



Study of Airplanes Annual Departure Effects on Design Airfield Thickness Using FAARFIELD Program

Jaber Hussein

Department of Civil Engineering, College of Engineering, Al-Muthanna University, Al-Muthanna, Samawah, Iraq.

Corresponding author E-mail: jaber.awadth@mu.edu.iq

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Abstract

Aircraft annual departure is one of the most important parameters used in the design and evaluation of runway performance. The selection of the annual departure by the critical aircraft with high impact plays a major role in determining the thickness of the runway layers. In this research, the annual departure was tested for several landing configurations of design aircraft according to the standards of the Federal Aviation Administration (FAA). It was found that increasing the annual departure by values ranging from (10,000-20,000) for all landing configurations for design aircraft leads to a change of 3% to 4% in the total thickness value of the runway pavement layers. For the same annual departure The study found that the required thickness in the case of the aircraft with a triple tandem configuration aircraft (B-777-200C) is four times the required thickness for the double dual tandem configuration aircraft (B747-200), 1.2 times for the dual tandem configuration aircraft (B767-200), 1.25 times that of dual configuration aircraft (B737-200) and 2.4 times the required thickness for the single-axle configuration aircraft (SW-60). This requires choosing the aircraft with a triple tandem configuration (B-777-200C) as the design aircraft due to its significant impact on the design thickness regardless of the amount of annual departure.

Keywords: Annual departure, Critical aircraft, Main gear configuration, Runway, Total pavement thickness.

1. Introduction

Aircraft annual departures refer to the total number of flights that depart from an airport within a calendar year. This metric provides valuable insights into the volume of air traffic, airport capacity, and the overall demand for air travel. Annual departures encompass various types of flights, including commercial airliners, general aviation, cargo operations, and military movements [1,2]. By analyzing annual departure data, aviation stakeholders can identify trends, optimize airport resources, make informed decisions about infrastructure development, air traffic management, and aviation policy [2,3]. Aircraft annual departures are used in various contexts including airport planning and management to assess airport capacity with optimize runway usage, plan for future infrastructure development, air traffic control and management to anticipate and manage air traffic flow to reduce congestion and minimize delays, and obtain the aviation industry analysis researches to study market trends with understand passenger demand, to measure the economic benefits of air travel, attract investments, promote tourism, and other environmental effects associated with air traffic [3,4,5].

The principles of runway pavement thickness design involve several key considerations to ensure the structural integrity and safety of the runway. Some of the main principles are the traffic volume, weight, and frequency of aircraft movements, bearing capacity of the underlying soil or subgrade to support the runway pavement, select materials with suitable strength, stiffness, and durability to resist traffic loading and environmental effects [4,5,8]. Federal Aviation Administration (FAA) adopts the multi-layer elastic system principle to calculate the thickness of flexible runway paving layers and adopts the 3D finite element principle to determine the thickness of the concrete slab for rigid runway paving. It uses the maximum vertical strain at the top of subgrade and maximum horizontal strain at the bottom of all asphalt layers as the predictor of pavement structure life [3,6]. The design aims to minimize the deformation of the subgrade and pavement surface under aircraft loading.

The apron is commonly designed with rigid pavement to make available stiffness support for aircraft and its loads during parking, loading and unloading cargo, refueling and passengers movements, while the runway can be either flexible or rigid

pavement or it is usually a combination of rigid and flexible pavement with the use of high-performance materials [5,6,7]. Federal Aviation Administration (FAA) had developed a computer software FAA Rigid and Flexible Interactive Elastic Layer Design (FAARFIELD) to obtain the design criteria. In the FAARFIELD the pavement's layers are selected and the design complete according to the critical airplane. The bearing capacity of the entire pavement thickness is obtained from the subgrade and pavement's materials strength are measured base on elasticity modulus according to standards for specifying construction of airports [3,8,9]. The FAA initiated the development of FAARFIELD as a response to the growing need for a standardized pavement design method (1980s-1990s). The initial version was based on the Asphalt Institute's MS-11 design method. First Generation (FAARFIELD 1.0, 1995) was released in 1995 which introduced a new design methodology based on the concept of "damage" accumulation. Second Generation (FAARFIELD 2.0, 2002) which is incorporated significant improvements such as Enhanced traffic modeling, Improved subgrade characterization, New pavement material models. FAARFIELD 1.42.003 was used in the analysis. the FAARFIELD was released September 30, 2009. Current version is FAARFIELD 1.42 as of September 2018 [10,11,12]. Many programs such as COMFAA program which is used for computing flexible and rigid runway pavement thickness Aircraft Classification Numbers (ACNs) and pavement thickness [12,13]. FAARFIELD calculate the required thickness of each layer based on traffic loading, subgrade strength, and material properties, apply safety factors to account for uncertainties, variability in material properties, and potential extreme loading conditions, design the runway with maintenance and repair in mind, including ease of access, repair materials, and potential future upgrades and comply with relevant regulations, standards, and guidelines, such as those set by the International Civil Aviation Organization (ICAO) or the Federal Aviation Administration (FAA) [14,15,16].

