Impact of New Large Aircraft on Airport Flexible Pavements

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Abstract
The objective of the study is to evaluate the effects of New Large Aircraft (NLA) on airport flexible pavement in terms of its expected impact on pavement life. The study is conducted using Hurghada Airport air fleet composition at four hypothetical annual departure levels, four standard subgrade strength categories, and introducing NLA at five different percentages. On the basis of the results of this research, it is concluded that, where an airport has a subgrade with CBR values higher than 6%, airport authority may permit the operation of A380 up to an additional 3% of the existing annual departures without losing more than 10 to 30 percent of pavement life. For airports with CBR values less than 6%, a significant reduction in pavement life as high as 40 to 90% should be anticipated in case of introducing the A380 at 3 percent share in the traffic mix or more. In case of subgrade strength CBR less than 6%, there is a high rate of pavement life reduction due to introduction of A380 up to 2% share in the traffic mix. However, there is a low rate of pavement life reduction due to introduction of A380 from 2% and up to 5% share in the traffic mix.
Keywords: Airports, New Large Aircraft, NLA, Flexible pavements, A380

1. Introduction

The aviation industry faced aggressive growth in air travel demand and a corresponding increase in aircraft manufacturing. Air traffic is expected to grow at an average annual rate of 4.6%. Airbus predicted $4 trillion to serve as a value for 31,358 new freight and passenger aircraft demand for the next twenty years (Airbus Global Market Forecast, 2014). Boeing expects air freight to rise by 5.2 percent annually, and air passenger to rise 5 percent annually. Boeing expects to sell a total of 35,280 planes in two decades. It expects this will make $4.8 trillion (Boeing Current Market Outlook, 2014).

To overcome such increase in demand, three alternatives are available (Barros, 2001):

1. Increasing the airport capacities (more runways, taxiways, aprons, terminal building, ground handling system …. etc.), but this alternative has reached its limit.
2. Increasing flight frequency, and this is still possible but not at the busiest airports.
3. Using larger aircrafts; i.e. the introduction and use of New Large Aircrafts.

The term New Large Aircraft is generally used to describe a new generation of aircrafts that have wingspans and lengths substantially greater than Boeing 747 aircraft, weigh up to 1.2 million pounds, and have a seating capacity ranging from 555 to 880 passengers. Airbus calls its NLA the A380, it is the largest passenger aircraft today, put into long distance nonstop service to highly capacity airports. Thirteen airlines had taken delivery of nearly 169 A380s as of September 2015, which are operating on routes around the world. In total, more than 100 million passengers have flown on A380 since its 2007 service entry (Airbus, 2015).

Thirteen different airlines (such as; Singapore, Emirates, Qantas, Air France, Lufthansa ….etc.) entered A380 into operation, to serve mainly the long range routes. Emirates Airline is the largest single A380 customer, Emirates has expanded its route network since initiating operations with the double-deck aircraft in July 2008. The A380 network covers some of the world's largest airports, including major hubs such as London-Heathrow, Dubai, Hong Kong, Paris-Charles de Gaulle, Singapore, Amsterdam, Frankfurt; Bangkok, Seoul and Kuala Lumpur, along with destinations such as Washington, D.C., New York, Tokyo,; Moscow, Rome, Manchester, Barcelona, Munich; Zurich, Toronto and other cities.

Nowadays many aircrafts with different weight and gear configuration are landing on airport runways. It is clear that this difference in airplane weight and gear configuration cause different quantity of damage on the rigid and flexible pavements. Table 1 shows a sample of main gear weight characteristics for wide body and New Large Aircrafts. Development in Airbus industry comes with consequences, that A380 have a heavy weight reaching 1,200,000 lbs., along with dramatic growth in A380 dimensions, A380 have long wing span of 79.75m, wheel base of 31.88m, and overall length of 72.72. Such change in aircraft dimensions and weight could shorten the lifetime of Airside pavement or make it simply unsafe, A380 would take longer time to finish its ground handling services, and would take a lot of time to land and take off. A380 manufacturer introduced new gear configuration with Main Landing Gear Group consists of two Wing Gears (4 Wheel Bogies) and two Body Gears (6 Wheel Bogies) as shown in Figure 1 (Airbus S.A.S., 2014).

