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Superseding AIR1780A

(R) Aircraft Flotation Analysis

RATIONALE

Recent regulatory changes have introduced new standards for international flotation calculation and reporting. The document is updated to bring it into line with current and upcoming practice in flotation analysis.

1. SCOPE

This document is divided into five parts. The first part deals with flotation analysis features and definitions to acquaint the engineer with elements common to the various methods and the meanings of the terms used. The second part identifies and describes current flotation analysis methods. Due to the close relationship between flotation analysis and runway design, methods for the latter are also included in this document. As runway design criteria are occasionally used for flotation evaluation, including some for runways built to now obsolete criteria, a listing of the majority of these criteria constitutes the third part. The fourth part of this document tabulates the most relevant documents, categorizing them for commercial and civil versus military usage, by military service to be satisfied, and by type of pavement. This document concludes with brief elaborations of some concepts for broadening the analyst's understanding of the subject. At revision B of this document, significant new material added is adapted from Reference [34], Schmidt, R. Kyle, *The Design of Aircraft Landing Gear*, SAE International, 2020.

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Documents

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1.1 Purpose

This document provides an overview of concepts in flotation, historical approaches, and background on currently accepted methods. For the most recent recommended methods, the reader is referred to ARP1821. An overview of historical cooperation on the flotation topic between SAE and the U.S. Army Corps of Engineers is found in AIR4243.

Aircraft flotation analysis can be characterized by a variety of methods, and this may lead to confusion. Sources of this variety are at least fourfold. First, the foundation of all runways, taxiways, and airside pavements is soil, which is not a homogenous material. Not only does it vary widely from place to place, but it also varies with time and/or as a function of the weather. Although soils have been classified into a limited number of groups, variability within each group prevents soil classification from providing a complete answer for defining properties of interest to the flotation analyst. A second source of flotation's varied nature stems from the diverse method used by different agencies and countries in solving their particular problems with the materials they have at hand. Third, the economics involved dictates, and will continue to dictate, differences in methods applicable to a given pavement construction. Fourth, and finally, the military is particularly interested in operation on semi-prepared and unpaved areas, such as mats, membranes, and unsurfaced soil. Although technology has not produced a uniform methodology, efforts have been applied in this direction on an international scale. While the product of these efforts cannot provide a total focus in the foreseeable future, a uniform method of reporting aircraft flotation has been adopted with good success. This method, termed Aircraft Classification Number/Pavement Classification Number (ACN/PCN), is supported around the world as a result of its promulgation by the International Civil Aviation Organization (ICAO) as a single airfield weight-bearing reporting method. ACN/PCN was devised for conventional flexible and rigid pavements and was not made applicable to mat, membrane, and unsurfaced soil landing fields. In order to update this successful reporting method to take into account more modern pavement analysis approaches, the ICAO is introducing a replacement method, the ACR/PCR system. Flotation analysis will continue to be concerned with the broad array of methods for design, evaluation, and weight bearing reporting of pavements and rapidly prepared unpaved landing areas. With the above in mind, the purpose of this document is to inform the aircraft flotation analyst of the various methods likely to be used and to characterize them for evaluating the capability of aircraft to operate on airport runways, taxiways, and airside pavements.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

Aircraft Ground Flotation Analysis Methods, ARP1821, Revision B, April 2016.

Landing Area/Landing Gear Compatibility - A Brief History of SAE/Corps of Engineers Cooperation, AIR4243, Revision A, December 2014.

2.1.2 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass, D2216, March 2019.

Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils, D4318, June 2017.

Standard Test Method for California Bearing Ratio (CBR) of Laboratory-Compacted Soils, D1883, December 2021.

Standard Test Method for CBR (California Bearing Ratio) of Soils in Place, D4429, February 2018.

2.1.3 U.S. Department of Defense Publications

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MIL-STD-621, Subgrade, Subbase, and Test Method for Pavement Base-Course Materials, Revision A, CN2, December 1968.

2.1.4 Other Publications

(Accession numbers for procurement from Defense Documentation Center shown in parentheses at the end of reference where applicable.)