2. Methodology

The determination of airfield pavement thickness required many design criteria such as layers characteristics and airplanes traffic calculations .so the study of annual departure effect on design thickness will follow the following process shown in figure 1 below:

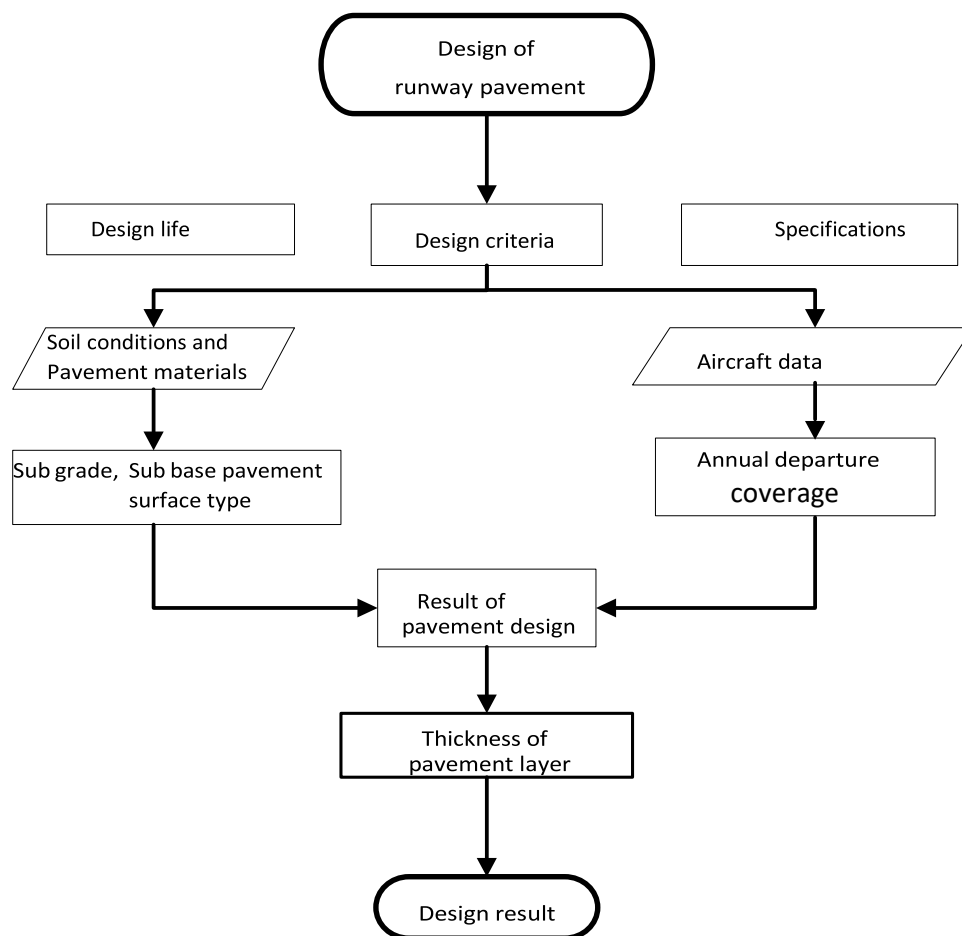


Fig. 1 : Runway pavement design structure .

3. Design criteria

1-Subgrade properties: In this study subgrade is used with 10% CBR (California Bearing Ratio) value to compute full depth of all layers above it.

2-Pavement design life :The thickness of a pavement is planned based on the ability of the pavement structure to serve a repetition load during the design life [11]. The FAA recommends a pavement structure life of 20 years [12].

3-Critical design aircraft: the design aircraft which have high Equivalent Single Wheel Load (ESWL) which is depend on aircraft gross weight and dual spacing (Sd) and tandem spacing (St) [3,4,9].

4-Main gear configuration of aircraft : There are many configurations for wheels distribution on main gear assembly . There are so many main configurations according to manufacture company of aircrafts. Some of these configurations are :

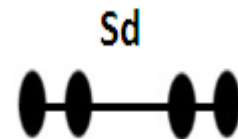
1-Single axle configuration.



I- Twin wheels configuration.

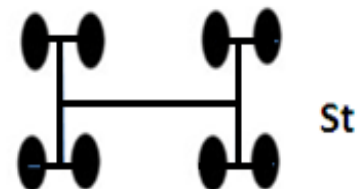


II- Dual tandem configuration.



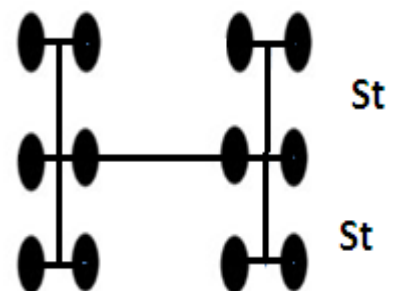
III- Double dual tandem configuration.

