ral Aviation Agency

DVISORY
IRCULAR

AC NO: AC 150/5320-8
AIRPORTS
EFFECTIVE: 4/5/63

: AIRPORT PAVING DESIGN CURVES BASED ON GROSS AIRCRAFT WEIGHT

)SE. This circular presents supplementary information which changes current Federal Aviation Agency airport pavement design standards equivalent load on a single isolated wheel terms to gross aircraft it terms.

ENCE. The material in this circular supplements the pavement design es found in Chapter III, Airport Paving, dated November 1962, a nt of the 1956 edition without technical changes. Airport Paving old for 45 cents by Superintendent of Documents, U. S. Government ing Office, Washington 25, D.C.

CATION. It is the intention that the provisions of this circular pplied in determining the strength of airport pavements and for nent designs of new projects under the Federal-aid Airport Program ated after the indicated effective date.

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1. INTRODUCTION.

a. The current airport pavement design curves of the Federal Aviation Agency are outlined in Chapter III of the publication, "Airport Paving", dated November 1962. The design curves refer to the strength of an airport pavement in terms of equivalent load on a single isolated wheel. Employment of single load as the standard strength unit necessitated adoption of procedures for resolving the loads on several wheels of multiple wheel gear aircraft to equivalent single isolated wheel loads. It became evident within the past few years that this ESWL design has been misunderstood and misinterpreted by various segments of the aviation community. This was largely due to the fact that as the industry expands more individuals outside the field of airport pavement design become interested in this subject.

b. This condition made it extremely desirable to present the design curves in terms which can be readily understood by all interested parties. For this reason, FAA modified its pavement design procedure from terms of equivalent single wheel load to terms of gross aircraft weight. With this presentation, the required pavement thickness for a specific aircraft at a particular airport can be determined from the following readily available information: the gross aircraft weight; the type of main gear undercarriage (single, dual, or dual-tandem); and the FAA subgrade classification at the airport. Thus, the necessity for converting from multiple wheel loads to equivalent isolated single wheel loads is eliminated.

c. The principal modifications made to the previous design curves are:

(1) The main undercarriages of the aircraft are now assumed to support 95% of the total weight of the aircraft instead of 90%. Practically all current civil aircraft are supported on a tricycle arrangement of landing wheels consisting of a nose gear and two main undercarriage assemblies. For design purposes in the past, it has been assumed that 10% of the aircraft weight was supported by the nose gear and the remaining 90% was distributed equally between the two main undercarriage assemblies. Recent information of current aircraft indicates that from 88% to 98% of the aircraft weight may be distributed to the main gear depending upon the type of aircraft and whether the aircraft is loaded with a forward or aft center of gravity. Due to this variation, it is desirable to consider that 5% of the weight is supported by the nose gear and that the remaining 95% is distributed equally between the two main undercarriage assemblies. The design curves based on gross aircraft weight will cover the three types of main gear assemblies in current use (single, dual, and dual-tandem). As new aircraft are developed with other gear arrangements, new design curves will be developed for them in the same manner as that described herein.

(2) The design curves, as previously stated, were changed to reflect gross aircraft weights instead of single wheel loads. The new curves will simplify the pavement thickness design procedures.

2. DEVELOPMENT OF NEW CURVES. In order to convert from equivalent single wheel load design to that based on gross aircraft weight, it was necessary to make some reasonable compromise on the effects of gear dimensions of existing civil aircraft. Although there was considerable variation, a study of the wheel spacings for current aircraft indicated a trend toward increased spacing as the aircraft weight increases. For this reason, a variation in wheel spacing was used for both flexible and rigid design curves in which the narrower spacings were used at the lighter weights and the wider spacings were used at the heavier weights.

a. Rigid Pavement Curves.

(1) The previous method of converting multiple wheel loads to equivalent single wheel loads involves the use of a rigid pavement design curve (shown as Figure 10 of Airport Paving) which was developed empirically from comprehensive pavement performance surveys conducted by FAA together with a conversion method developed by the United Kingdom. This method utilized nests of curves taking into account the spacing of wheels of the undercarriage and the area of contact of the tire prints. In using this method in an attempt to prepare the new gross weight curves, it was found that for equal single wheel loads and ESWL loads on dual and dual-tandem gears the stresses were not equal. This was understandable since Figure 10 in itself was not consistent in stress; and the nests of curves developed by the United Kingdom were simplifications prepared from Dr. H. M. Westergaard's formulae.

(2) It was necessary to use the "Influence Charts for Concrete Pavement", developed by Pickett and Ray, to prepare the new curves. The following parameters were used in this work:

k = 300 pounds per cubic inch

s = 400 psi working stress

q = 150 psi tire pressure

E = 4,000,000 psi

Poisson's Ratio = 0.15

Dual Spacing = 20 and 30 inches

Dual-Tandem Spacing = 20 x 45 and 30 x 55 inches

(3) The 20-inch spacing represents a more critical arrangement for a dual gear undercarriage while the 30-inch spacing represents a less critical arrangement. Likewise, a 20 x 45-inch spacing for a dual-tandem gear undercarriage represents a more critical arrangement while the 30 x 55-inch spacing represents a less critical arrangement.