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3. FLOTATION ANALYSIS FEATURES AND DEFINITIONS

In order for the aircraft designer to ensure that satisfactory flotation characteristics are incorporated in an aircraft, one or more of the many available specialized analytical methods must be applied. Since the problem involves the interaction of the aircraft and the runway, analysis methods developed over the years require use of both aircraft and runway characteristics. Therefore, this section includes brief descriptions of pertinent aircraft and airfield parameters, and also serves to introduce the degree of specialization of the analytical methods which are discussed in Section 4.

3.1 Flotation Definition

Aircraft flotation is a measure of an aircraft's ability to operate over an airfield surface without applying an unduly severe loading to the airfield surface. The surface may be paved or unpaved and includes both runway and taxiway areas. In general, lower tire loads and/or lower tire pressures induces less stress on the various layers of runway surfaces, thereby increasing flotation capability. Increasing the number of tires on gears can also increase flotation capability when a specific flotation capability is a desired operational requirement.

3.2 Aircraft Flotation Parameters

Aircraft parameters which are pertinent to its flotation characteristics, and which typically are inputs to the analytical methods discussed in Section 4, include wheel load, tire contact area or pressure, and tire footprint spacing. Tire inflation pressure relates the wheel load and tire contact area. Two types of wheel loads are considered, as applicable. For landing gear with one wheel the applied load is termed single wheel load (SWL). For multi-wheel landing gear, the term equivalent single wheel load (ESWL) has assumed a decisive role in reflecting the cumulative effect of multiple wheel loads.

All early pavement design, and flotation methodology also, were concerned with single-wheel landing gear. With the advent of multiple-wheel landing gear, initially dual and dual-tandem wheel gear, the established single wheel design and flotation technology were extended to accommodate multiple-wheel loadings by establishing the concept of ESWL.

The conclusions of Technical Report AFWL-TR-70-113 [33], state: "based on the analysis, the principle of superposition is not valid, and stress-strain characteristics of the soil are nonlinear and dependent on stress level." This conclusion, therefore, invalidates the concept of ESWL since ESWL is entirely dependent on the principle of superposition. Regardless, ESWL is still the dominant concept in pavement design and evaluation primarily because pavement designs based on this criteria have performed well and because currently, there is no technique that is clearly superior.

3.2.1 Definition of ESWL

ESWL is the load which, if applied to a single wheel would have the same effect on the runway as the particular multiple wheel arrangement being considered. Since the ESWL is a conceptual load on a single tire larger than the load on the one tire of the multiple wheel configuration it represents, and since load relates directly to pressure and tire contact area, it is necessary to arbitrarily select some aspect of the pressure-contact area relation in order to specifically evaluate ESWL for design or flotation. This can be – and has been – done in various ways, which should be understood to avoid misapplication of flotation concepts. The Army Corps of Engineers, waterways experiment station (WES), make use of the contact area of the one wheel of a multiple-wheel gear to define ESWL for flexible pavements. For load classification number (LCN) purposes discussed in 5.1.9, the British select the tire pressure of the multiple-wheels and let contact area increase to permit the determination of ESWL. Occasionally, a contact area is fixed without relation to the tires or the actual gear, or in relation to the area of all tires together.

3.2.2 ESWL in Relation to Pavement

A pavement structure consists of strong upper layers distributing the high intensity tire loads at the surface to the weaker lower layers. The way in which pavement strength requirements vary from surface to subgrade is substantially different for single-wheel than for multiple-wheel landing gear. Thus, a specific ESWL can be based directly on depth (thickness) of pavement structure for flexible pavement and indirectly on radius of relative stiffness (1) for rigid pavement. It follows that the ESWL for a particular multiple-wheel configuration and load will be quite different for pavements on high strength subgrade (thinner pavement, smaller radius of relative stiffness), than for pavements of low strength subgrade (thicker pavement, larger radius of relative stiffness).