Sd



IV- Triple tandem axle configuration.

Sd



4-Annual departure: annual departure is calculated according to critical design aircraft and then coverage is computed for each aircraft by using pass-to-coverage ratio as using equation (1) :

$$C = \text{Ann} \times \text{design life} / \text{P.T.C}$$

(1)

Where :

C: coverage in design life

Ann: equivalent annual departure by design aircraft.

P.T.C: Pass to coverage ratio , pass-to-coverage ratio (P.C.R) The ratio between the number of aircraft passes and the number of aircraft coverage , affected by the wheel spacing and degree of aircraft wander across the width of the pavement [11,15].

Design life of runway pavement : usually taken 20 years [12,14].

5- The FAARFIELD input and output data accompanies AC 150/5320-6E [1,2] :

i- Firstly selection of pavement type from the list as shown on the Figure 2 below:

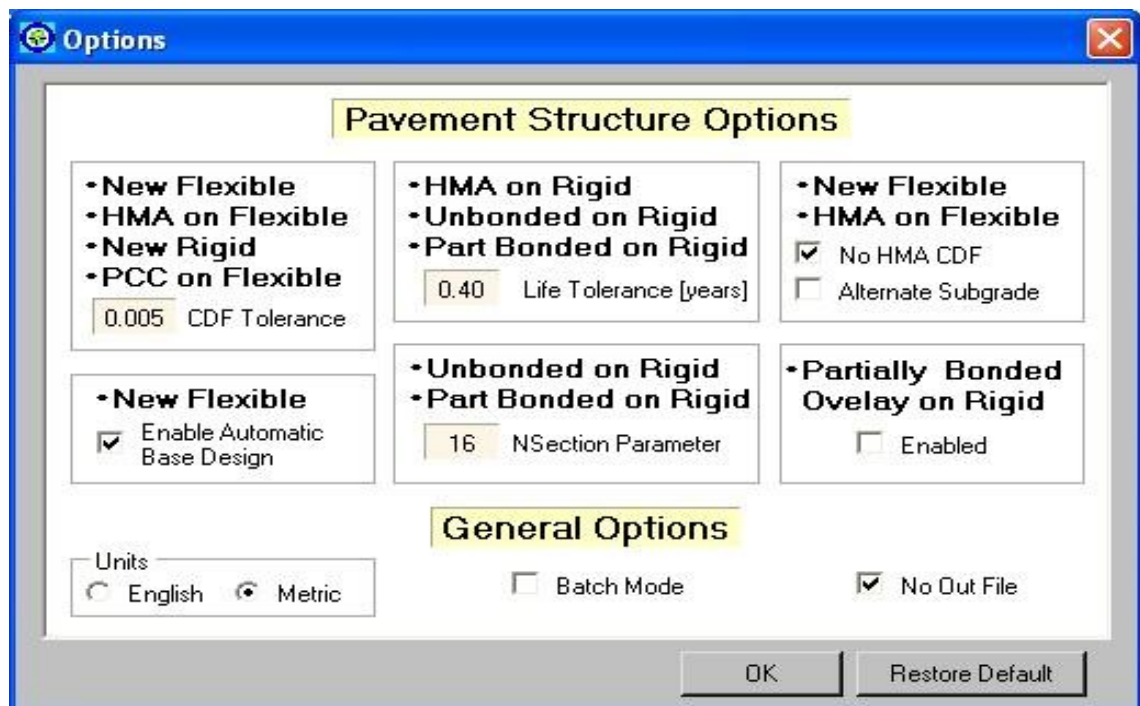


Fig. 2 : pavement structure options.

ii- Layers type selection as shown on the Figure 3 below:

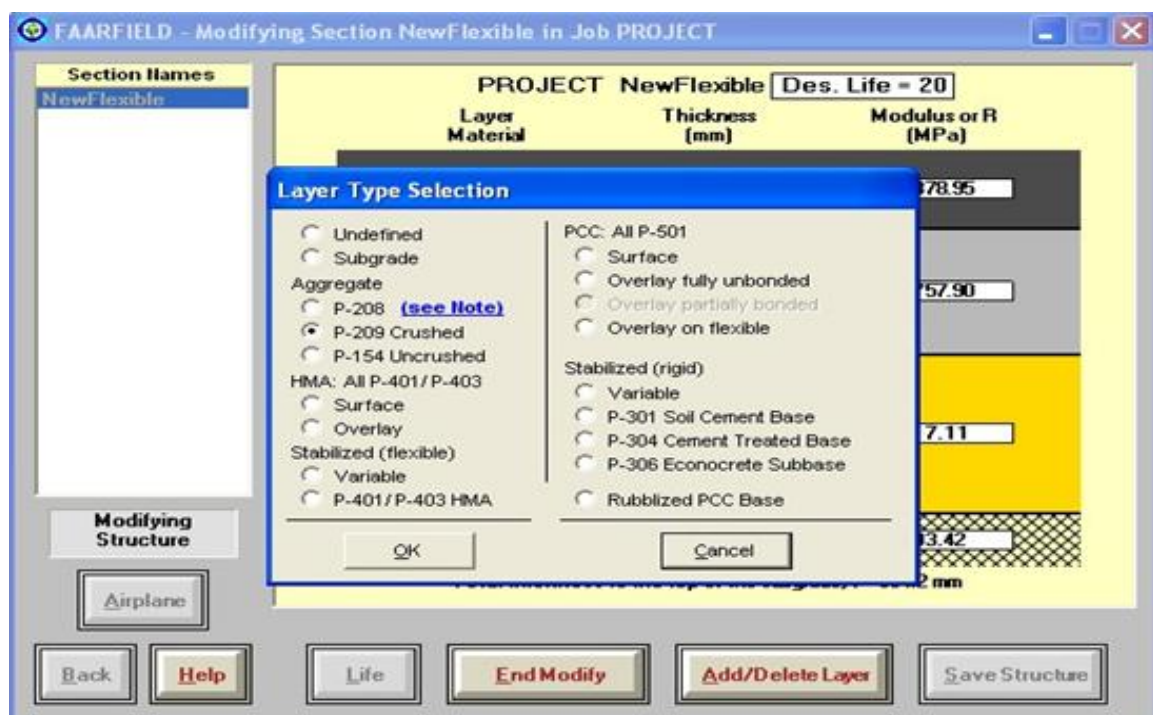


Fig. 3 : layer type options

iii- Selection of the aircrafts mix with its annual departure as shown on the Figure 4 below:

FAARFIELD - Create or Modify Airplanes for Section NewFlexible in Job PROJECT

Airplane Group

- Generic
- Airbus
- Boeing
- Other Commercial
- General Aviation
- Military
- External Library

Library Airplanes

- SWL-50
- Sngl Whl-3
- Sngl Whl-5
- Sngl Whl-10
- Sngl Whl-12.5
- Sngl Whl-15
- Sngl Whl-20
- Sngl Whl-30
- Sngl Whl-45
- Sngl Whl-60
- Sngl Whl-75
- Dual Whl-10
- Dual Whl-20
- Dual Whl-30
- Dual Whl-45
- Dual Whl-50
- Dual Whl-60
- Dual Whl-75
- Dual Whl-100

Airplane Name (11)	Gross Taxi Weight (tns)	Annual Departures	% Annual Growth
A320-100	68.400	600	0.00
A340-600 std	365.200	1,000	0.00
A340-600 std Belly	365.200	1,000	0.00
A380-800	562.001	300	0.00
B737-800	79.243	2,000	0.00
B747-400B Combi	397.801	400	0.00
B747-400ER Passenger	414.130	300	0.00

Buttons: Add, Remove, Save List, Clear List, Save to Float, Add Float, Back, Help, CDF Graph, View Gear, Float Airplanes

Fig. 4 : Aircraft mix options.

- iv- Input the subgrade CBR% value and design life to determine the total thickness above subgrade and thickness for each layer as shown on Figure 5 below:

FAARFIELD - Modify and Design Section NewFlexible in Job PROJECT

Section Names

- NewFlexible

PROJECT NewFlexible Des. Life = 20

Layer Material	Thickness (mm)	Modulus or R (MPa)
P-401/P-403 HMA Surface	127.0	1,378.95
P-401/P-403 St (Flex)	203.2	2,757.90
P-209 CrAg	254.0	517.11
Subgrade	CBR = 10.0	103.42

Total thickness to the top of the subgrade, t = 584.2 mm

Buttons: Back, Help, Life, Modify Structure, Design Structure, Save Structure, Airplane, Status

Fig. 5 : Pavement layers thicknesses.

4. Assumptions and simulations

1-Critical aircraft :

Selection of design aircraft needs to examine all the aircrafts in traffic mix to determine maximum annual departure. Many factors effect on computation of annual departure such aircraft gross weight, number of wheels on main gear, configuration of gear assembly, and repetition of aircraft[15]. All the aircrafts types on a traffic mix convert to the design aircraft by a suitable conversion factor [1, 10, 11] as shown in table 1 below:

Table 1: Conversion factors.

To convert from	To	Multiply annual departure by
Single wheel	Dual wheel	0.8
Single wheel	Dual tandem	0.8
Dual wheel	Dual tandem	0.6
Double-dual tandem	Dual tandem	1.0
Dual tandem	Single wheel	2.0
Dual tandem	Dual wheel	1.7
Dual wheel	Single wheel	1.3
Double-dual tandem	Dual wheel	1.7

Annual departure by critical aircraft after conversion for it is calculated using equation (2) [2,3,10]:

$$\text{Log } R1 = \text{Log } R2 \times (W2 // W1)^{0.5} \quad (2)$$

Where :

R1 : equivalent annual departure by the design aircraft.

R2 : annual departure expressed in design aircraft landing gear.

W1: wheel load of the design aircraft.

W2: wheel load of the aircraft in question.

