.1 cm) of the asphalt concrete to 3.2 inches (8.1 cm) of crushed aggregate by multiplying 2 by 1.6. This leaves 3 inches (7.6 cm) of asphalt surface for the MWHGL equivalent structure (figure 1(b)).

2. Add the 3.2 inches (8.1 cm) of crushed aggregate to the existing 8 inches (20.3 cm) of crushed aggregate.

3. Subtract 6 inches (15.2 cm) of crushed aggregate for the MWHGL equivalent structure (figure 1(c)).

4. Convert the remaining 5.2 inches (13.2 cm) of crushed aggregate to 8.3 inches (21.1 cm) of standard quality subbase by multiplying by 1.6 (figure 1(d)).

5. Convert 16 inches (40.6 cm) of high-quality subbase to 19.2 inches (48.8 cm) of SQS by multiplying 16 by 1.2 (figure 1(e)).

6. Add 8.3 inches (21.1 cm) of SQS to 19.2 inches (48.8 cm) of SQS to give 27.5 inches (69.8 cm) of SQS (figure 1(f)).

7. The total thickness of the MWHGL equivalent structure is therefore 3 + 6 + 27.5 = 36.5 inches (92.7 cm). This is used to calculate the alpha factors for the two load cases on LFC1.

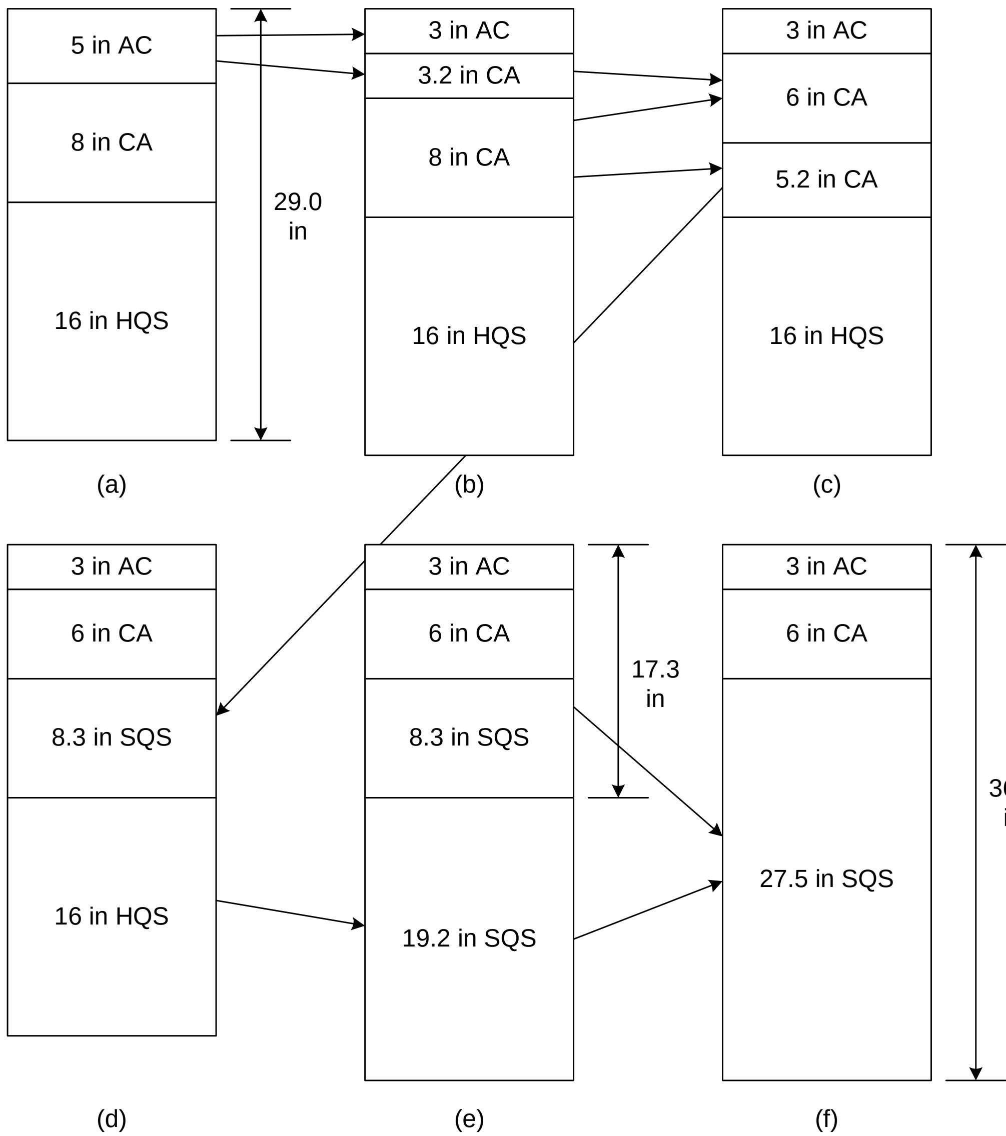

FIGURE 1. PROCEDURE FOR CONVERTING NAPTF STRUCTURES TO EQUIVALENT MWHGL STRUCTURES (1 in. = 2.54 cm)

All other NAPTF conventional test items had the same surface and base course layer thicknesses as CC3-LFC1, and the MWHGL equivalent structures for these test items were found by adding 17.3 inches (43.9 cm) to 1.2 times the thickness of the NAPTF subbase for SQS = 1.6 × CA (see figure 1(e)). For SQS = 1.4 × CA, 16.3 inches (41.4 cm) is added to 1.2 times the thickness of the NAPTF subbase.

The NAPTF stabilized base test item MFS consisted of 5 inches (12.7 cm) of asphalt surface, 5 inches (12.7 cm) of asphalt base course (P-401), and 8.5 inches (21.6 cm) of crushed-aggregate subbase course (P-209). The MWHGL equivalent structure for this test item was found as follows:

1. Convert 7 inches (17.8 cm) of the asphalt layers to 11.2 inches (28.4 cm) of crushed aggregate by multiplying by 1.6.

2. For SQS = 1.6 × CA, convert 11.2 + 8.5 – 6 = 13.7 inches (34.8 cm) of crushed aggregate to 21.9 inches (55.6 cm) of standard quality subbase by multiplying by 1.6.

3. For SQS = 1.4 × CA, convert 13.7 inches (34.8 cm) of crushed aggregate to 19.2 inches (48.8 cm) of standard quality subbase by multiplying by 1.4.

4. The total thickness of the MWHGL equivalent structure is therefore 3 + 6 + 21.9 = 30.9 inches (78.5 cm) for SQS = 1.6 × CA and 3 + 6 + 19.2 = 28.2 inches (71.6 cm) for SQS = 1.4 × CA. These thicknesses are used to calculate the alpha factors for the four-wheel load case on MFS.

5. CALCULATION OF ALPHA FACTORS.

Before the MWHGL test series, the CBR equation in use for airport pavement design was

$$t = (0.23\log_{10}(C) + 0.15)\sqrt{\frac{P}{8.1\,CBR} - \frac{A}{\pi}} \tag{1}$$

where

t = total thickness of the pavement to the top of the subgrade, inches

C = coverages to failure

P = ESWL, pounds

CBR = CBR of the subgrade

A = contact area of the ESWL, inches (contact area of each tire on the landing gear (all assumed to be equal))

The results of the MWHGL tests indicated that the traffic portion of the equation (0.23 $\log_{10}(C)$ + 0.15) did not apply well to gears with multiple wheels and a load repetition factor or alpha factor was introduced. The alpha factor was assumed to vary with the number of wheels on a gear. The equation then became

$$t = \alpha\sqrt{\frac{P}{8.1\,CBR} - \frac{A}{\pi}} \tag{2}$$

with α a function of coverages to failure.

It was also found that equation 2 departs from full-scale test data under some circumstances, and an alternative cubic equation curve fit to the full-scale test data was derived:

$$t = \alpha\sqrt{A}\left\{-0.0481 - 1.1562\left(\log_{10}\frac{CBR}{p}\right) - 0.6414\left(\log_{10}\frac{CBR}{p}\right)^2 - 0.473\left(\log_{10}\frac{CBR}{p}\right)^3\right\} \quad (3)$$

Where all symbols are as indicated above for equations 1 and 2 except

$p = \frac{P}{A} = \text{contact pressure of the ESWL, pounds per square inch}$

Note that p is not equal to the tire pressure of the landing gear wheels.