3.2.3 Radius of Relative Stiffness

Radius of relative stiffness, which is a function of the concrete's modulus of elasticity, thickness, Poisson's ratio, and the modulus of subgrade reaction, relates the stiffness of a concrete slab to that of the subgrade. It is used in determination of ESWL for rigid pavement. Figure 1 illustrates the physical meaning of this quantity.

3.3 Airfield Runway Parameters

Runway parameters pertinent to the analysis of aircraft flotation are basically pavement thickness and strength of the support beneath. Treatment by pavement type is as follows:

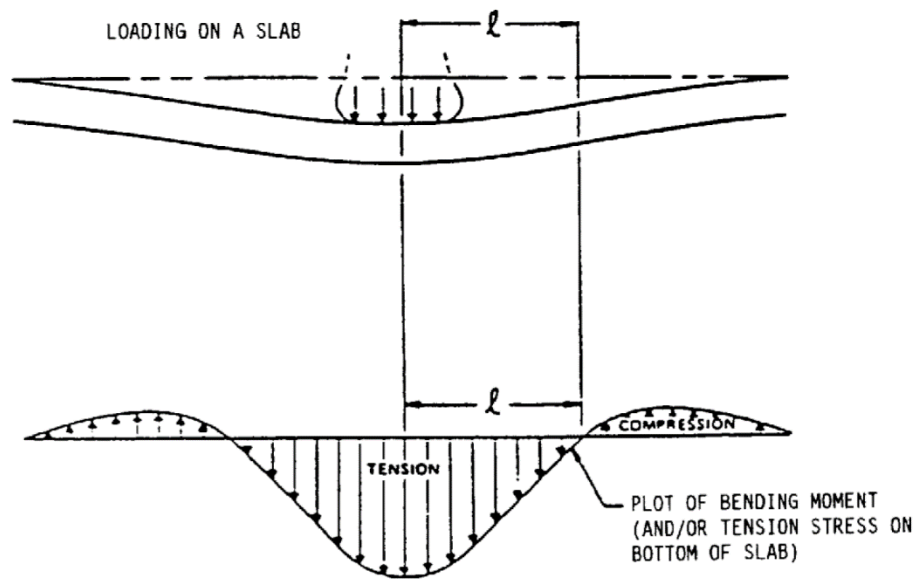


Figure 1 - Physical meaning of Westergaard's "radius of relative stiffness", l

3.3.1 Paved Surface

Paved surfaces can be classified according to the method of their construction as either rigid or flexible in most instances. Regardless of such classification they are all concerned with the performance of the subgrade on which they are built. Portions of a given pavement are also classified according to the nature and frequency of loading to which they are exposed. For instance, portions such as runway ends which are subject to sustained loads require stronger pavement than the central portions of the runway which are momentarily loaded. The military groups pavements into traffic areas. An example for a typical layout for heavy load Air Force pavements is shown in Figure 2.

3.3.1.1 Rigid Pavements

Rigid pavements are all basically made of Portland Cement concrete. After initial construction they may be overlaid to increase their load bearing capability. The thickness of the pavement is the thickness of the concrete and does not include the thickness of any strengthening layers that may exist between the subgrade and the concrete. Common rigid pavement thicknesses are 8 to 14 inches (20 to 36 cm). Rigid pavements can be jointed, reinforced or nonreinforced, continuously reinforced, fibrous reinforced, or prestressed.