Knowing that the wheel load is determined by dividing 95% of gross weight of aircraft over total number of wheels

2- Pavement Layers Type

The runway pavement construction material used in this study according to the FAA specification AC-150-5370-10H [1,2], the selected pavement structure layers are:

- A- Surface uses HMA P-401/P-403
- B- Stabilize using HMA P-401/P-403 Stabilized
- C- Base using crushed aggregate P-209

5. Results and discussions

In this paper many main gear configurations for aircrafts are used to calculate full thickness of paving materials by FAARFILD program as shown in table 2 below:

Table 2: Aircrafts information [1,2,15].

Aircraft type	Main gear config.	Gross weight kip.	P.T.C Ratio	Ann. Departure range
SW-60	Single axle	267	5.18	10000-20000
B-727-200	dual	769.85	3.48	10000-20000
B-767-200	Dual tandem	1490.75	1.84	10000-20000
B-777-200C	Triple tandem	3212.9	1.81	10000-20000
B-747-B8	Twin dual tandem	3462.1	1.85	10000-20000

Annual departure of total mix is assumed with constant annual growth percent 10% and reliability (confidence of data collection) of 95% [3,4].

The effect of annual departure variation of the selected design airplane on full pavement thickness is shown as follow:

For the single axle gear configuration design airplane (SW-60) the increasing of annual departure from 10000 to 20000 repetitions increased the total thickness pavement with 4% and total thickness value range from 49.7cm to 51.7 cm ,which means that the low effect of single axle aircraft on full pavement thickness of runway. The load of a single wheel gear is considered low even if the annual departure volume increases, which does not require a large thickness of runway layers . as shown in Figure.6 below:

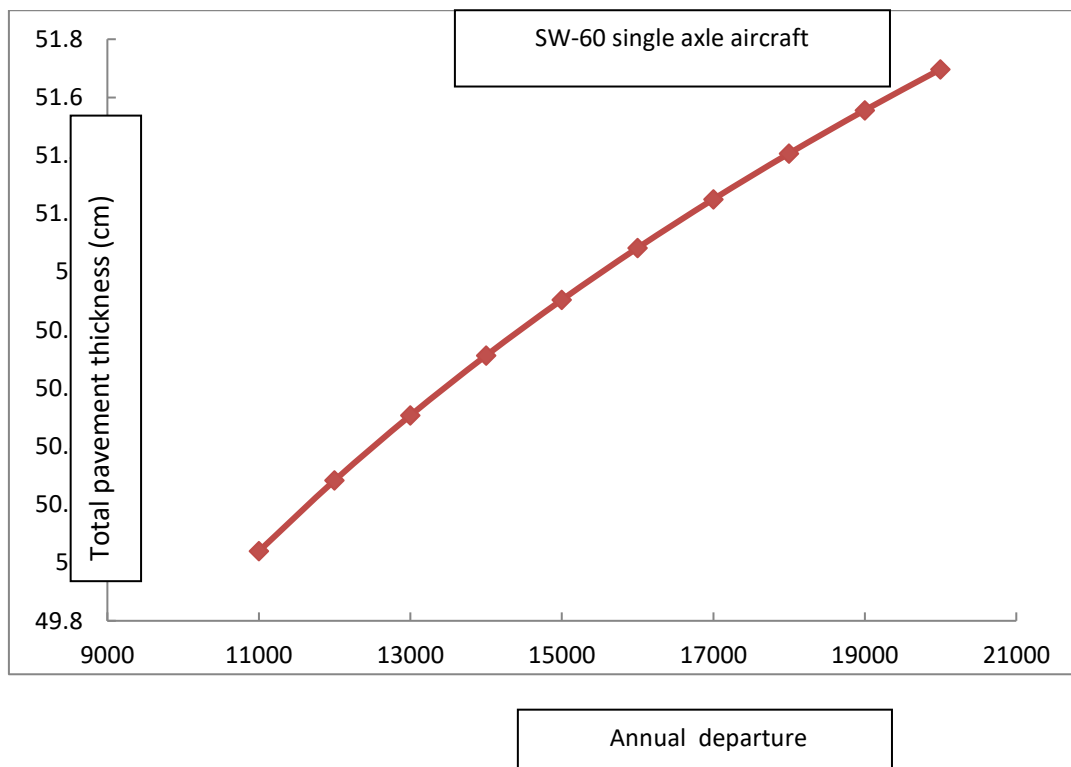


Fig. 6 : Effect of annual departure on total pavement thickness for single axle aircraft (SW-60).