It is sometimes useful to work with equation 2 because it indicates the relationship between the variables better than equation 3. The two equations diverge significantly when $\frac{CBR}{p}$ exceeds about 0.25. More details on the development of the CBR models are given in references 2, 5, and 6.

In the ICAO computer program [3], equation 3 is used to calculate pavement thickness for the landing gear of interest, and equation 2 is used to calculate pavement thickness for the reference single-wheel gear.

The alpha factor for a full-scale test point is calculated by rearranging equations 2 or 3 and solving for α. For example,

$$\alpha = \frac{t}{\sqrt{\frac{P}{8.1\,CBR} - \frac{A}{\pi}}} \quad (4)$$

where

t = total equivalent thickness of the test pavement to the top of the subgrade, inches

P = ESWL of the test landing gear at the top of the subgrade, pounds

CBR = CBR of the subgrade of the test pavement

A = contact area of the ESWL, inches (contact area of each tire on the landing gear (all assumed to be equal))

p = contact pressure of the ESWL, if using equation 3 rearranged, pounds per square inch

For this report, alpha factors were calculated using the COMFAA computer program [7]. COMFAA is a direct implementation of the ICAO computer source code for computing ACNs published in the ICAO pavement design manual. Figure 2 shows a screen shot of the program. The correct gear configuration is either selected or created and the Gross Weight entered to provide the correct wheel load for the test point. Pavement Design is selected as the computational mode and the correct CBR for the test point is entered by clicking on the CBR heading in the table. Clicking the AC Design button displays the total design thickness in the CBR t column of the table. A different Input Alpha is entered by clicking on the display box for Input Alpha, and then the AC Design button is clicked to find a new design thickness. Input Alpha is adjusted repeatedly until the design thickness matches the equivalent thickness of the test structure. The value of coverages does not need to be changed or set to the number of coverages to failure for the test. When all the alpha factors for a given gear configuration have been computed, they are plotted against coverages to failure with the coverages for each point as determined in the tests.

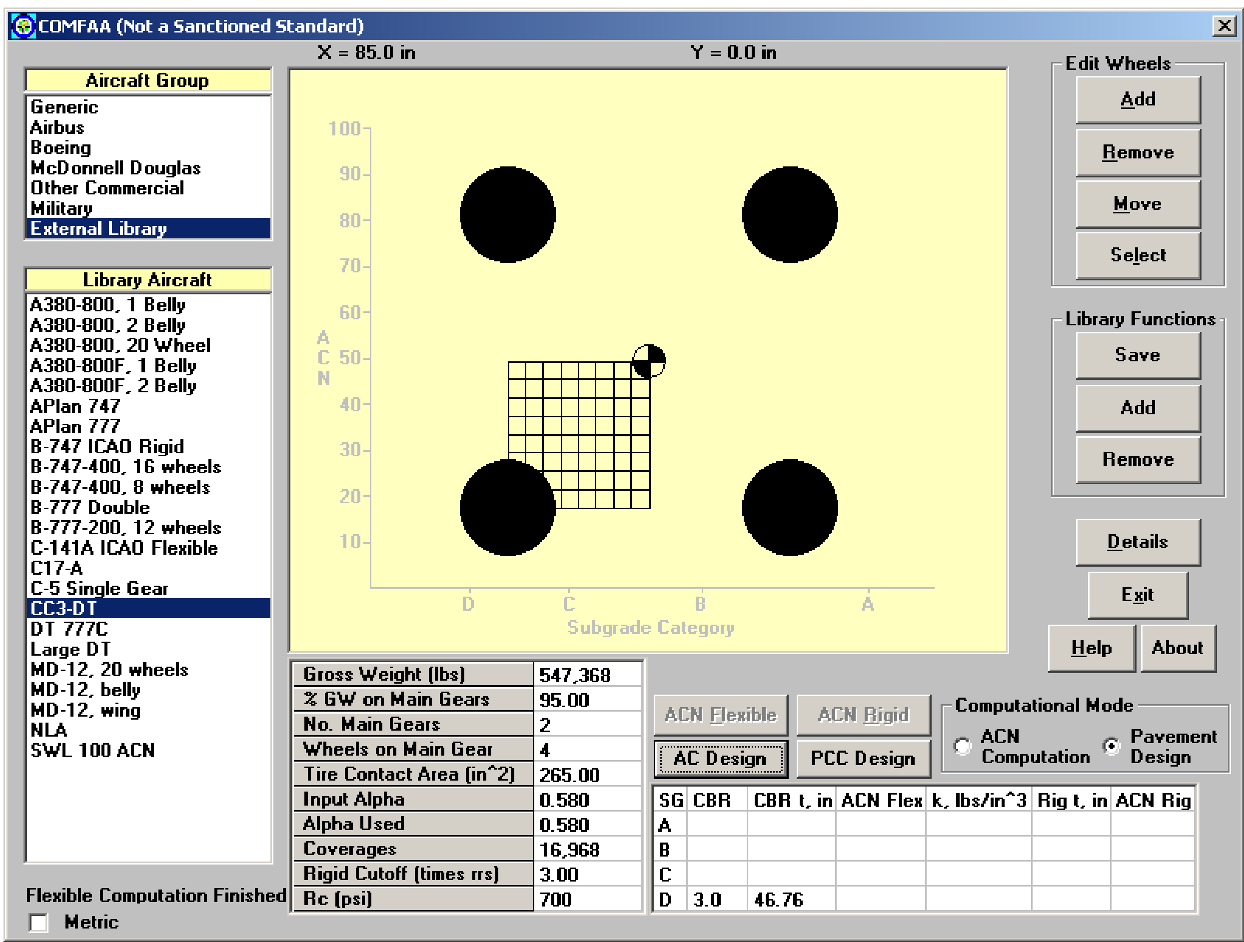

FIGURE 2. SCREEN SHOT OF THE COMFAA COMPUTER PROGRAM FOR CALCULATING ACN

6. MWHGL ALPHA FACTORS.

Computed alpha factors for all of the MWHGL test items and gear configurations, with associated test data, are reported in the MWHGL Report [5]. However, the C5-A gear configuration was considered to be a 12-wheel gear. This is not compatible with the six-wheel configuration used in the NAPTF tests, and it has also been proposed by some investigators that, in practical terms, the two, six-wheel groups on each side of the C5-A are so far apart that they operate as two separate six-wheel gears. Six-wheel alpha factors were therefore calculated for the C5-A test results and compared with the reported 12-wheel results. (The difference is in the calculation of the ESWLs.) Table 6 shows the C5-A data. All entries except those in the last two columns are for Lane 1 from Table 16, page 185 of the MWHGL Report [5]. Twelve-wheel alpha factors were also calculated with the COMFAA computer program [7]. Good correspondence is shown with the values from the MWHGL report. COMFAA was then used to compute six-wheel alpha factors for the same conditions. The results are shown in the next to last column of table 6. The number of coverages to failure in the test results is the same for both 12- and 6-wheel cases because the pass-to-coverage ratio for the 12-wheel case is calculated by finding the pass-to-coverage ratio for one 6-wheel group and dividing by two. The number of coverages in the tests is therefore the same whether the wheels are considered to be one 12-wheel group or two 6-wheel groups.

TABLE 6. TWELVE- AND SIX-WHEEL ALPHA FACTORS FOR THE C5-A AIRCRAFT*

Test Item Number	Coverages to Failure	Total Thickness		Rated Subgrade CBR	12-Wheel Alpha Factor From Report	12-Wheel Alpha Factor From COMFAA	6-Wheel Alpha Factor From COMFAA	Percent Increase
		in.	cm					
1	8	15	38.1	3.7	0.336	0.337	0.362	7.4
2	104	24	61.0	4.4	0.525	0.525	0.572	9.0
3	1500	33	83.8	3.8	0.605	0.607	0.667	9.9
4	1500	33	83.8	4.0	0.621	0.623	0.684	9.8
5	3850**	41	104.1	4.0	0.719	0.719	0.797	10.8

* All test data from the MWHGL Report, table 16, lane 1

** Nonfailure. Trafficking was terminated with minimal pavement distress and no indication that failure would occur within a reasonable number of additional passes. The as-constructed thickness of this test item was also 1 inch (2.54 cm) less than the design thickness listed in table 2.