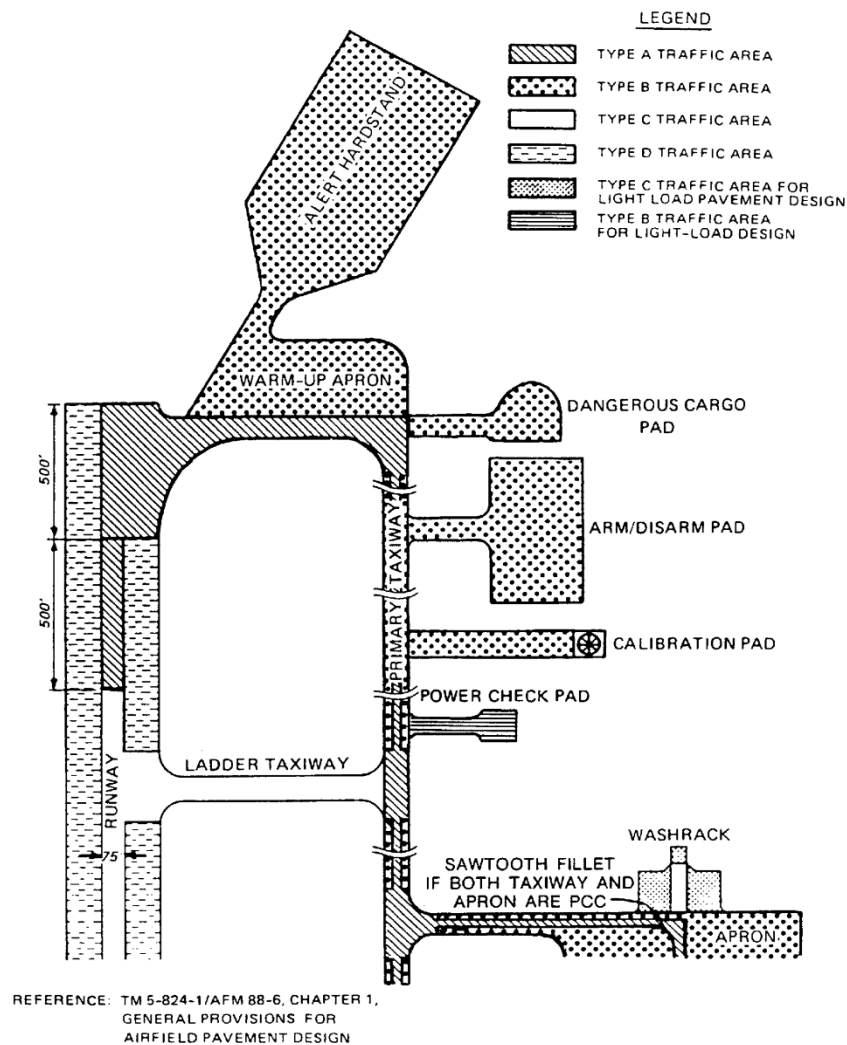


Figure 2 - Typical layout of Air Force heavy-load airfield

Pavement design considers three kinds of loading: interior, edge, and corner. Interior loading is that where the location of the load is remote from the edge of the slab. Loading across joints provides higher pavement moment, and therefore load transfer structure is frequently provided to transfer a portion of the edge load to the adjacent slab. Historically, design has been based on interior loading, considering that load transfer devices between adjacent edges cause the paved area to act as a continuous slab. In modern analysis, edge and corner loading are also considered.

Rigid pavement theory is historically based on the theories of Westergaard (references [1] and [2]) where the subgrade is assumed to act as a dense liquid. Several investigators have indicated that the subgrade probably behaves more as an elastic solid. Indeed, modern analysis methods now utilize a linear elastic method.

Although the Corps of Engineers prefers to measure the strength of rigid pavement in terms of its 90-day flexural strength, the modulus of rupture of concrete is often used. The range of modulus for design varies between 650 and 750 psi (4.48 and 5.17 MPa). This agrees with the nominal reported in reference [3], which also states that the minimum safety factors for critical areas and noncritical areas are 1.75 and 1.5, respectively. In some instances, these have been reported as low as 1.25 and as high as 2.0. Therefore, to allow for safety factors, the commonly used value for working stress is 400 psi (2.76 MPa).

3.3.1.2 Flexible Pavements

A flexible pavement is composed of one or more layers placed on a prepared subgrade and consists of a surface course of bituminous material (generally asphalt), a base course of treated or untreated granular material, and a subbase course of treated or untreated material. The complexity of their construction is illustrated in the schematic of Figure 3, which identifies the many layers that may be used. The total thickness of the pavement is usually considered the thickness above the subgrade. Common thicknesses of flexible pavements range from 8 to 60 inches (20 to 152 cm) or more. While not strictly a pavement, runways made of rolled gravel or crushed rock are used. For strength and flotation evaluation they are considered flexible pavements.