(4) Two design curves (gross aircraft weight versus pavement thickness) for the dual gear aircraft were prepared using the appropriate parameters previously shown. A compromise curve was drawn between these two curves in which the narrower spacing was favored for the lighter aircraft and the wider spacing for the heavier aircraft. The same procedure was used for the dual-tandem undercarriage. The curve for single wheel gear aircraft was developed from the influence charts. All of these curves are presented on Figure 1.

(5) The single wheel curve together with the compromise dual and dual-tandem gear aircraft curves represent the rigid pavement design curves and are shown on Figure 2. The rigid pavement thickness requirements for critical areas are determined by use of the top group of design curves given in Figure 2. For noncritical areas, it is only necessary to take 80% of the portland cement concrete pavement as determined from those curves. This thickness should not be less than 6 inches. Note that subbase requirements for both critical and noncritical areas are determined from the critical pavement thickness requirements; there is no reduction in subbase thickness in noncritical areas.

b. Flexible Pavement Curves.

(1) Since the design thickness for single wheel gear aircraft is determined by the load on one wheel or gear and is independent of depth, it was only necessary to multiply the single wheel load scale by 1/0.475. This then represents the gross aircraft weight requirements for single wheel gear aircraft and is shown on Figure 5.

(2) As in the case of rigid pavements, it was necessary to make some reasonable compromise on gear dimensions in order to convert from equivalent single wheel loads to gross aircraft weight. For flexible pavement, the measurements in question are the clear space between dual tires (d), the wheel spacing (S) for dual gear aircraft, and the diagonal spacing from one front wheel to the diagonally opposite rear wheel (S_D) for dual-tandem aircraft. These dimensions are shown on Figure 15 of Airport Paving. These dimensions again tend to increase as the weight of the aircraft increases. Plots of these dimensions

for most multiple wheel undercarriages indicate that a straight-line variation between 15,000 pounds and 50,000 pounds with corresponding d/2 dimensions of 5 inches and 10 inches, respectively, would satisfy most of these dual and dual-tandem gears. These plots are represented by "line a" on Figures 3 and 4 for dual and dual-tandem gear aircraft. These plots also indicate that a straight-line variation between 15,000 pounds and 100,000 pounds for 2S dimensions of 35 inches and 60 inches, respectively, would satisfy most dual gear aircraft. These plots are represented by "line b" on Figure 3. Additionally, the variation between 50,000 pounds and 200,000 pounds for $2S_D$ dimensions of 80 inches and 130 inches, respectively, would satisfy most dual-tandem gear aircraft. These plots are represented by "line d" on Figure 4.

(3) Lines representing dual gear aircraft with gross weights of 50,000; 100,000 and 200,000 pounds were plotted on Figure 3. A new graph was plotted (Figure 6) with gross aircraft weight on the vertical axis and the total pavement thickness on the horizontal axis on a log-log scale. From Figure 3, total pavement thickness requirements for each gross aircraft weight were plotted for each subgrade classification. Connection of the three points (for 50,000; 100,000 and 200,000-pound gross weights) for each subgrade classification by a straight line resulted in the reorientation of the subgrade curves. Figure 7 for dual-tandem gear aircraft was established by using Figure 4 in a like manner.

(4) The dashed lines on Figures 5, 6 and 7, representing the required nonbituminous base course thickness for critical and noncritical areas, were derived from existing base course thickness requirements. The area between two dashed lines represents those gross weights where the same base course thickness is required. This base course thickness requirement is indicated along the right edge of the F10 subgrade classification line.

(5) The bituminous surface course has been modified to a uniform 3-inch thickness for critical areas in lieu of a variable thickness. The surfacing for noncritical area thickness remains at 2 inches. No change has been made with respect to the basic principle of substituting a thinner base thickness when Item P-201 is used.

3. DESIGN EXAMPLES. As an example in the use of these curves, we will assume that the soil group is E-7 and that poor drainage and severe frost conditions exist. This results in a subgrade classification of Rc and F6 for rigid and flexible pavement, respectively. It is further

assumed that a preliminary design has determined that a 160,000-pound dual gear aircraft is the critical aircraft. Using the appropriate curves, the following design thicknesses are determined:

RIGID

Critical Area	Noncritical Area
11" PCC	9" PCC
9.5" Subbase	9.5" Subbase

FLEXIBLE

Critical Area	Noncritical Area
3" AC	2" AC
10" Base (Nonbituminous)	8" Base (Nonbituminous)
17" Subbase	14" Subbase
30"	24"

a. Explanation of the Rigid Pavement Design.

(1) The upper portion of Figure 2 is entered on the left at the appropriate gross aircraft weight (point a) and a horizontal line is projected until it intersects the "dual" curve at point a'. A line is then projected vertically downward from point a' until it intersects the pavement thickness scale at t (11.3 inches in this case). The concrete thickness for the critical area will be 11 inches since the fractional thickness is under 0.5 inch. The noncritical area concrete thickness is obtained by taking 80% of the critical area concrete thickness.

(2) The subbase thickness is obtained by extending line a't down until it intersects the Rc subgrade classification line at point 1. This point (point 1) is then projected horizontally to the left until it intersects the subbase thickness scale at point 1'. The subbase thickness can then be read (9.5 inches). Note that the subbase thickness is predicated on the critical area pavement thickness and is used for both the critical and noncritical areas.

b. Explanation of the Flexible Pavement Design.