Table 1. Main gear weight characteristics for wide body and new large aircrafts

Aircraft	Maximum Takeoff Weight (MTOW) (lbs.)	Wheel Load (lbs.)
A380-800 (NLA)	1,239,000	58,852
B747-400	913,000	54,210
A340-600	805,128	63,740
B777-300	662,000	52,408

AIRBUS S.A.S. Customer Services provided procedures to develop flexible and rigid pavement design, to accommodate A380. The flexible pavement procedure provided by Airbus is based on the US Army Corps of Engineers Design Method. In order to design the flexible pavement the CBR value, annual departure level, and the weight on one Main Landing Gear must be known.

The Federal Aviation Administration's (FAA) introduced another design procedure for flexible and rigid pavement. FAArfield (Federal Aviation Administration's Rigid and Flexible Iterative Elastic Layered Design) was introduced by FAA to replace the use of LEDFAA 1.3 and FAA design charts based on the California Bearing Ratio (CBR) and Westergaard methods as a standard design procedure in the latest revision of Advisory Circular. FAArfield is also used for the pavement life evaluation. FAA design process for flexible pavement design depends on two modes of failure (Federal Aviation Administration, 2009):

1. Vertical strain in the subgrade, to prevent failure by subgrade rutting.
2. Horizontal strain in the asphalt layer, to preclude pavement failure initiated by cracking of the asphalt surface layer.

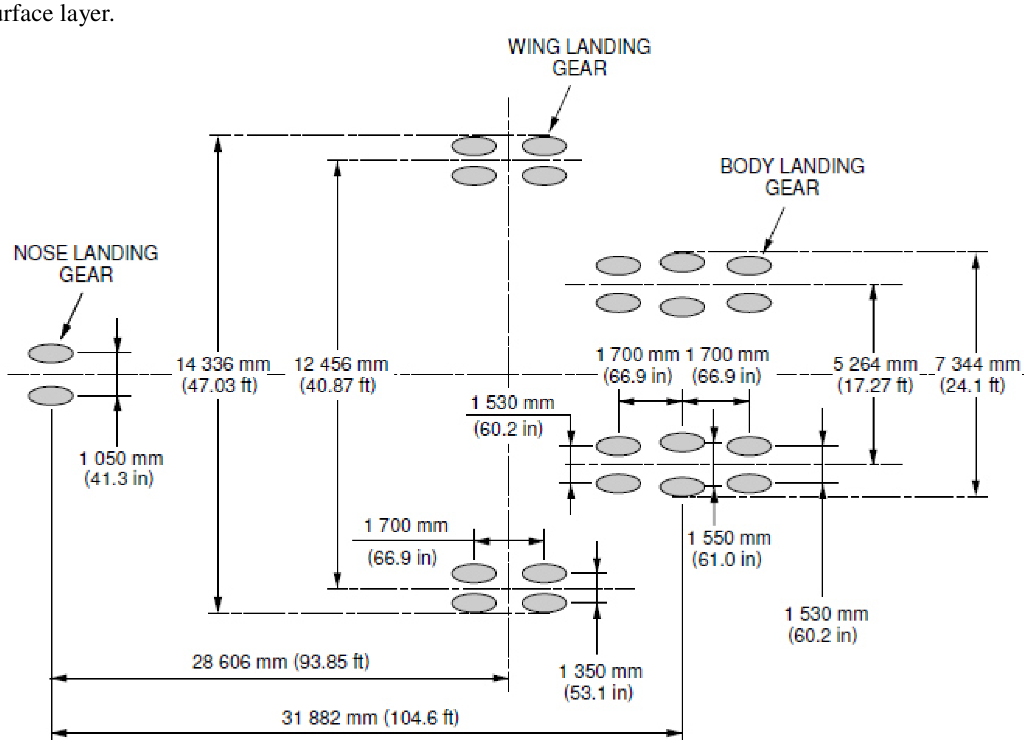

Figure 1. A380 gear configuration

The FAA has made a preliminary version of FAArfield, called FEDFAA, and it was available for download since 2004. FAArfield continues to use layered elastic analysis for flexible pavement and flexible overlay design. FAArfield is based on the Cumulative Damage Factor (CDF) concept, in which the contribution of each airplane in a given traffic mix to total damage is separately analyzed. CDF is expressed as the ratio of applied load repetitions to allowable load repetitions to failure. For a single airplane and constant annual departures, CDF is expressed as:

$$CDF = \frac{\text{number of applied load reptitions}}{\text{number of allowable reptitions to failure}}$$

FAArfield software has several capabilities to analyze the cumulative damage factor for any aircraft in the pavement system. Also FAArfield is used for detecting critical zones of runway and evaluating the effect of gear configuration and lateral distance from centerline of runway. According to Shafabakhsh and Kashi (2014), B777-300 ER, and A340-500/600 has the highest CDF rate among other aircrafts, in case of equal annual departure levels (including A380-800F), and this is same for both flexible and rigid pavements, as shown in Figure 2.