Alpha factors for the four-wheel MWHGL test results are shown in table 7.

TABLE 7. FOUR-WHEEL ALPHA FACTORS*

Test Item Number	Coverages to Failure	Total Thickness		Rated Subgrade CBR	Alpha Factor
		in.	cm		
3	40	33	83.8	3.8	0.524
4	40	33	83.8	4.0	0.538
5	280	41	104.1	4.0	0.621

* From the MWHGL Report, table 16, lane 3B

Wheel loads in all of the MWHGL C5-A tests were 30,000 lb (133.4 kN), giving a six-wheel gear load of 180,000 lb (800.6 kN). Wheel loads in all of the MWHGL four-wheel tests were 60,000 lb (266.9 kN), giving a four-wheel gear load of 240,000 lb (1,067.5 kN). The four-wheel gear had the same geometry as a single B-747 main landing gear.

Figure 3 shows a chart of alpha factor versus coverages to failure for all of the MWHGL test points and where the C5-A is considered to be a 12-wheel gear. Figure 4 shows the same data except that the C5-A is considered to be a six-wheel gear.

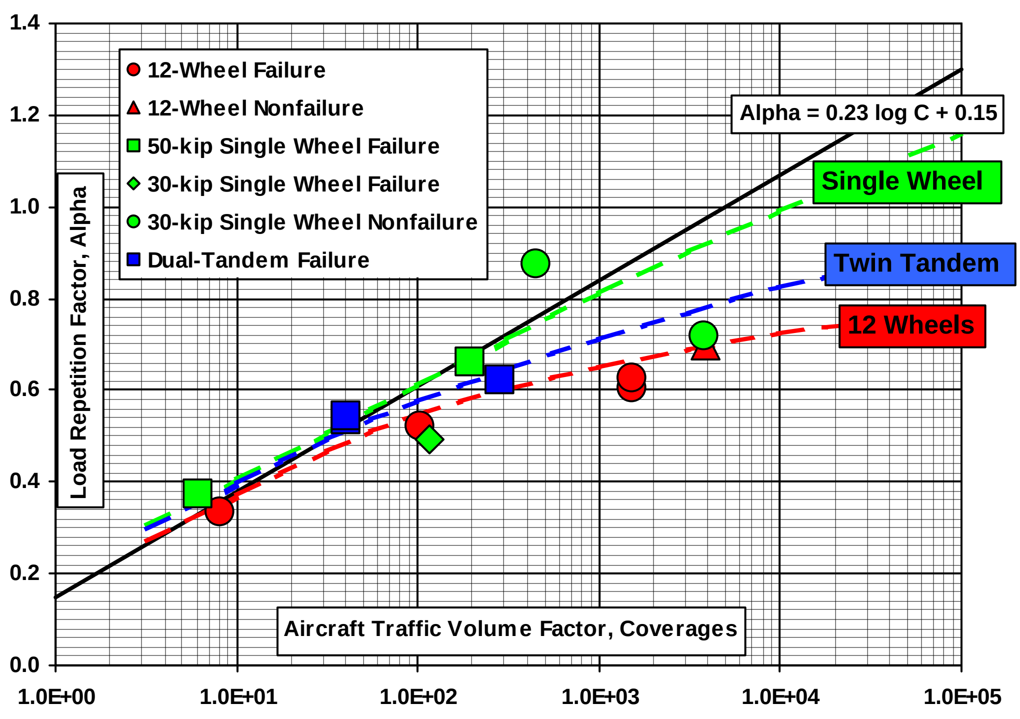

FIGURE 3. MWHGL ALPHA FACTOR VERSUS COVERAGES TO FAILURE WITH C5-A AS A 12-WHEEL GEAR

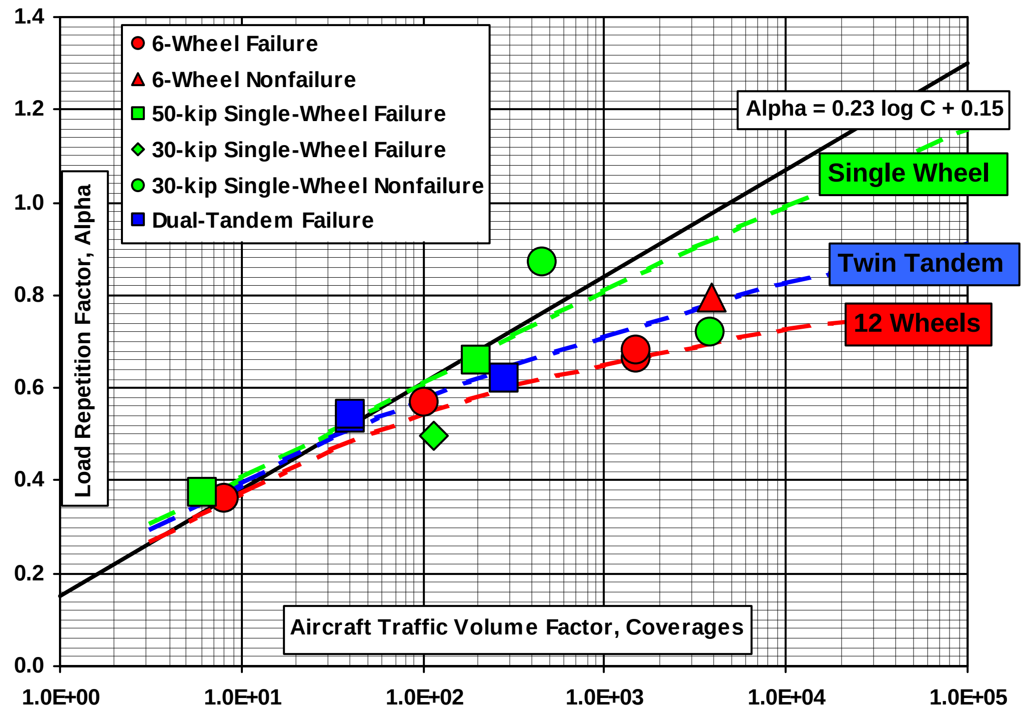

FIGURE 4. MWHGL ALPHA FACTOR VERSUS COVERAGES TO FAILURE WITH C5-A AS A SIX-WHEEL GEAR

7. NAPTF ALPHA FACTORS.

Table 8 summarizes the data from all of the NAPTF flexible pavement traffic tests that resulted in structural failure of the pavement or, as in one case, gave a clear indication that structural failure would have occurred if trafficking had continued. Equivalent thicknesses of the pavements relating the NAPTF structures to the MWHGL structures are listed in table 9 together with alpha factors computed for each test. The equivalent thicknesses and alpha factors were calculated as described previously. The subgrade CBR values listed in table 8 were calculated as the averages of the following measurements:

- Average of the acceptance test measurements made on the top lift of each test item.
- Average of the measurements made on the surface of the subgrade in posttraffic trenches.
- Average of the measurements made 12 inches (30.5 cm) below the surface of the subgrade in posttraffic trenches.
- Average of the measurements made 24 inches (61.0 cm) below the surface of the subgrade in posttraffic trenches.

TABLE 8. SUMMARY OF NAPTF FLEXIBLE PAVEMENT FULL-SCALE TEST RESULTS

Wheel Configuration	Test Item	Wheel Load, lb[1]	Repetitions to Failure	Coverages to Failure	Design Thickness		Subgrade CBR[3]
					in.	cm	
6 Wheel	CC3-LFC1	55,000	90	57.3	29	73.7	3.72
	CC3-LFC2	55,000	1,584	1,009	37	94.0	4.38
	CC3-LFC3	65,000	20,000	12,739	47	119.4	4.38[4]
	CC1-MFC	45,000	13,000	8,280	25	63.5	7.45
4 Wheel	CC3-LFC1	55,000	132	55.9	29	73.7	4.32
	CC3-LFC2	55,000	2,970	1,258	37	94.0	4.32
	CC3-LFC3	65,000	40,000[2]	16,949	47	119.4	4.32[4]
	CC1-MFC	45,000	12,000	5,825	25	63.5	7.34
	CC1-MFS	45,000	19,000	9,223	18.5	47.0	7.43

Notes:

1. 45 kips = 200 kN, 55 kips = 244 kN, 65 kips = 289 kN.
2. Repetitions to failure for LFC3: 4-wheel is from extrapolated rut depth curve.
3. CBR computed as the average of the following measurements: acceptance surface, trench surface, and trench pits 12 and 24 inches (30.5 and 61.0 cm) from the surface of the subgrade.
4. Trench not opened in LFC3. The CBR values for LFC3 have been given the same values as those in LFC2.