(1) Figure 6 is entered on the left at the appropriate gross aircraft weight (point a) and a horizontal line is projected until it

intersects the F6 subgrade classification line (point a'). From point a', project a vertical line up and down until it intersects the total pavement thickness scales at the top (24 inches) and bottom (30 inches) of the graph, which determine the noncritical area and critical area total pavement thicknesses, respectively. From point a', proceed to the right parallel to the sets of dashed lines until the base thickness scale is intersected. The base thicknesses for the critical areas (10 inches) and noncritical areas (8 inches) are obtained. The note on the graph indicates that 3 inches of asphaltic concrete surface is required for critical areas and 2 inches of asphaltic concrete surface is required for noncritical areas.

(2) The flexible pavement design is completed by subtracting the surface and base thicknesses from the total thickness to obtain the subbase thickness. The critical area calculations are shown in the following example: 30" - (3"+10") = 17" subbase. Final design: 3" asphaltic concrete surface, 10" base, 17" subbase.

(3) In the above example, it was stated that a 160,000-pound dual gear aircraft was considered to be the critical aircraft for pavement design thickness. It should be noted that the heaviest aircraft of each type (single, dual, and dual-tandem) must be analyzed to determine which one is critical for the flexible pavement design with respect to a specific subgrade classification. The same aircraft may not necessarily control for all subgrade classifications.

(4) As an example, consider a 160,000-pound dual gear aircraft and a 240,000-pound dual-tandem gear aircraft. The 160,000-pound dual gear aircraft controls the pavement thickness for all subgrade classifications up to and including F7, and the 240,000-pound dual-tandem gear aircraft controls the pavement thickness for the remaining subgrade classifications.

4. COMPARISON BETWEEN OLD AND NEW DESIGN METHODS.

a. Critical area pavement thicknesses were determined for different aircraft on various subgrade classifications using the old and the new design curves. In making this comparison for rigid pavements, the following gross weight aircraft were considered: Example 1 - 40,000-pound single wheel; Example 2 - 160,000-pound dual gear; Example 3 - 240,000-pound dual-tandem gear. The following table shows this comparison:

	Example 1		Example 2		Example 3	
Pavement Component	Old	New	Old	New	Old	New
Concrete	7"	7"	11"	11"	10"	11"
Subbase	The thickness requirements for the subbase have not been changed.					

b. For flexible pavement design, the same aircraft were used for several subgrade classifications. The table below gives a summary of this comparison for the aircraft and subgrade classifications indicated.

	Example 1 - F2		Example 2 - F6		Example 3 - F9	
Pavement Component	Old	New	Old	New	Old	New
Surface	2"	3"	3"	3"	3"	3"
Base	7"	6"	10"	10"	10"	11"
Subbase	2"	2"	16"	17"	30"	31"

c. It can be seen from the above tables that the design pavement thicknesses of the new method compare very favorably with those of the previous method.

d. The new pavement design curves present a simplified method of arriving at these comparable thicknesses and should eliminate the misinterpretations associated with the ESWL method.