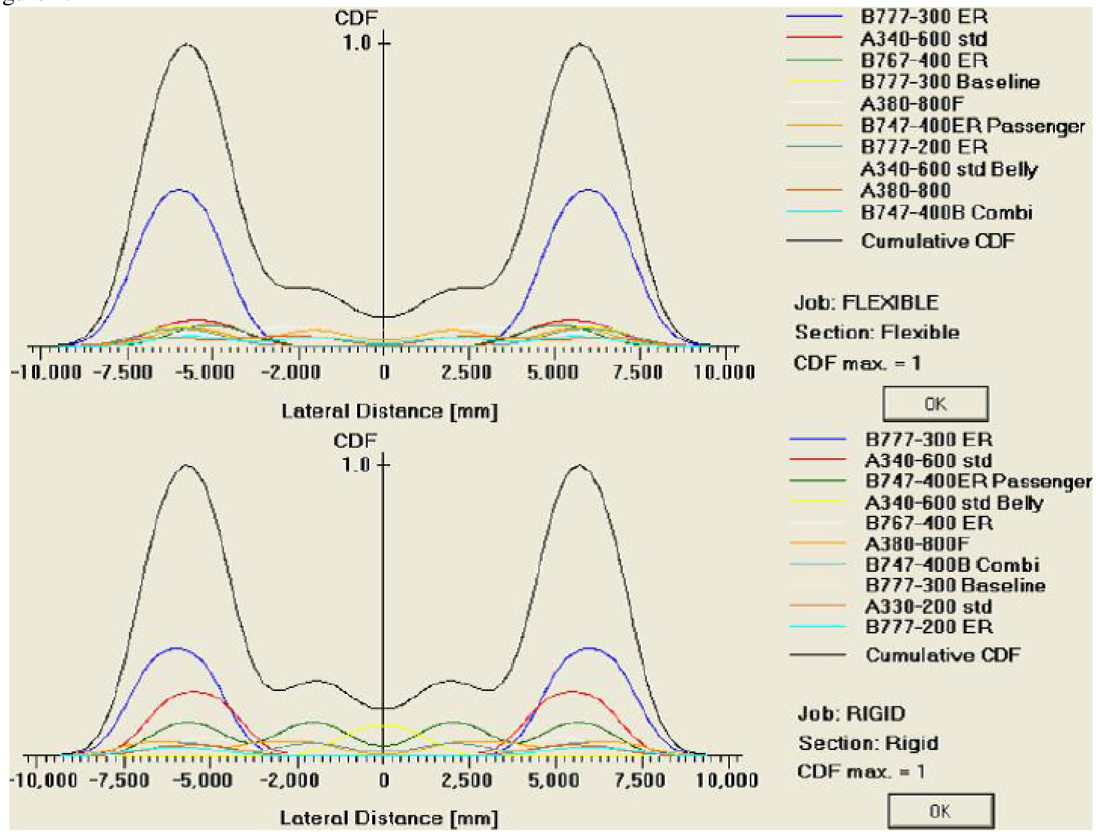

Figure 2. FAArfield CDF rate diagram for aircraft mixed traffic for flexible and rigid pavement (Shafabakhsh & Kashi, 2014)

2. Pavement overloading

Overloading of pavement can be a result of the increase in loading or increase in application rate. When applied loads exceed the design or evaluation load, these loads could shorten the design life. Since pavements are not a brittle material, pavement can sustain a certain load for an expected number of repetitions before failure. Small acceleration of pavement deterioration is allowed with certain criteria. For those loads the following criteria are suggested (ICAO, Annex 14):

a) For flexible pavement occasional movement by aircraft with Aircraft Classification Number (ACN) not exceeding 10 percent above the reported Pavement Classification Number (PCN) should not adversely affect the pavement;
b) For rigid or composite pavement, in which a rigid pavement layer provides a primary element of the structure, occasional movements by aircraft with ACN not exceeding 5 percent above the reported PCN should not adversely affect the pavement;
c) If the flexible pavement or rigid pavement structure is unknown, the increase in loading or in application rate should be limited to 5 percent.
d) The annual number of overload movement should not exceed approximately 5 per cent of total annual aircraft movement.