A comprehensive description of posttraffic testing of test item CC1-MFC is given in reference 8. The procedures described in reference 8 are typical of the posttraffic testing performed in all other NAPTF test items.

TABLE 9. NAPTF FLEXIBLE PAVEMENT EQUIVALENT THICKNESSES AND ALPHA FACTORS

Wheel Configuration	Test Item	SQS = 1.6 × CA			SQS = 1.4 × CA		
		Equivalent Thickness[1]		Alpha Factor	Equivalent Thickness[2]		Alpha Factor
		in.	cm		in.	cm	
6 Wheel	CC3-LFC1	36.5	92.7	0.527	35.5	90.2	0.517
	CC3-LFC2	46.1	117.1	0.665	45.1	114.6	0.656
	CC3-LFC3	58.1	147.6	0.713	57.1	145.0	0.704
	CC1-MFC	31.7	80.5	0.761	30.7	78.0	0.744
4 Wheel	CC3-LFC1	36.5	92.7	0.646	35.5	90.2	0.634
	CC3-LFC2	46.1	117.1	0.751	45.1	114.6	0.740
	CC3-LFC3	58.1	147.6	0.808	57.1	145.0	0.798
	CC1-MFC	31.7	80.5	0.831	30.7	78.0	0.814
	CC1-MFS	30.9	78.5	0.823	28.2	71.6	0.770

Notes:

All NAPTF structures were converted to equivalent structures to be compatible with MWHGL pavements:

- MWHGL = 3 inches (7.6 cm) of asphalt, 6 inches (15.2 cm) of crushed-aggregate base and balance of uncrushed subbase.
- NAPTF P-401 converted to crushed-aggregate base with 1.6 equivalent thickness factor.
- NAPTF P-154 converted to uncrushed-aggregate subbase with 1.2 equivalent thickness factor.

1. NAPTF P-209 converted to uncrushed-aggregate subbase with 1.6 equivalent thickness factor.
2. NAPTF P-209 converted to uncrushed-aggregate subbase with 1.4 equivalent thickness factor.

8. COMBINED ALPHA FACTOR RESULTS.

Alpha factors for the MWHGL and NAPTF test results listed in tables 6, 7, and 9 are plotted in figures 5 and 6 against the logarithm of coverages to failure. Figure 5 shows SQS = 1.6 × CA, and figure 6 shows SQS = 1.4 × CA. The upper curve in each figure, marked 4-Wheel, is a least squares quadratic curve fit of all of the four-wheel data points, three from MWHGL and five from NAPTF. The lower curve in each figure, marked 6-Wheel, is a least squares quadratic curve fit of all of the six-wheel data points for which failure occurred, four from MWHGL and four from NAPTF. The six-wheel MWHGL alpha factors in the figures are the 6-Wheel Alpha Factor from COMFAA values listed in table 6. It should be noted that the curves in the figures are not intended to represent or redefine the alpha factor curves published in the MWHGL report [5] or in AC 150/5320-6D [1]. The primary purpose was to provide a mechanical means of calculating the alpha factors at 10,000 coverages for comparison with the requirements of the ACN standard. In other words, the curves are only used to estimate the value of alpha at 10,000 coverages. The curves may not represent valid alpha values at coverage levels other than 10,000. For example, as a second order (quadratic) polynomial curve fit was used to select the value at 10,000 coverages, only the portion of the curve near 10,000 is representative of the appropriate alpha values. As the value of coverages moves away from 10,000, the accuracy of the curve becomes increasingly suspect. A more rigorous analysis and curve fitting effort would be required before replacement of the existing curves would be appropriate, particularly for greater than 15,000 coverages where extrapolation is required outside the range of the existing full-scale test data.

The nonfailure point for test item 5 in the MWGHL test results (see table 6) is not included in figures 5 or 6.

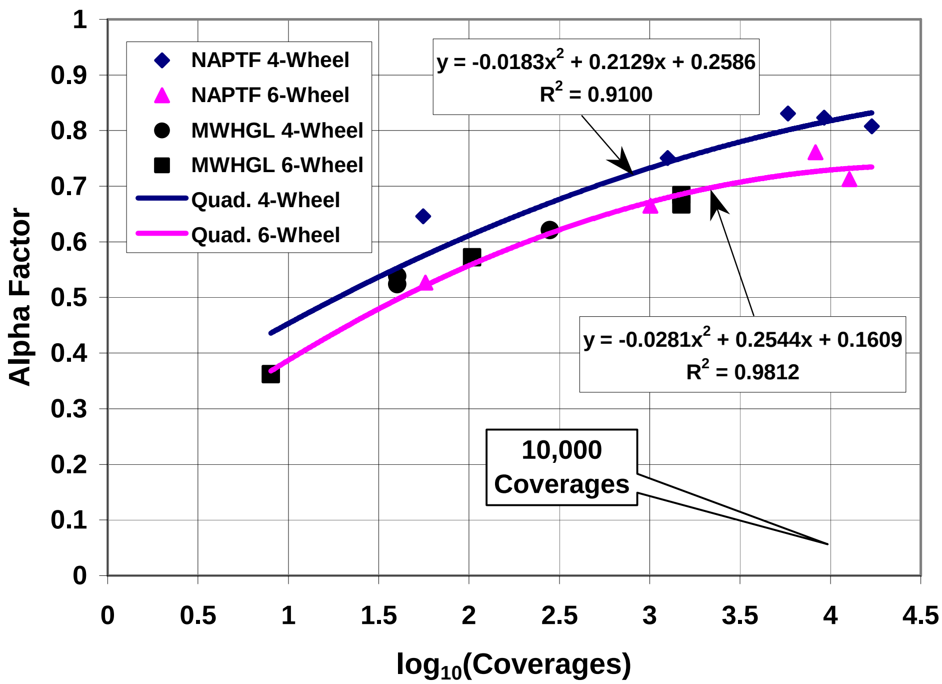

FIGURE 5. ALPHA FACTOR PLOTS WITH COMBINED MWHGL AND NAPTF FULL-SCALE TEST DATA POINTS, QUADRATIC CURVE FITS, SQS = 1.6 x CA
(4-Wheel curve crosses 10,000 coverages at α = 0.8174
6-Wheel curve crosses 10,000 coverages at α = 0.7289
Ratio of 6-Wheel:4-Wheel = 0.8917 at 10,000 coverages)

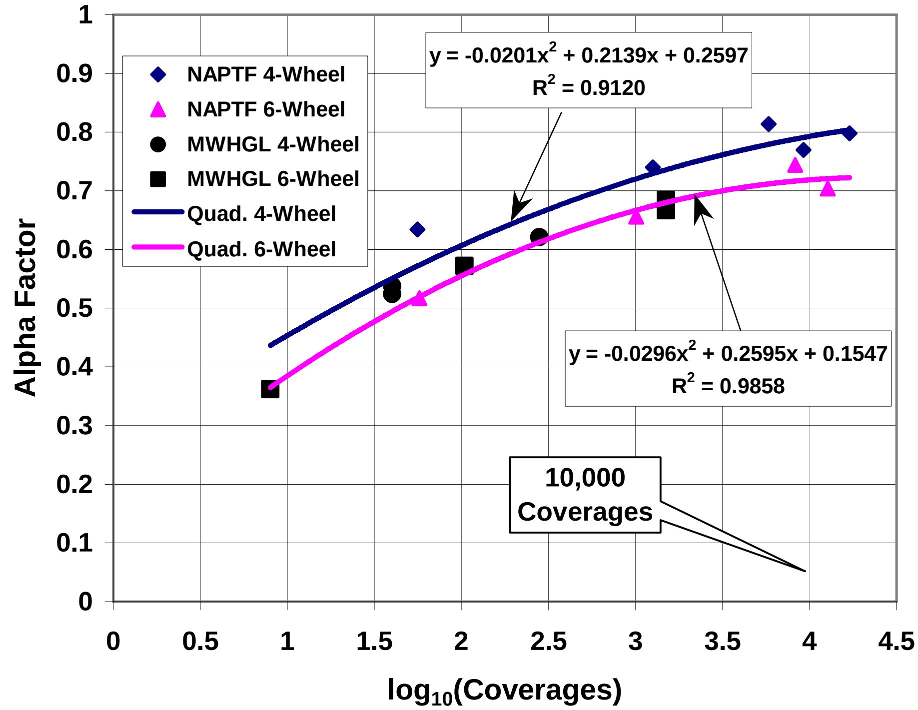

FIGURE 6. ALPHA FACTOR PLOTS WITH COMBINED MWHGL AND NAPTF FULL-SCALE TEST DATA POINTS, QUADRATIC CURVE FITS, SQS = 1.4 x CA
(4-Wheel curve crosses 10,000 coverages at α = 0.7937
6-Wheel curve crosses 10,000 coverages at α = 0.7191
Ratio of 6-Wheel:4-Wheel = 0.9060 at 10,000 coverages)