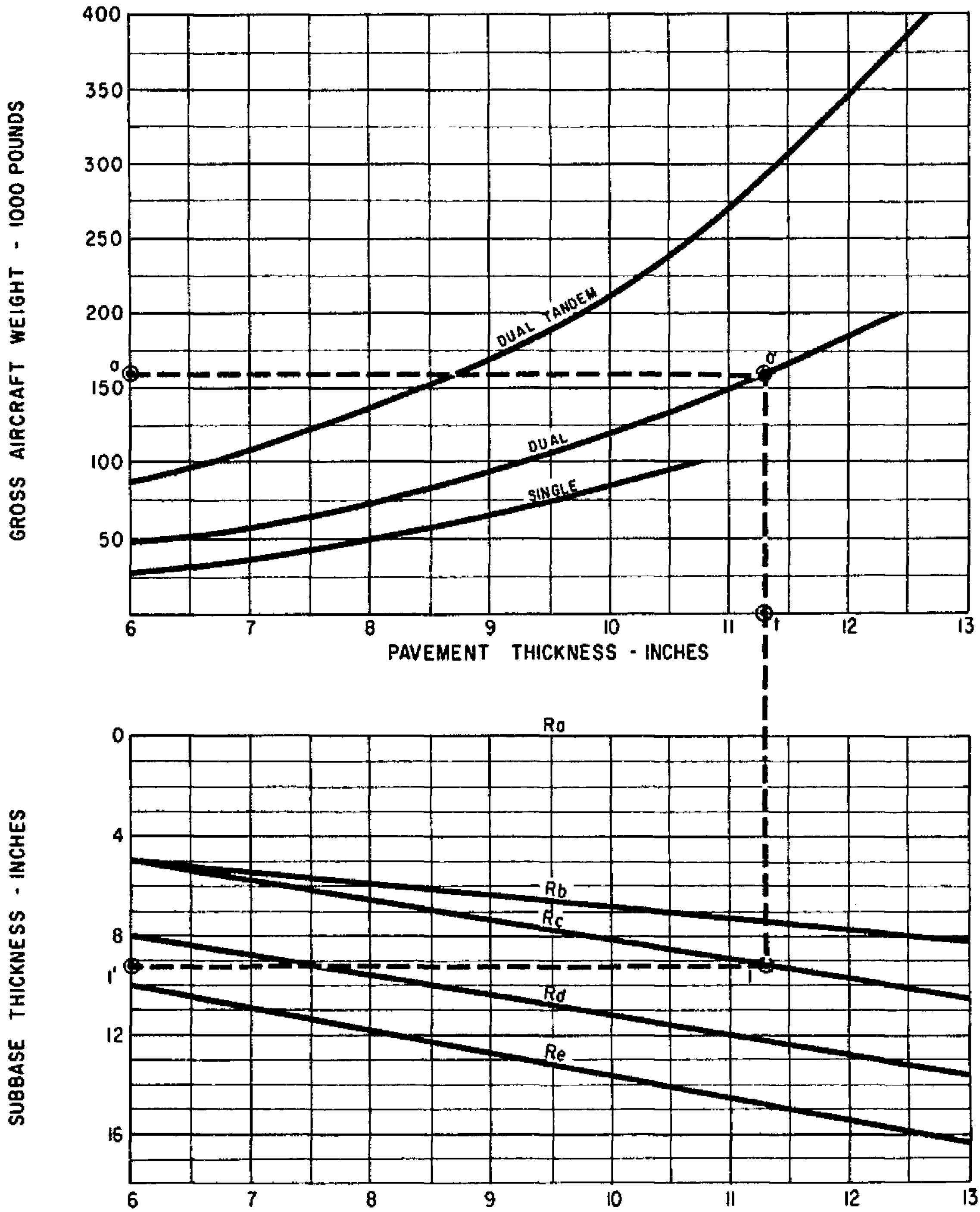

FIGURE 2 DESIGN CURVES - RIGID PAVEMENT CRITICAL AREA

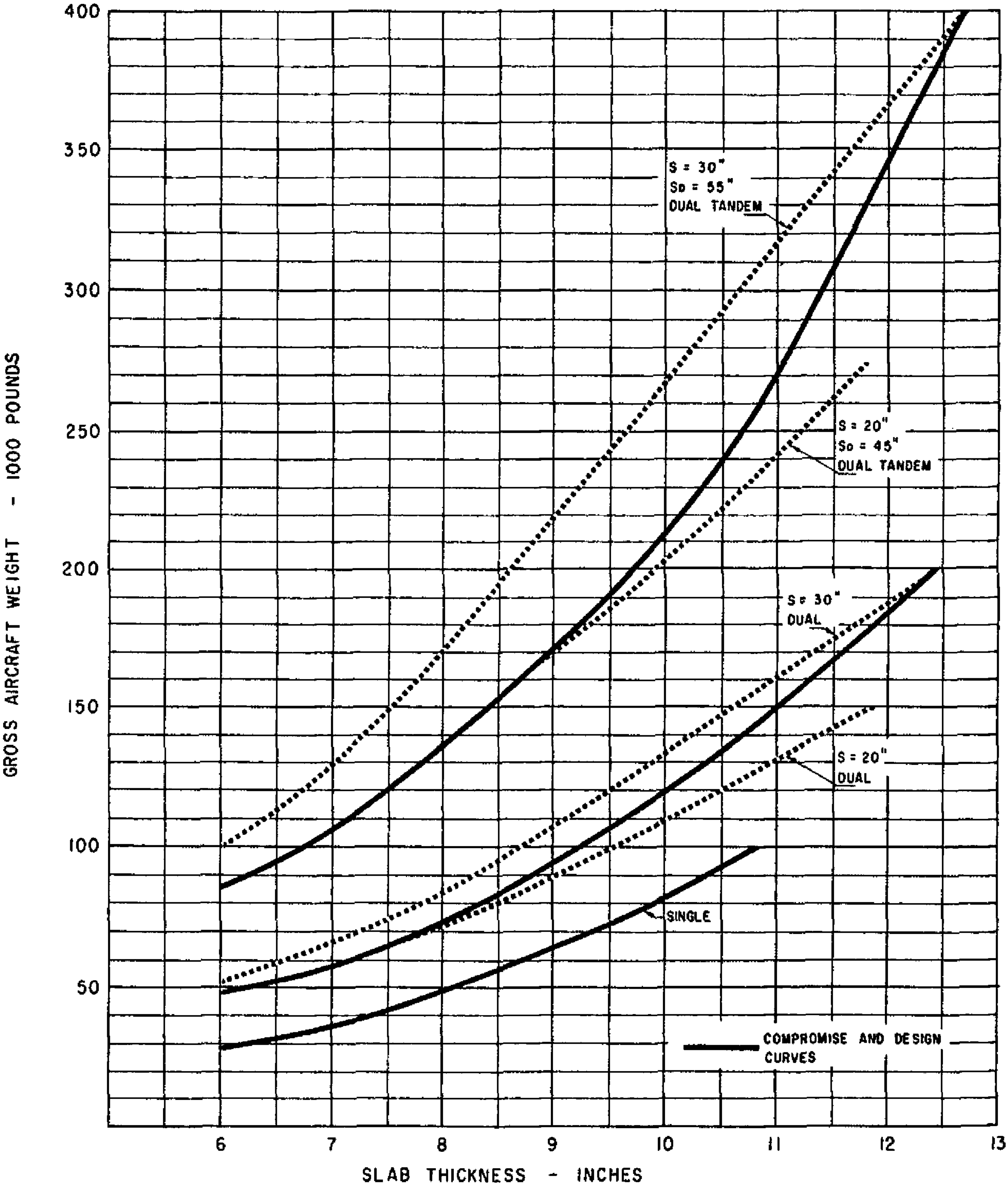