For dual axle gear assembly configuration design airplane (B737-200) the increasing of annual departure from 10000 to 20000 repetitions increased the total thickness pavement with 3.7% and total thickness value range from 97.1 cm to 99.3 cm, which means that the low to medium effect of dual axle gear assembly aircraft on full pavement thickness of runway. It is noted that the dual axle gear construction generates more loads, which requires greater layer thickness to disperse the applied weight, as shown in Figure 7 below:

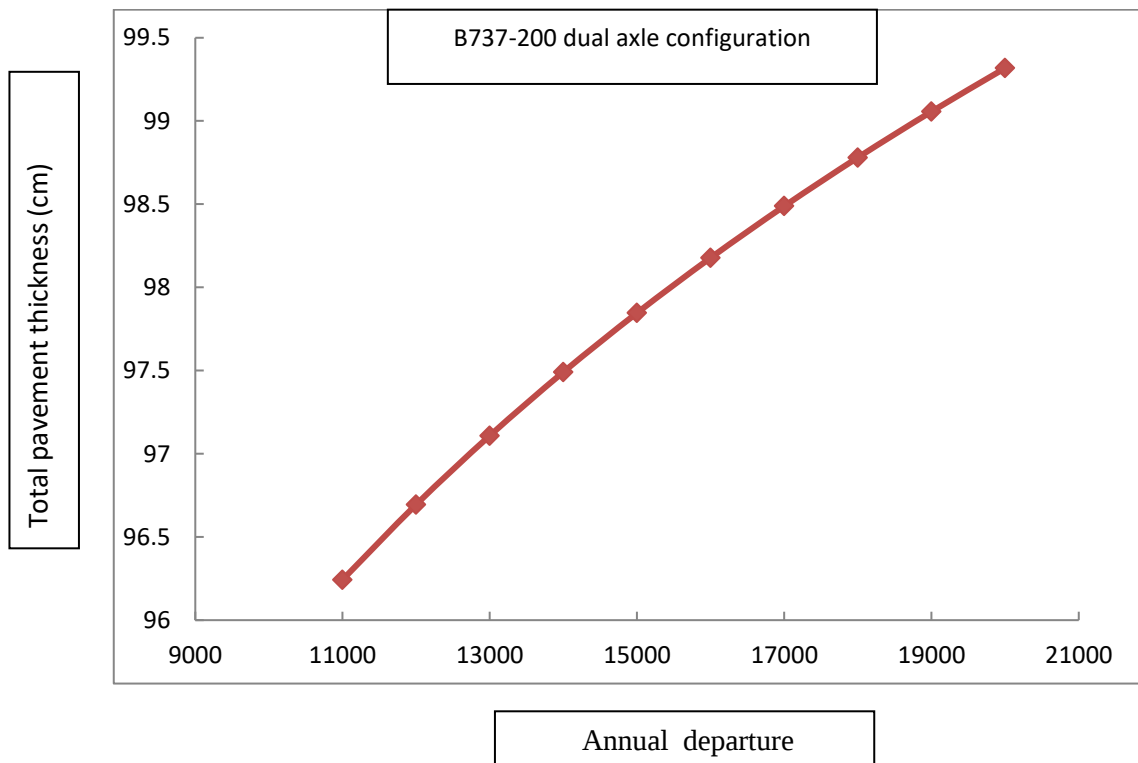


Fig. 7: Effect of annual departure on total pavement thickness for dual axle aircraft (B737-200).

For dual tandem axle gear assembly configuration design airplane (B767-200) the increasing of annual departure from 10000 to 20000 repetitions increased the total thickness pavement with 3.1 % and total thickness value range from 97.14 cm to 100.5 cm , which means that the medium to high effect of dual tandem axle gear assembly aircraft on full pavement

thickness of runway. In the case of dual tandem axle gear formation, the thickness of the runway increases significantly, and therefore care must be taken in selecting high-quality materials for the layers, as shown in Figure 8 below:

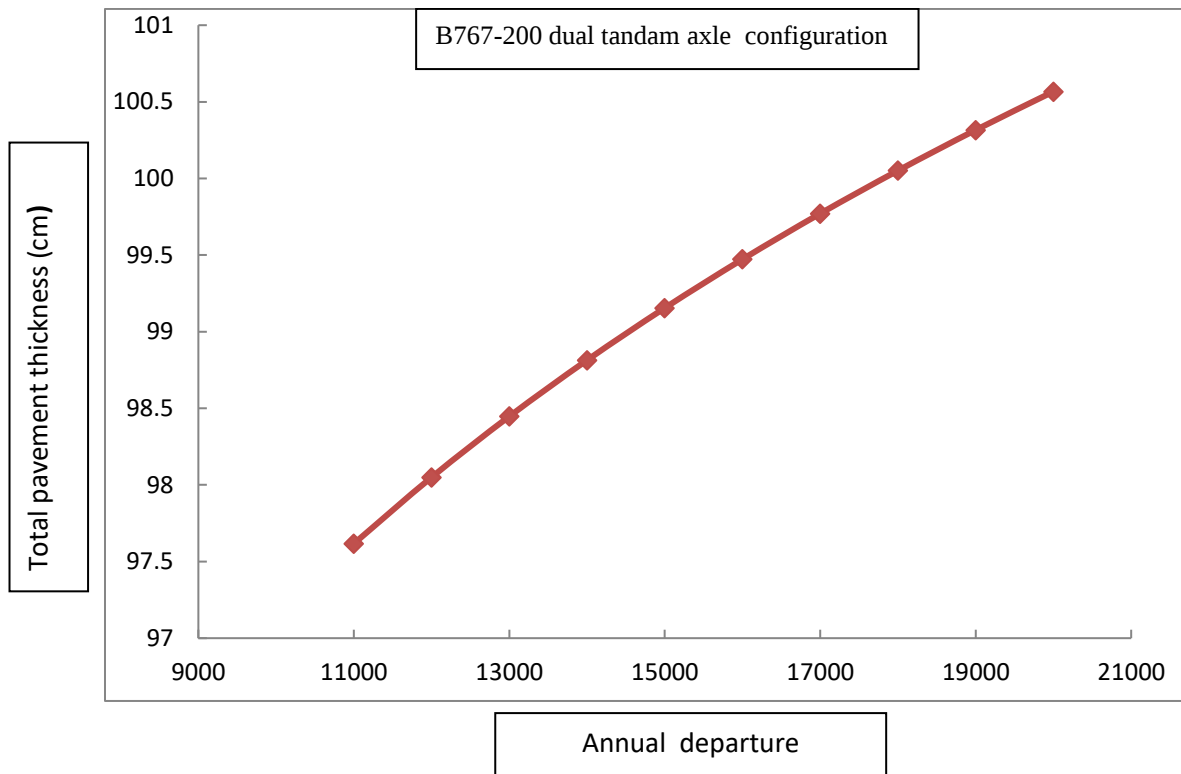


Fig. 8: Effect of annual departure on total pavement thickness for dual tandem axle aircraft (B767-200).

For triple tandem axle gear assembly configuration design airplane (B767-200) the increasing of annual departure from 10000 to 20000 repetitions increased the total thickness pavement with 3.1 % and total thickness value range from 120.7 cm to 125 cm which means that the very high effect of triple tandem axle gear assembly configuration on full pavement thickness of runway. The triple tandem axle gear exerts a very high load due to the overlapping of the weights, which requires the selection of layer materials with good performance so that they can disperse the weights with less layer thickness. This configuration of the aircraft is often the chosen design, as shown in Figure 9 below:

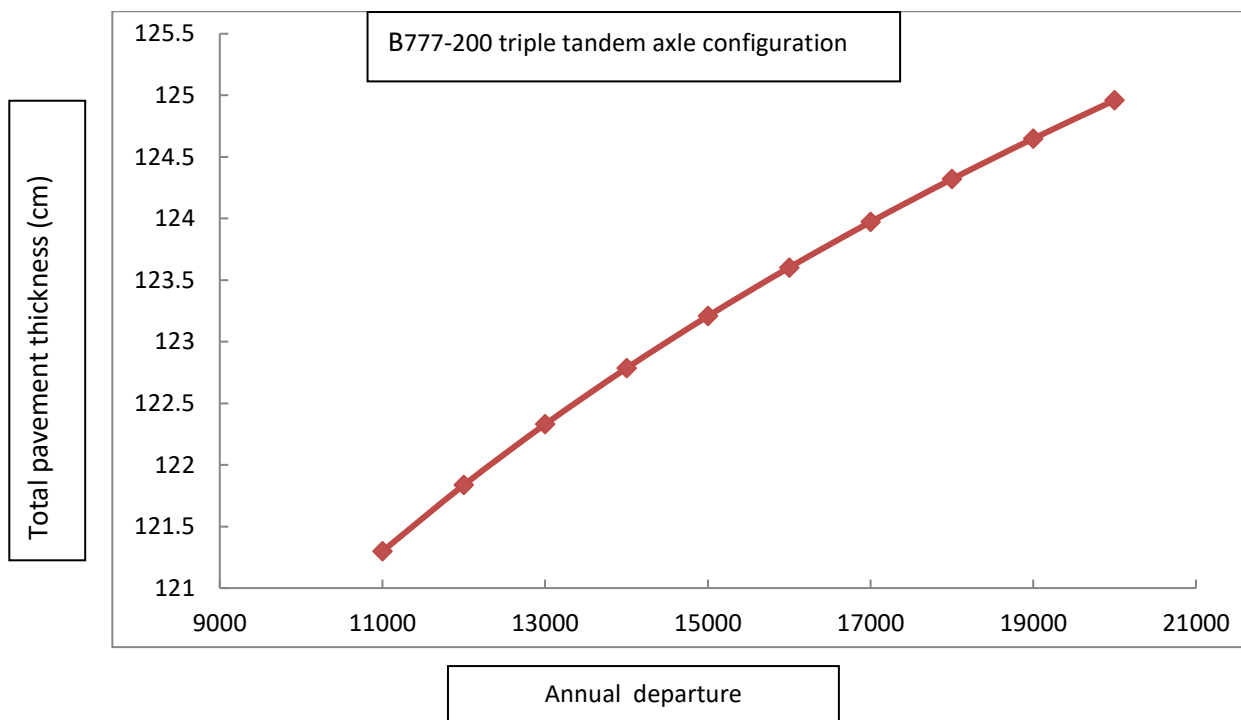


Fig. 9 : Effect of annual departure on total pavement thickness for triple tandem axle aircraft (B777-200).