9. CONCLUSIONS.

Analysis of data from two different sets of full-scale traffic tests on flexible airport pavements with four- and six-wheel, heavy-load landing gears resulted in the following findings.

1. For alpha factor comparisons between full-scale tests run on different pavement structures to be valid, one of the set of structures must be converted to be equivalent to the other set of structures. A method for doing this is described and applied in this report.

2. Alpha factors for the MWHGL C5-A test results must be recalculated based on six-wheel loading from each of the wheel groups in order for the alpha factors to be compatible with those from the NAPTF test results.

3. A least squares quadratic curve fit through combined MWHGL and NAPTF test data gives an alpha factor at 10,000 coverages for four-wheel gears of 0.7937 to 0.8174.

4. A least squares quadratic curve fit through combined MWHGL and NAPTF test data gives an alpha factor at 10,000 coverages for six-wheel gears of 0.7191 to 0.7289.

5. The relative relationship between the four-wheel and six-wheel alpha factors at 10,000 coverages is approximately 0.8917 to 0.9060.

10. REFERENCES.

1. FAA, Advisory Circular, "Airport Pavement Design and Evaluation," AC 150/5320-6D, 1995.

2. Ahlvin, Richard G., "Origin of Developments for Structural Design of Pavements," Technical Report GL-91-26, U.S. Army Waterways Experiment Station, Vicksburg, Mississippi, 1991.

3. Ahlvin, R.G., Ulery, H.H., Hutchinson, R.L., and Rice, J.L., "Multiple-Wheel Heavy Gear Load Pavement Tests, Volume I, Basic Report," Technical Report AFWL-TR-70-113, Vol I, Air Force Weapons Laboratory, November 1971.

4. ICAO, "Aerodrome Design Manual, Part 3, Pavements, (Doc 9157-AN/901), Second Edition, Montreal, Canada, 1983.

5. FAA, Advisory Circular, "Standards for Specifying Construction of Airports," AC 150/5370-10A, 1989-2004.

6. Hammit, G.M. II, Hutchinson, R.L., and Rice, J.L., "Multiple-Wheel Heavy Gear Load Pavement Tests, Volume IV, Analysis of Behavior Under Traffic," Technical Report AFWL-TR-70-113, Vol IV, Air Force Weapons Laboratory, November 1971.

7. Kawa, Izydor and Hayhoe, Gordon F., "Development of a Computer Program to Compute Pavement Thickness and Strength," *FAA Airport Technology Transfer Conference*, Atlantic City, NJ, May 2002.

8. Garg, Navneet, "Posttraffic Testing at the National Airport Pavement Test Facility: Test Item MFC," FAA report DOT/FAA/AR-TN01/49, September 2001.

APPENDIX A—EFFECT OF SUBBASE QUALITY ON FLEXIBLE PAVEMENT LIFE AND EQUIVALENT THICKNESS

A.1 BITUMINOUS LAYER STUDY.

During the summer of 1970 the U.S. Army Corps of Engineers (USACE) conducted full-scale tests on flexible pavements to "(a) compare the performance of bituminous-stabilized base and subbase materials with that of unbound granular materials as used in the original multiple-wheel, heavy gear load (MWHGL) test section and (b) determine the difference in performance between a high quality bituminous base constructed of crushed aggregate and a bituminous base constructed of a lower quality uncrushed material (reference 9)." Objective (a) is of primary interest here and the results are summarized to demonstrate that improving the quality of the subbase material of a flexible pavement will lead to increased life. This series of tests is referred to as the bituminous layers study (BLS).

For the BLS study, lane 1 of test items 1 and 2 of the original MWHGL test pavement was replaced by four test items newly constructed on top of the existing heavy clay subgrade. The total pavement depths were the same as the original pavements; 15 inches (38.1 cm) for new items 1 and 2 and 24 inches (61.0 cm) for new items 3 and 4. The materials and thicknesses of the test item layers are shown in table A-1 and descriptions of the materials are given in table A-2.

TABLE A-1. LAYER MATERIALS AND THICKNESSES FOR THE BLS

Layer	Test Item 1			Test Item 2			Test Item 3			Test Item 4		
	Material	Thickness		Material	Thickness		Material	Thickness		Material	Thickness	
		in.	cm		in.	cm		in.	cm		in.	cm
Surface	Asphalt	3	7.6	Asphalt	3	7.6	Asphalt	3	7.6	Asphalt	3	7.6
Base	Uncrushed filled and stabilized	6	15.2	Asphalt	6	15.2	Asphalt	6	15.2	Asphalt	6	15.2
Subbase	Uncrushed filled and stabilized	6	15.2	Asphalt	6	15.2	Uncrushed stabilized	15	38.1	Uncrushed aggregate	15	38.1

TABLE A-2. DESCRIPTIONS OF THE LAYER MATERIALS LISTED IN TABLE A-1

Material Type	Description
Asphalt	Asphaltic surface course material. The aggregate (crushed limestone) and the asphalt cement were from the same source as used in the MWHGL pavements.
Uncrushed aggregate	Uncrushed gravelly river sand from the same source as used in the MWHGL pavements.
Uncrushed stabilized	Same as uncrushed aggregate except stabilized with 6 percent of asphalt cement.
Uncrushed filled and stabilized	Same as uncrushed aggregate except 6.5 percent of cement filler added to improve gradation and stabilized with 5.5 percent of asphalt cement.

Each of the new test items was 30 feet long by 30 feet wide (9.1 by 9.1 m) and separated into two lanes. Lane 1 was 16 feet (4.9 m) wide with a 5-foot (1.5-m) shoulder. Lane 2 was 6 feet (1.8 m) wide and immediately adjacent to lane 1 with a 3-foot (0.9-m) -wide shoulder.

Lane 1 was trafficked by the 12-wheel load cart at 360,000 lb (1,600 kN) (30,000 lb (133 kN) per wheel). Lane 2 was trafficked by a 75,000-lb (333.6-kN) single-wheel load. Additional 75,000-lb (333.6-kN) single-wheel traffic was applied to previously untrafficked areas of test items 4 and 5 of the original MWHGL test pavement. The same wander patterns were used as in the MWHGL tests.

Table A-3 summarizes the results of the test. The rated California Bearing Ratio (CBR) values were calculated in the same way as for the MWHGL tests: "The rated CBR values of the subgrade were based on the numerical average of the CBR values measured immediately after construction (table 2) and after traffic (table 5). In general, the CBR values used were from tests conducted at the surface and 6 and 12 in. (15.2 and 30.5 cm) into the subgrade"[A-1].