FIGURE 1 DEVELOPMENT OF RIGID PAVEMENT CURVES

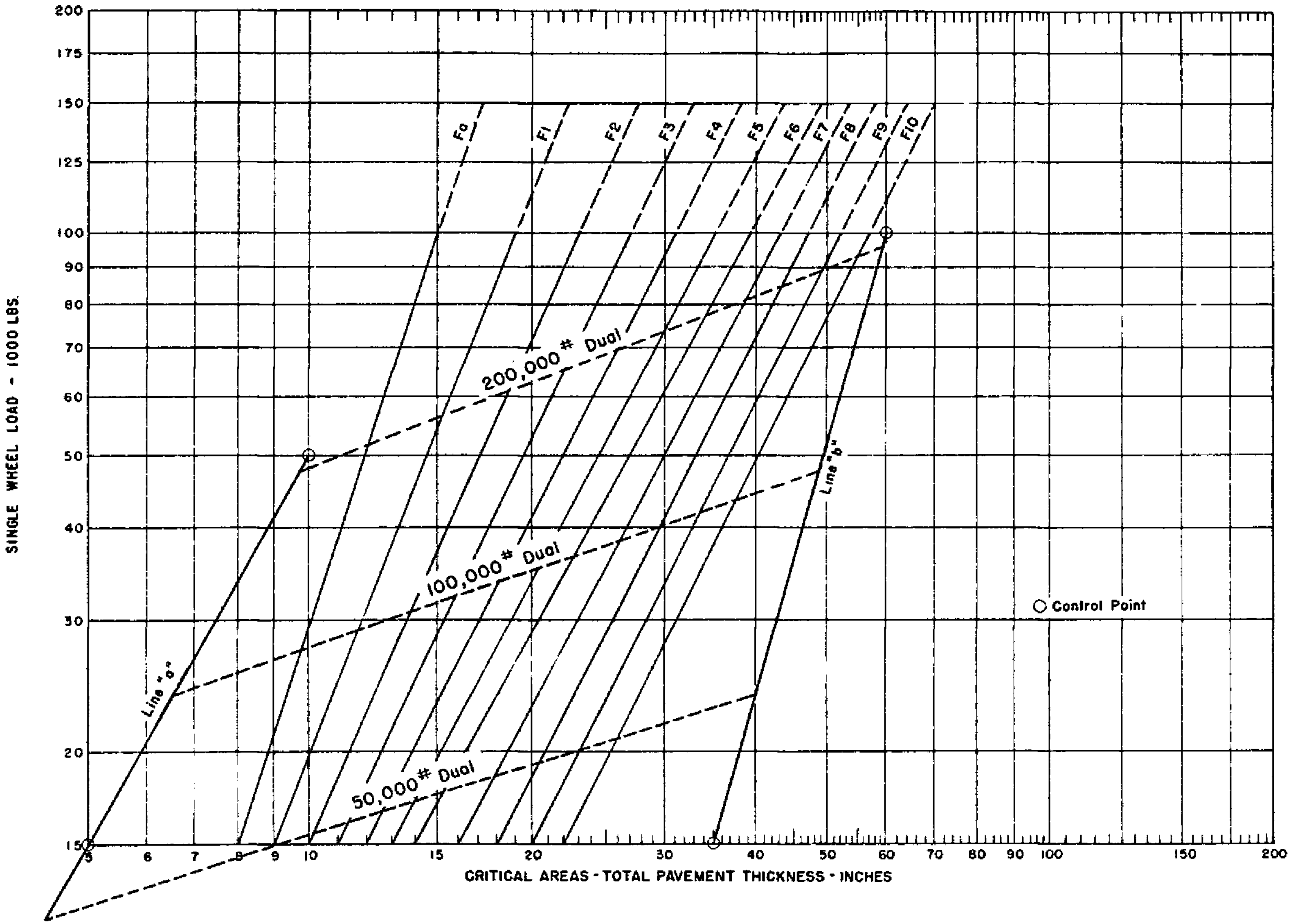

FIGURE 3 DEVELOPMENT OF FLEXIBLE PAVEMENT CURVES - DUAL GEAR