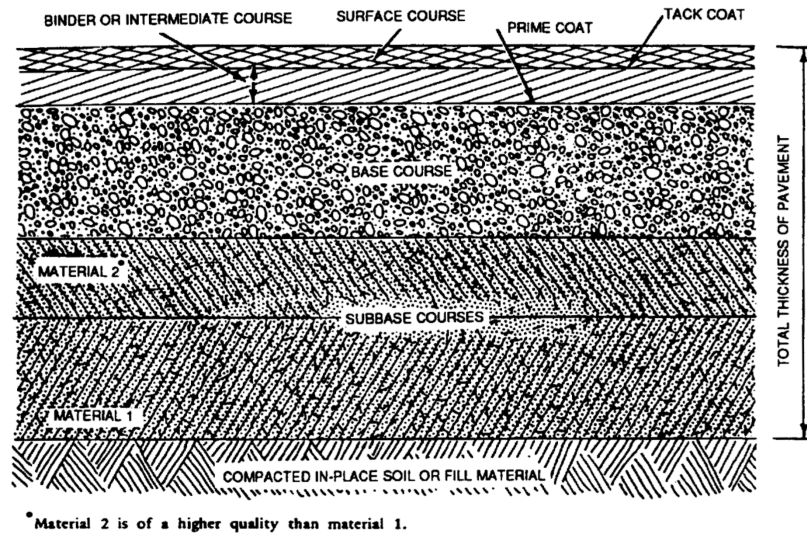
3.3.1.3 Other Pavements

Historically airfield pavements have been designed by a myriad of techniques, including many state highway methods. One that is unique was devised by the Port Authority of New York and New Jersey for use at airports under their control. The principal structure layer in the pavement is made of lime, cement, and flyash (L-C-F) mixed with sand.

Soil stabilization can be used to improve the load carrying capability and durability characteristics of soil through the use of admixtures such as cement, lime, bitumens, L-C-F, or a combination of these. Note that the term soil stabilization should not be confused with soil modification, which is used by the Corps of Engineers. For modification, additives are applied to improve the soil characteristics sufficiently to provide a working platform for airfield construction. In the case of soil stabilization credit is given for increase in strength, whereas it is not for soil modification.

3.3.1.4 Overlays

Overlays of concrete or asphalt are used to serve one or more purposes, such as extending the pavement service life, improving the surface topology, restoring the surface friction, or strengthening the pavement. Overlays are most commonly flexible; but rigid overlays on rigid pavements are used, and rigid overlays of flexible pavements are sometimes employed.



PAVEMENT	Combination of subbase, base, and surface constructed on subgrade
SURFACE COURSE	A hot mixed bituminous concrete designed as a structural member with weather and abrasion resisting properties. May consist of wearing and intermediate courses.
PRIME COAT	Application of a low viscosity liquid bitumen to the surface of the base course. The prime penetrates into the base and helps bind it to the overlying bituminous course
SEAL COAT	A thin bituminous surface treatment containing aggregate used to waterproof and improve the texture of the surface course
COMPACTED SUBGRADE	Upper part of the subgrade which is compacted to a density greater than the soil below
TACK COAT	A light application of liquid or emulsified bitumen on an existing paved surface to provide a bond with the super-imposed bituminous course
SUBGRADE	Natural in-place soil, or fill material