TABLE A-3. SUMMARY OF THE TRAFFIC TEST RESULTS FROM THE BLS REPORT*

Traffic	Test Item Number	Total Thickness		Rated Subgrade CBR	Coverages to Failure
		in.	cm		
360,000 lb (1,600 kN) 12 Wheel	1	15	38.1	4.4	98
	2	15	38.1	4.2	425
	3	24	61.0	4.9	2198
	4	24	61.0	3.8	734
75,000 lb (333.6 kN) Single Wheel	1	15	38.1	4.5	6
	2	15	38.1	4.0	8
	3	24	61.0	4.9	90
	4	24	61.0	4.1	12
	4 Orig.	33	83.8	4.0	18
	5 Orig.	41	104.1	4.0	70

* See Table 7, page 42 of BLS Study

The test results are not analyzed in the BLS report to the level of calculating alpha factors and adding the data points to the alpha factor plots. Nor are thickness equivalency factors calculated or reported. Instead, the results are plotted on graphs of total pavement thickness versus the logarithm of coverages to failure and general conclusions are drawn as to the effects of improving the quality of materials in a pavement structure. Figures A-1 and A-2 show these graphs. The original MWHGL results plot as a straight line through four failure points for the 12-wheel gear in figure A-1 (test items 3 and 4 had the same total thickness and the same number of coverages to failure). It is also assumed that the single-wheel results for the tests run on the original MWHGL structures plot as a straight line when extrapolated through two points, as shown in figure A-2.

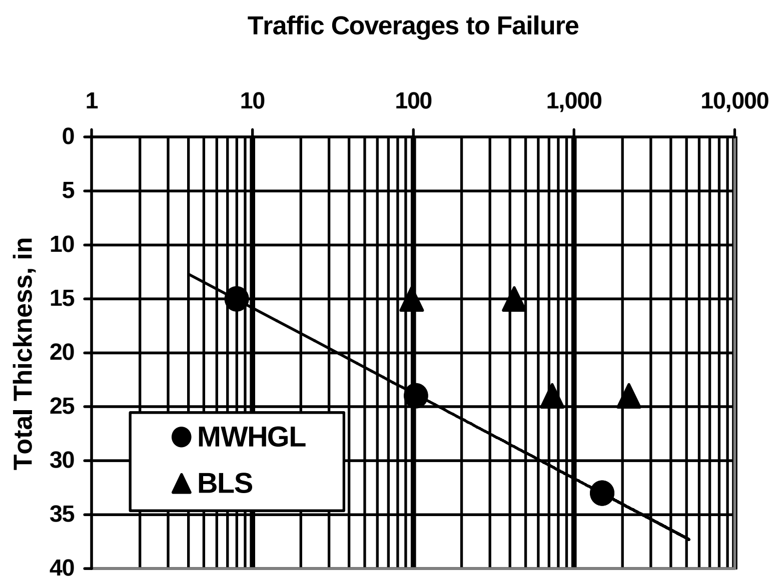

FIGURE A-1. COVERAGES VERSUS THICKNESS, 12-WHEEL GEAR, 360,000 lb (1,600 kN) GEAR LOAD, 100 psi (0.69 kPa) TIRE PRESSURE
(Reproduction of plate 29 from the BLS report.)

From figures A-1 and A-2, it can be seen that all the test items with improved materials, compared to those in the original MWHGL structures, showed significantly longer life than MWHGL structures of the same thickness. And quoting from the report (paragraph 84, page 34) [A-1]:

> "One of the implications from this study and from related work being conducted at the WES is that the quality of material used in all elements of a pavement structure has a significant effect on the load-carrying capability of the pavement: where higher quality materials are used, thickness reductions can be made. In current CE design procedures, no credit is given for the use of subbase materials with strengths higher than the minimum required at a specified depth in the structure. Yet the test data reported herein show that equal performance can be obtained on thinner pavement structures, where the subbase material is upgraded by stabilization or replaced by a high quality crushed stone or bituminous base course."

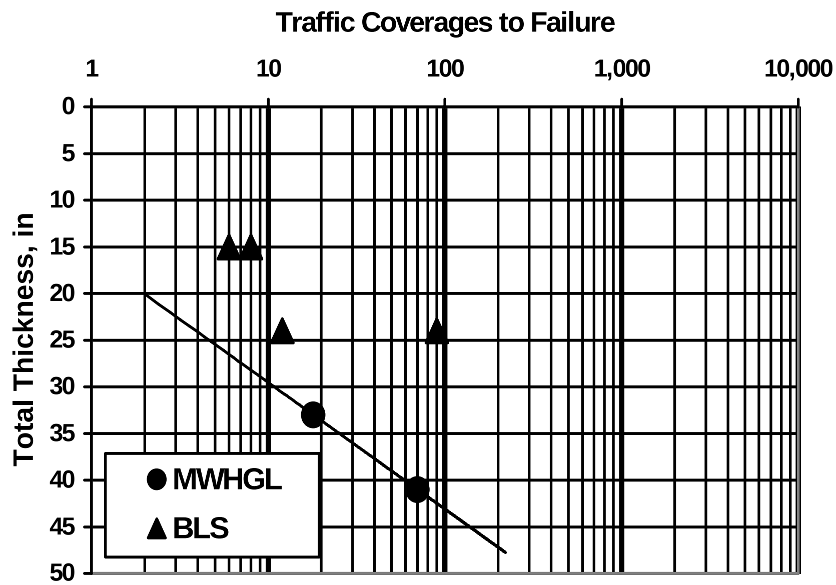

FIGURE A-2. COVERAGES VERSUS THICKNESS, 75,000 lb (333 kN) SINGLE-WHEEL, 290 psi (2.0 mPa) TIRE PRESSURE
(Reproduction of plate 30 from the BLS report)

A further implication is that the improved structures can be converted to equivalent MWHGL structures as is done in this report for the National Airport Pavement Test Facility (NAPTF) structures (the reverse of the flexible pavement design procedure), including the addition of equivalent thickness for the higher-quality subbase. Tables A-4 and A-5 show thickness equivalency factors applied to the BLS materials to convert them to equivalent MWHGL structures. Asphalt is converted to the standard quality subbase (SQS) by a combined factor of 1.6 × 1.6 = 2.56. The filled and stabilized uncrushed aggregate (FSUA) is converted to the SQS by a combined factor of 1.2 × 1.6. The stabilized uncrushed aggregate is converted to the SQS by a combined factor of 1.0 × 1.6 = 1.6. The stabilized uncrushed-aggregate (SUA) material is therefore considered to be equivalent to the crushed-aggregate (CA) base material used in the MWHGL pavements. Table A-6 shows the equivalent thicknesses calculated for the BLS structures using the factors in table A-5.

TABLE A-4. LEGEND FOR MATERIAL IDENTIFICATION

Identifier	Description
AC	Asphaltic concrete MWHGL and BLS surface course material
CA	Crushed aggregate MWHGL base course material
SQS	Standard quality subbase MWHGL subbase course material and BLS uncrushed aggregate
SUA	Stabilized uncrushed aggregate in BLS
FSUA	Filled and stabilized uncrushed aggregate in BLS

TABLE A-5. LAYER THICKNESS EQUIVALENCY FACTORS

Identifier	Description
CA	1.6 × AC
CA	1.2 × FSUA
CA	1.0 × SUA
SQS	1.6 × CA

TABLE A-6. EQUIVALENT THICKNESSES FOR BLS C5-A AND SINGLE-WHEEL TRAFFIC

Traffic	Test Item Number	Total Thickness		Equivalent Thickness		Rated Subgrade CBR	Coverages to Failure
		in.	cm	in.	cm		
360,000 lb (1,600 kN) 12 Wheel	1	15	38.1	22.4	56.9	4.4	98
	2	15	38.1	30.1	76.5	4.2	425
	3	24	61.0	34.3	87.1	4.9	2198
	4	24	61.0	29.8	75.7	3.8	734
75,000 lb (333.6 kN) Single Wheel	1	15	38.1	22.4	56.9	4.5	6
	2	15	38.1	30.1	76.5	4.0	8
	3	24	61.0	34.3	87.1	4.9	90
	4	24	61.0	29.8	75.7	4.1	12
	4 Orig.	33	83.8	33.0	83.8	4.0	18
	5 Orig.	41	104.1	41.0	104.1	4.0	70

Applying the equivalency factors of 1.6 from table A-5 to convert the full-depth asphalt BLS test item 2 to an equivalent structure consisting of 3 inches of AC surface, 6 inches of CA base and the balance of SQS subbase gave an equivalent thickness that compared well with the MWHGL thickness at the same coverage level. The same values were therefore used in the conversion of the other three BLS test items to equivalent MWHGL structures. The equivalency factors for converting the SUA and FSUA materials to CA base material were then adjusted so that the thickness of the BLS equivalent structures matched the thickness of the MWHGL line at the appropriate coverage levels.