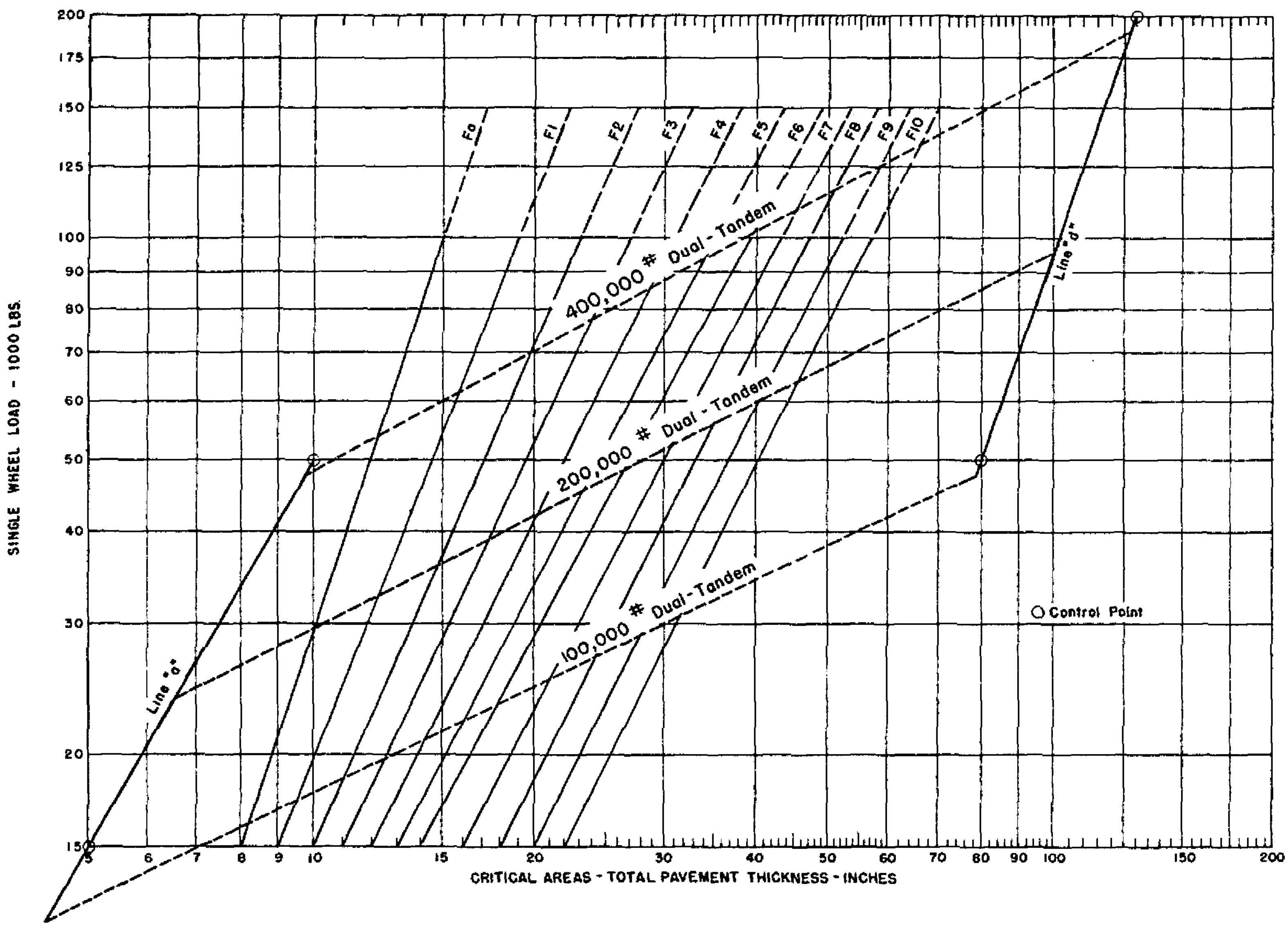

FIGURE 4 DEVELOPMENT OF FLEXIBLE PAVEMENT CURVES - DUAL-TANDEM GEAR

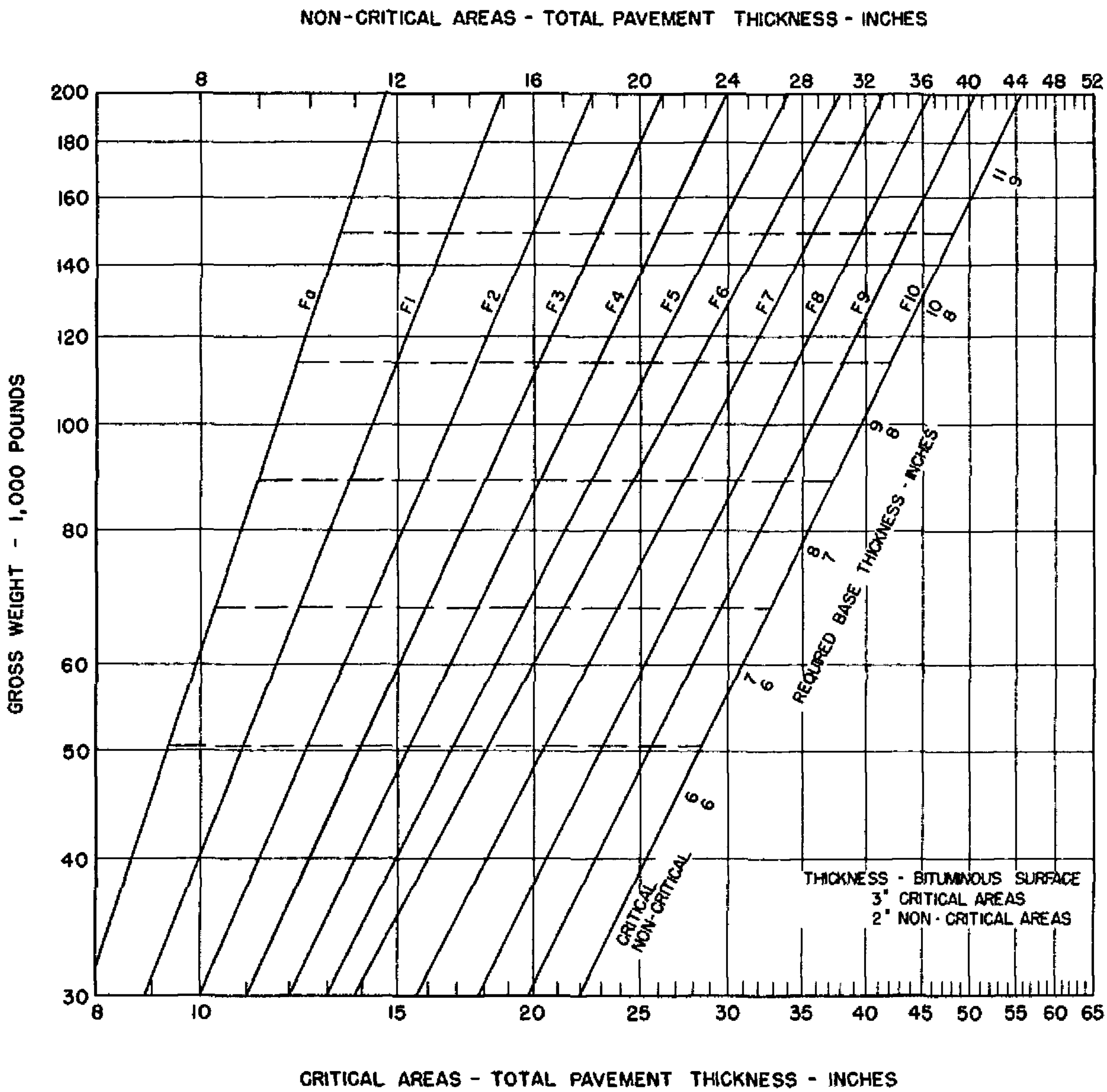