Overloading of pavement should not be allowed in the following cases:

1. Presence of signs of pavement distress or failure.
2. During any periods of thaw following frost penetration.
3. When the strength of the pavement or its subgrade could be weakened by water.

Due to dramatic increase in mass load and gear load of the NLA, the pavement would require adequate pavement support. Bituminous bound wearing course is able to reduce the pressure from NLA gears layer by layer, because bituminous bound wearing course can yield more under surface loading.

Evaluation for existing pavement is necessary to determine the validity of the pavement and undercarriage design to accommodate the NLA. PCN value should be equal to or greater than ACN value for a certain NLA. These may require an operational solution by providing another alternative taxi routings to avoid using a certain taxiway, apron, or any facility that has a PCN value lower than the NLA ACN value. Such operational procedures may, however, lower the capacity of the airport.

3. Research Methodology

3.1 Quantifying NLA Impact on Pavement Life

Figure 3 shows the analysis approach to be followed in this study for quantifying the expected impact of NLA on flexible pavement life. As shown in the figure 3, using Hurghada Airport airfleet composition data, four hypothetical scenarios of annual departure levels, and four subgrade strength categories. The required pavement typical cross sections for 20 years' design life are determined using FAArfield software. The designed typical sections consist of three layers as follows:

- Hot Mix Asphalt (HMA) layer.
- Bituminous Base Course (BBC) layer (the use of BBC is assumed to meet ICAO recommendations for pavement subjected to loading for aircrafts weight higher than 100,000 Ibs).
- Crushed aggregate base layer.
- Variable subgrade strength categories.

After introduction of A380-800 at five different percentages, as discussed in 3.1.2, the effect on pavement life for each of the typical pavement sections was determined using FAArfield software. Scenarios for the analysis of NLA impact on pavement life is shown in Figure 4. In this study, FAArfield is used for evaluation of A380 effects on flexible pavement damage using FAA method which is based on Layered Elastic Design method.