Figures A-3 and A-4 reproduce figures A-1 and A-2 except that the BLS equivalent pavement thicknesses are plotted instead of the design thicknesses. The equivalent thicknesses for the BLS data points plot very close to the MWGHL line in figure A-3, indicating that, at least for this series of tests and combinations of materials, the equivalent thickness methodology has a sound experimental basis. The single-wheel results plotted in figure A-4 are not as close to the MWHGL line as the 12-wheel results in figure A-3, but when figure A-4 is compared with figure A-2 it provides a much better description of general pavement behavior than simply reporting total thickness.

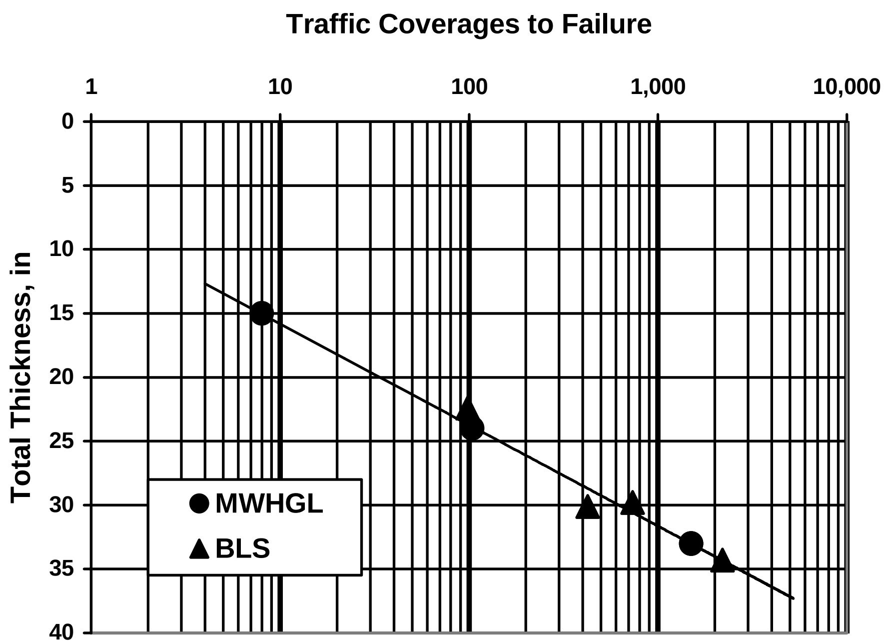

FIGURE A-3. THE BLS DATA IN FIGURE A-1 REPLACED BY THE EQUIVALENT PAVEMENT THICKNESSES, 12-WHEEL TRAFFIC

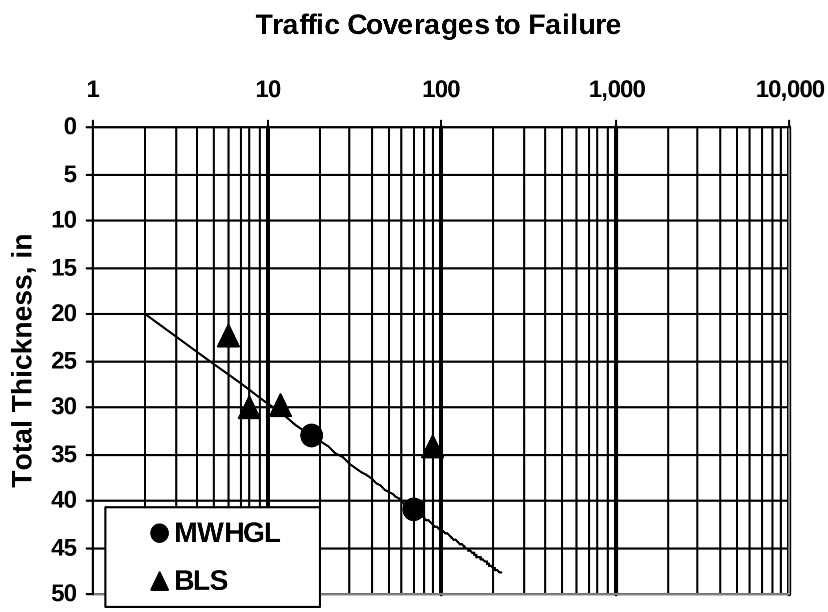

FIGURE A-4. THE BLS DATA IN FIGURE A-2 REPLACED BY THE EQUIVALENT PAVEMENT THICKNESSES, SINGLE-WHEEL TRAFFIC

A.2 THICKNESS EQUIVALENCY FACTORS.

The recommended equivalency factors are given in four tables in AC 150/5320-6D [A-2] and are reproduced in tables A-7 through A-10.

TABLE A-7. RECOMMENDED EQUIVALENCY FACTOR RANGES FOR HIGH-QUALITY GRANULAR SUBBASE

Material	Equivalency Factor Range
P-208, Aggregate base course	1.0 – 1.5
P-209, Crushed-aggregate base course	1.2 – 1.8
P-211, Lime rock base course	1.0 – 1.5

Reproduced from table 3-6 of AC 150/5320-6D.

TABLE A-8. RECOMMENDED EQUIVALENCY FACTOR RANGES FOR STABILIZED SUBBASE

Material	Equivalency Factor Range
P-301, Soil-cement base course	1.0 – 1.5
P-304, Cement-treated base course	1.6 – 2.3
P-306, Econocrete subbase course	1.6 – 2.3
P-401, Plant-mix bituminous pavements	1.7 – 2.3

Reproduced from table 3-7 of AC 150/5320-6D.

TABLE A-9. RECOMMENDED EQUIVALENCY FACTOR RANGES FOR GRANULAR BASE

Material	Equivalency Factor Range
P-208, Aggregate base course	1.0
P-211, Lime rock base course	1.0

Reproduced from table 3-8 of AC 150/5320-6D.

TABLE A-10. RECOMMENDED EQUIVALENCY FACTOR RANGES FOR STABILIZED BASE

Material	Equivalency Factor Range
P-304, Cement-treated base course	1.2 – 1.6
P-306, Econocrete subbase course	1.2 – 1.6
P-401, Plant mix bituminous pavements	1.2 – 1.6

Reproduced from table 3-9 of AC 150/5320-6D.

A.3 EQUIVALENCY FACTOR FOR NAPTF SUBBASE RELATIVE TO THE MWHGL SUBBASE.

The as-constructed average CBR values for the subbase layers of the MWHGL and NAPTF pavements were 13.6 and 37 respectively. The NAPTF value was therefore 2.7 times the MWHGL value. An established mathematical relationship does not exist for converting the difference in CBR values to equivalency factor because, for such different types of material, the relationship would have to be established empirically. An estimate of the equivalency factor was made as follows.

The equivalency factors in AC 150/5320-6D [A-2] for granular base course relative to granular subbase course are based on assumed CBR values of 80 for the base course (P-209, crushed aggregate) and 20 for the subbase course (P-154). The equivalency factor range in table A-7, to convert P-209 to P-154, is 1.2 to 1.8. Assuming a value of 1.6 for 80 CBR to 20 CBR and a linear relationship between equivalency factor and CBR, then, for a 2.7 times improvement from 20 CBR to 54 CBR, gives an equivalency factor of

$$\frac{1.6-1.0}{80-20}\times(2.7\times20-20)+1.0=1.34 \tag{A-1}$$

An alternative procedure is to assume an improvement from 20 CBR (the reference) to 37 CBR (the target):

$$\frac{1.6-1.0}{80-20}\times(37-20)+1.0=1.17 \tag{A-2}$$

From these two numbers, a factor of 1.2 appears to be a reasonable lower limit and was selected for converting the NAPTF crushed argillite screenings to an equivalent thickness of MWHGL gravelly river sand subbase.

Further support for considering that the NAPTF subbase was of higher quality than the MWHGL subbase is that the NAPTF material suffered less deterioration, or showed higher increase in strength, during trafficking. This is illustrated by the posttraffic CBR measurements made in trenches and pits and shown in tables A-11 and A-12. The CBR values of 4.2 and 4.3 measured in MWHGL test item 1 indicate that the subbase lost compaction, presumably due to shear flow.