FIGURE 5 DESIGN CURVES - FLEXIBLE PAVEMENT SINGLE GEAR

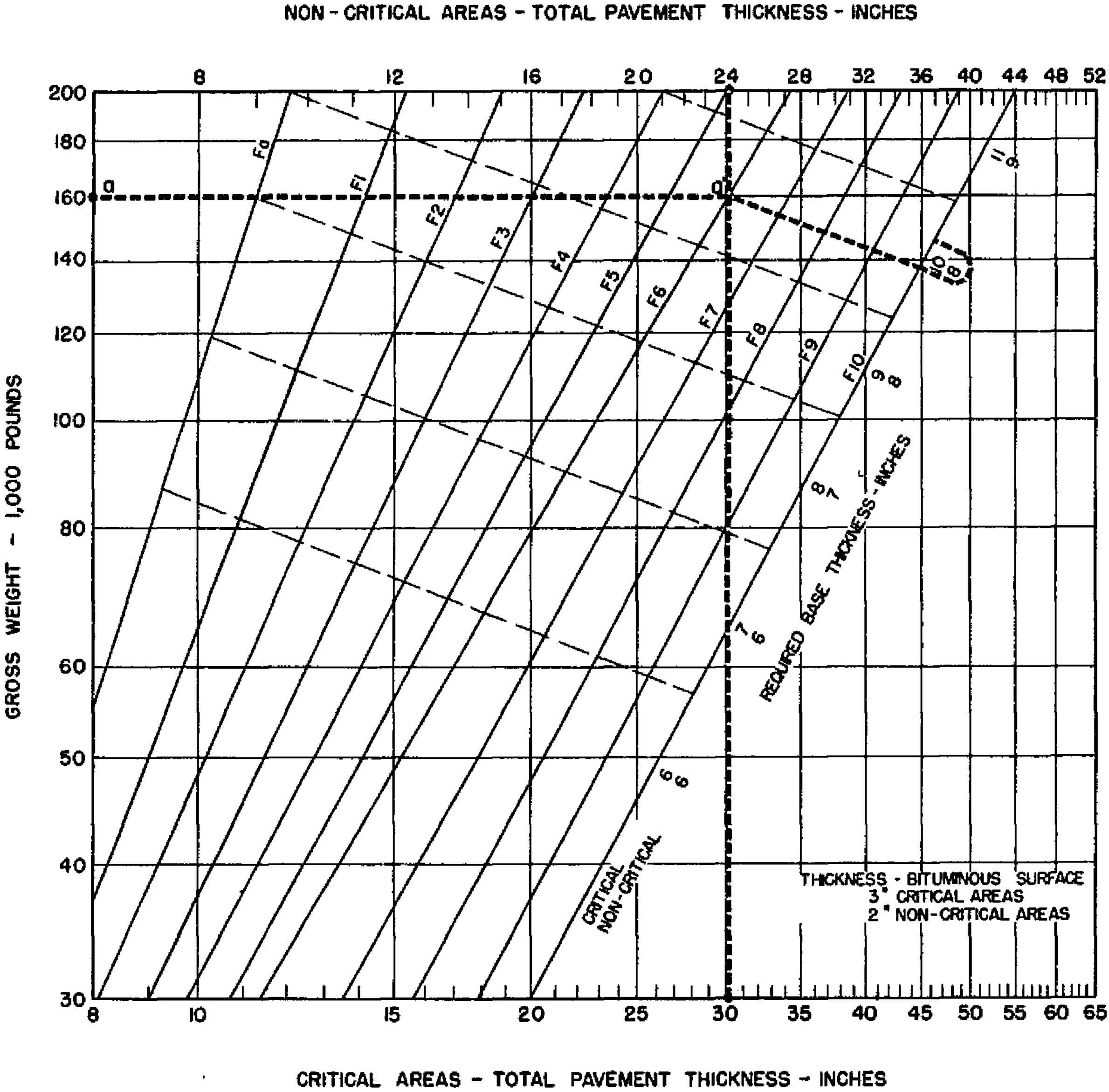

FIGURE 6 DESIGN CURVES - FLEXIBLE PAVEMENT DUAL GEAR