Figure 3 - Typical flexible pavement and terminology

3.3.2 Subgrade Strength

Subgrade strength is commonly defined by either the Modulus of Subgrade Soil or Soil Reaction or California Bearing Ratio (CBR). The modulus of subgrade reaction, k , is defined as the applied load in pounds per square inch divided by the soil deflection in inches. Thus, k has the dimensions of pounds per inch cubed, values usually considered varying from 50 to 500 (13.6 to 135.7 MN/m³). Base course materials are often placed over natural subgrade to improve the overall k value, which is typically associated with rigid pavement strength estimation. The CBR of the soil or subgrade is measured by either laboratory or field tests employing a standard loading device forcing a plunger into the soil. CBR is the load expressed as a percentage of the load required to obtain the same penetration in a standard, compacted, crushed-stone sample. The range of CBR usually considered is from 4, which will support airfield construction equipment, to 100. CBR is the strength parameter typically associated with flexible pavements and unpaved soil airfields. Procedures for determining modulus of subgrade reaction and CBR are described in reference [4]. An approximate correlation between k and CBR is shown in Figure 4.

The military may also use more expediently determined parameters, namely cone index and airfield index. These are obtained by measuring the resistance to penetration of a cone by the soil. The latter is especially adaptable for troops in the field. Their approximate correlation with CBR is shown in Figure 5.

3.3.3 Unpaved Surfaces

Unpaved surfaces make up a category of runways and taxiways ranging from natural, unprepared, bare soil or turf to surfaces covered with metal mats or synthetic membranes. The strength of the soil for unpaved surfaces is typically expressed in terms of CBR.

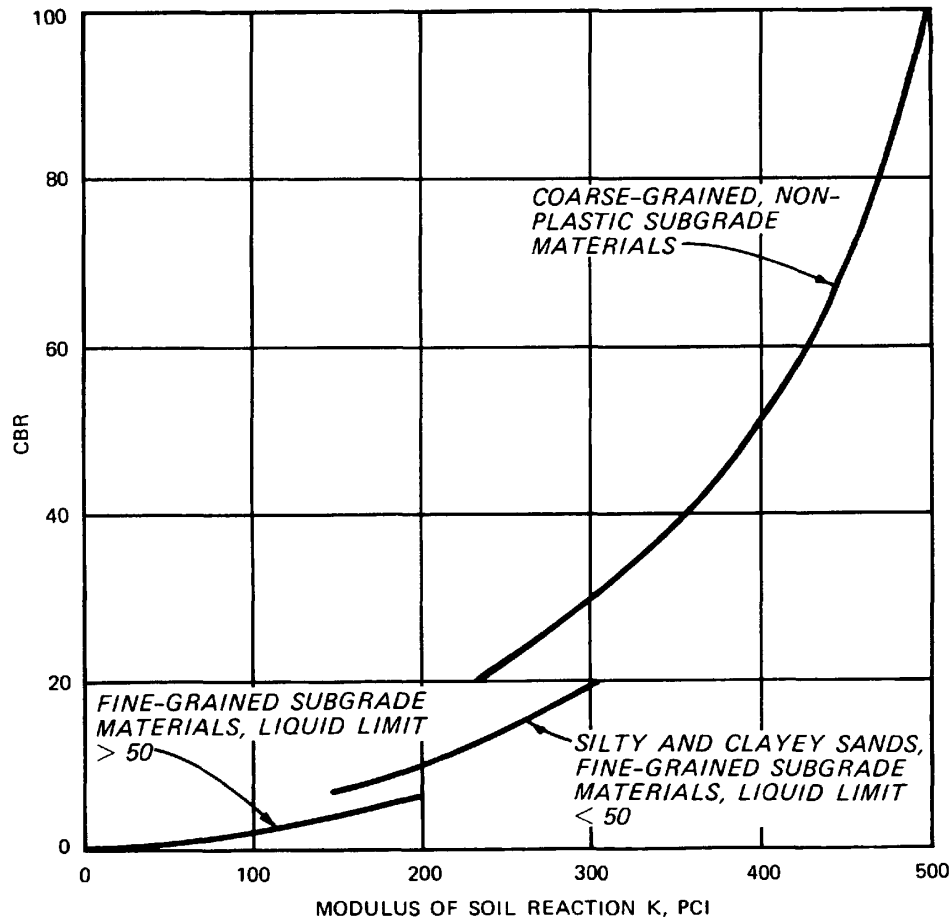


Figure 4 - Approximate inter-relationship of bearing values