For twin dual tandem axle aircraft gear assembly configuration design airplane (B747-200) the increasing of annual departure from 10000 to 20000 repetitions increased the total thickness pavement with 3.2 % and total thickness value range from 30.5 cm to 31.6 cm , which means that the low to medium effect of twin dual tandem axle aircraft on full pavement thickness of runway. When the number of wheels in the twin dual tandem axle increases, the weight will distribute and the thickness of the layers becomes acceptable. This does not require high quality layers with high costs. Despite the increase in the weight of the aircraft, the axial load is dispersed with the lowest possible and logical thickness., as shown in Figure 10 below:

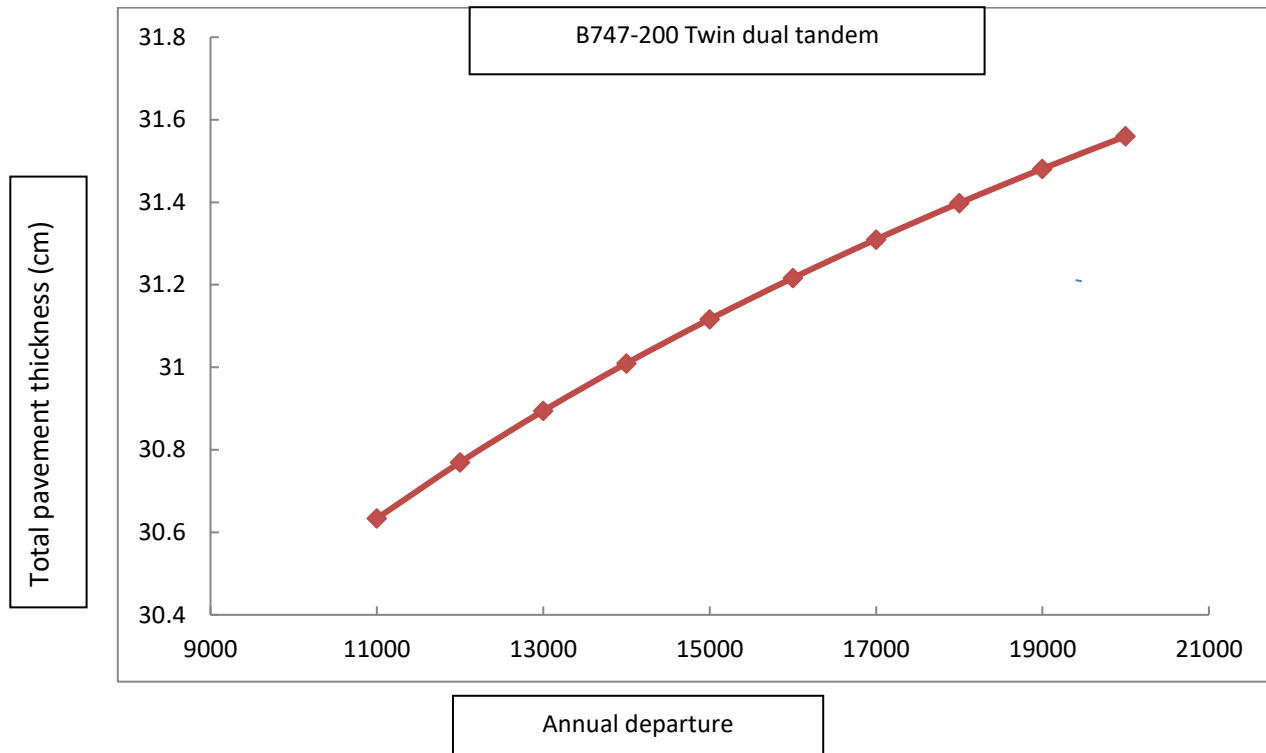


Fig. 10 : Effect of annual departure on total pavement thickness for Twin dual tandem axle aircraft (B747-200).

6. Conclusions and recommendations

- 1-The results of testing and examining a wide range of annual departures of aircraft with different tire configurations showed that the annual departure effect rate is about 4%. This is a small effect rate when compared to the effect of the configuration of the design aircraft.
- 2-The experimental results of different aircraft tire configurations indicated that the type of design aircraft configuration has a significant effect on the total thickness of the runway layers. It was shown that the design aircraft with a twin triple tandem configuration is significantly higher than the single axle , dual ,double dual and twin dual tandem axle aircraft.
- 3-Triple tandem axle aircraft must be a design aircraft, even if its frequency is low, due to the high value of ESWL generated by its passage.
- 4-According to the results of the FAARFIELD runway design thickness program, care must be taken in selecting the critical aircraft, especially those with complex tire distribution configurations.
- 5-The use of high quality and high bearing paving layers provides a runway thickness sufficient to minimize distortions in the aircraft path on the airport runway.

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