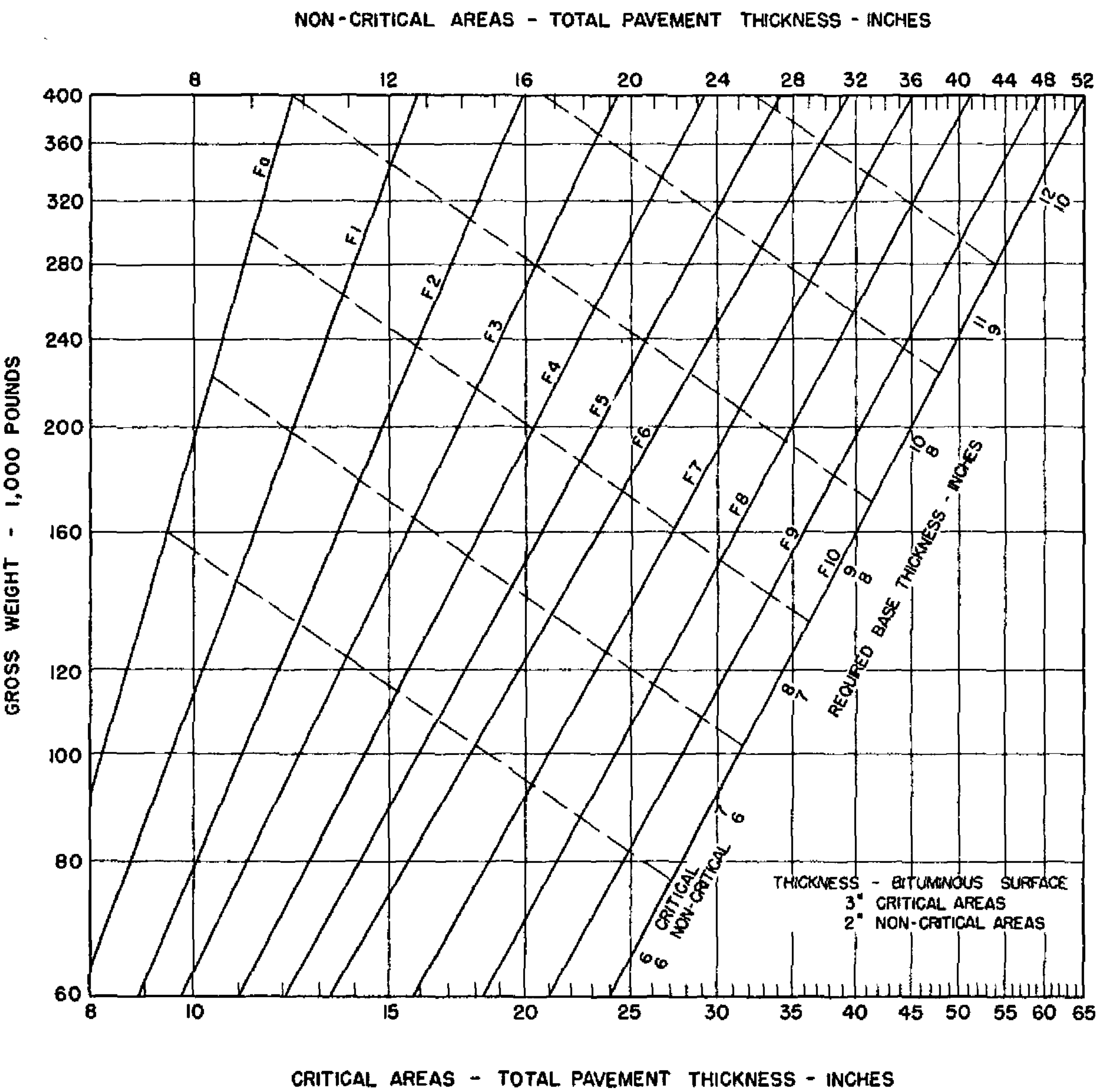

FIGURE 7 DESIGN CURVES - FLEXIBLE PAVEMENT DUAL-TANDEM GEAR

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