TABLE A-11. THE MWHGL SUBBASE CBR AFTER TRAFFIC

Test Item	Total Design Thickness		Pit No.	Subbase CBR Inside the Wheel Track	Subbase CBR Outside the Wheel Track
	in.	cm			
1	15	38.1	1	4.3	21
1	15	38.1	2	4.2	7
2	24	61.0	3	15	20
3	33	83.8	4	23	32
3	33	83.8	5	27	-
4	33	83.8	6	38	31
5	42	106.7	7	33	19

From table 7, MWHGL Report, Vol. 1, page 174. Measurements made only in the 360 kip (1,600 kN) 12-wheel traffic lane.

TABLE A-12. THE NAPTF SUBBASE CBR AFTER TRAFFIC

		Test Item		
		CC1-MFC	CC3-LFC1	CC3-LFC2
Total Design Thickness	in.	25	29	37
	cm	63.5	73.7	94.0
Subbase CBR 6-wheel traffic path outside the wheel track		19	56	69
Subbase CBR 6-wheel traffic path inside the wheel track		70	50	125
Subbase CBR pavement centerline		52	44	59
Subbase CBR 4-wheel traffic path inside the wheel track		50	38	122
Subbase CBR 4-wheel traffic path outside the wheel track		15	52	76

Each entry is the average of three tests, three penetrations per test.

A.4 REFERENCES.

A-1. Burns, C.D., Ledbetter, R.H., and Grau, R.W., "Study of Behavior of Bituminous-Stabilized Pavement Layers," Miscellaneous Paper S-73-4, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, March 1973.

A-2. FAA Advisory Circular, "Airport Pavement Design and Evaluation," AC 150/5320-6D, 1995.

APPENDIX B—PASS-TO-COVERAGE RATIOS FOR NAPTF WANDER PATTERNS

The coverages to failure given in the multiple-wheel heavy gear load (MWHGL) report [B-1] for flexible pavements were computed by considering the number of times the surface of each area of pavement was covered by one of the tires on the trafficking gear. The coverages on the area of pavement suffering the largest number of coverages over one complete wander cycle is divided by the number of repetitions in one complete wander cycle to give the coverage-to-pass ratio. The pass-to-coverage ratio is the reciprocal of the coverage-to-pass ratio.

Tables B-1 and B-2 give the pass-to-coverage ratios and the coverage-to-pass ratios for the NAPTF tests computed in the same way as for the MWHGL tests. Figure B-1 illustrates the procedure used to find the number of surface coverages in one wander cycle for the two dual-wheel spacings used in the NAPTF tests.

TABLE B-1. PASS-TO-COVERAGE RATIOS AT THE PAVEMENT SURFACE FOR FLEXIBLE PAVEMENTS

		Pass-to-Coverage Ratio		
Dual Spacing		One Axle (dual)	Two Axles (dual tandem)	Three Axles (triple-dual-tandem)
in.	cm			
54	137.2	66 / 14 = 4.71	2.36	1.57
44	111.8	66 / 16 = 4.12	2.06	1.38

Compatible with the MWHGL pass-to-coverage ratios for full-scale tests.

TABLE B-2. COVERAGE-TO-PASS RATIOS AT THE PAVEMENT SURFACE FOR FLEXIBLE PAVEMENTS

		Coverage-to-Pass Ratio		
Dual Spacing		One Axle (dual)	Two Axles (dual tandem)	Three Axles (triple-dual-tandem)
in.	cm			
54	137.2	14 / 66 = 0.21	0.42	0.64
44	111.8	16 / 66 = 0.24	0.48	0.73

Compatible with the MWHGL coverage-to-pass ratios for full-scale tests.

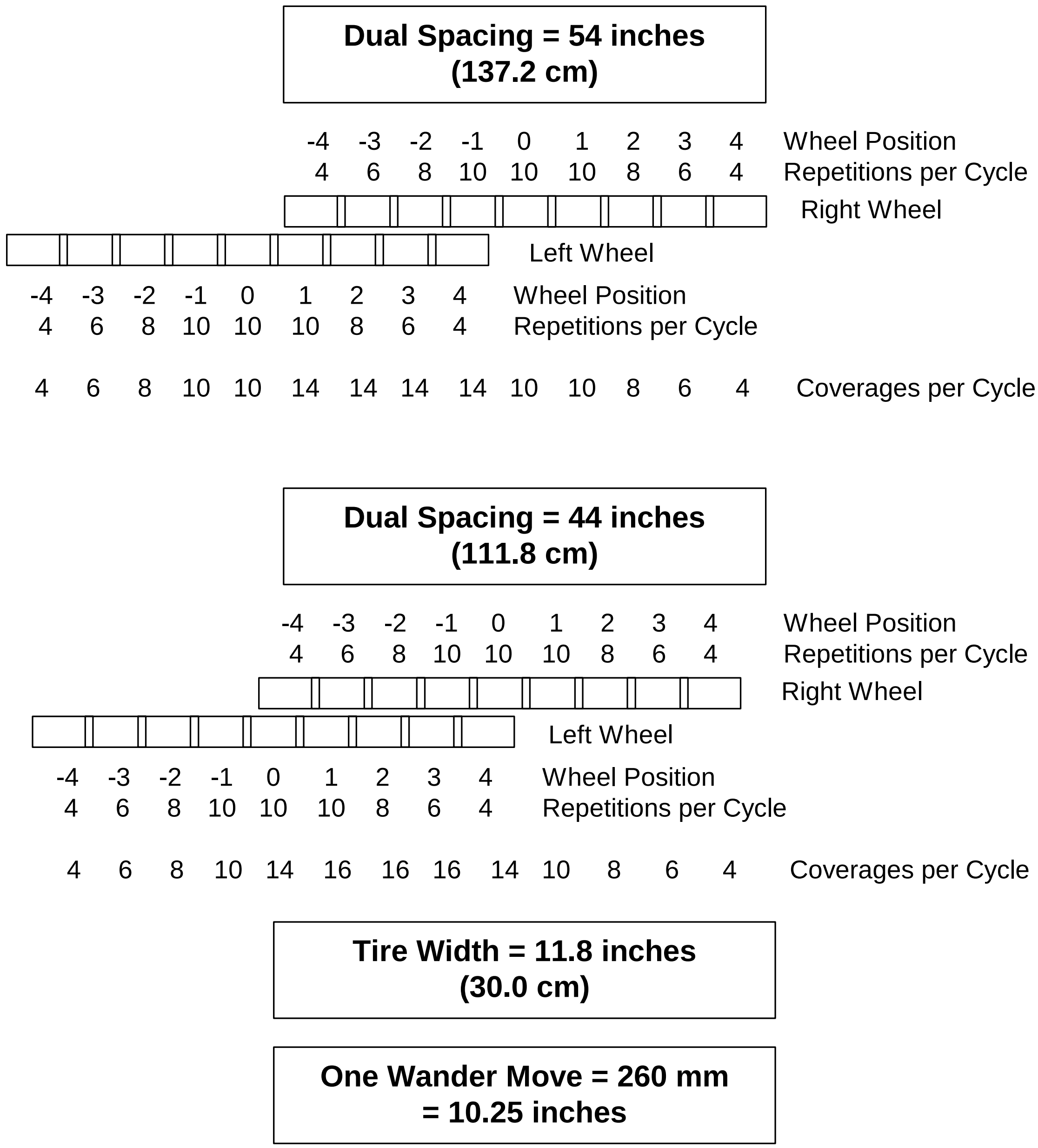

FIGURE B-1. SCHEMATICS OF LATERAL TIRE COVERAGE POSITIONS FOR ALL WANDER POSITIONS IN ONE CYCLE
(Dual spacings were 44 inches (111.8 cm) for the 4-wheel CC1 tests and 54 inches (137.2 cm) for all other configurations (CC1 6-wheel, CC3 4-wheel, and CC3 6-wheel.)

B.1 REFERENCES.

B-1. Ahlvin, R.G., Ulery, H.H., Hutchinson, R.L., and Rice, J.L., "Multiple-Wheel Heavy Gear Load Pavement Tests, Volume I, Basic Report," Technical Report AFWL-TR-70-113, Vol. I, Air Force Weapons Laboratory, November 1971.