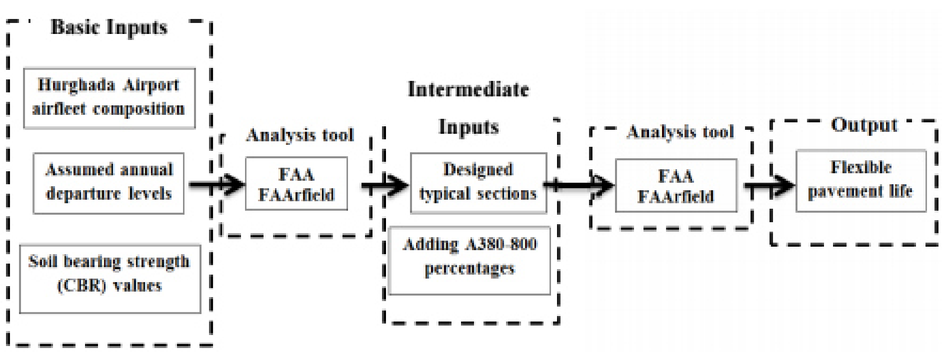

Figure 3. The flow chart for quantifying NLA impact on pavement life

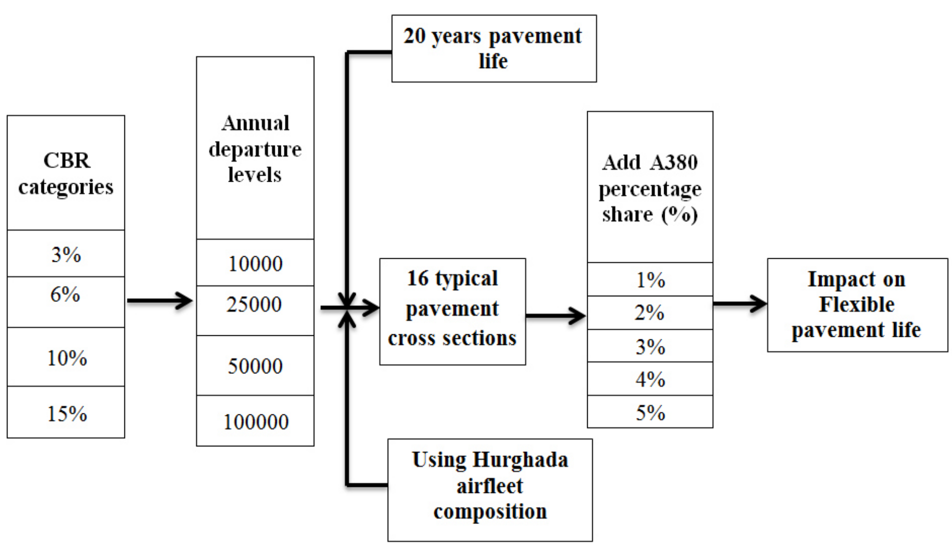

Figure 4. Scenarios for the analysis of NLA impact on pavement life

3.1.1 Hurghada Airport airfleet composition

Hurghada International Airport is an international airport located in the Red Sea City of Hurghada, Egypt. It is the second busiest airport in Egypt after Cairo International Airport. The airport is currently served by one terminal and two runway, so Aircraft movements at Hurghada Runway 16L-34R for the year 2006 are shown in Table 2, the data indicates the following:

1. Twenty different aircraft types mainly used Hurghada Airport during 2006 with 23,843 annual departures.
2. Gear configuration is an important characteristic that defines the impact of the traffic mix on pavement. Hurghada air traffic mix consists of:
   - Three different aircraft types with complex gear configuration representing 2.3% share in the traffic mix.
   - Seven different aircraft types with dual tandem gear configuration representing 24.2% share in the traffic mix.
   - Ten different aircraft type with dual gear configuration representing 73.5% share in the traffic mix.
3. Wide body aircrafts have a contribution of 4.6% share in the traffic mix:
   - B747-200 has a contribution of only 0.12% share in the traffic mix.
   - A340-200 has a contribution of only 1.04% share in the traffic mix.
   - B777-300 has a contribution of only 1.1% share in the traffic mix.

Hurghada air traffic characteristics for the year 2006 are shown in Table 2. The data is arranged by aircraft annual departures levels in descending order.

Table 2. Hurghada Airport air traffic characteristics for the year 2006

ID.	Type	Gear Type	Aircraft mix class*	Maximum Takeoff Weight (MTOW) (lbs.)	Annual Departures.	Share in traffic mix (%)
1	A320-200	DUAL	C	162,922	6,972	29.24
2	A321-200	DUAL	C	179,039	5,100	21.39
3	B737-200	DUAL	C	117,500	4,700	19.71
4	A310-300	DUAL TANDEM	D	315,041	3,600	15.1
5	A310-200	DUAL TANDEM	D	315,041	1,435	6.02
6	MD83	DUAL	C	161,000	427	1.79
7	A300-B4	DUAL TANDEM	D	365,747	371	1.56
8	B777-300	COMPLEX	D	662,000	266	1.12
9	A340-200	COMPLEX	D	568,563	248	1.04
10	B757-200	DUAL TANDEM	C	256,000	146	0.61
11	MD90	DUAL	C	168,500	103	0.43
12	DC9	DUAL	C	122,000	97	0.41
13	B767-200	DUAL TANDEM	D	361,000	91	0.38
14	A330-300	DUAL TANDEM	D	509,047	85	0.36
15	B737-400	DUAL	C	150,500	72	0.3
16	B757-300	DUAL TANDEM	C	273,500	50	0.21
17	B747-200	COMPLEX	D	836,000	28	0.12
18	LJ35	DUAL	C	18,000	21	0.09
19	B737-500	DUAL	C	134,000	18	0.08
20	G-IV	DUAL	C	75,000	13	0.05

* Aircraft mix classes

A: 12,500 or less (lbs.) with single engine.
B: 12,500 or less (lbs.) with multi engine.
C: 12,500 - 300,000 (lbs.) with multi engine.
D: 300,000 or more (lbs.) with multi engine.

3.1.2 Scenarios for annual departure levels

Four levels of annual departures are assumed to evaluate pavement performance under different levels of loading. These levels are 10,000 annual departures to represent ultra-low intensity level, 25,000 annual departures to represent low intensity level, 50,000 annual departures to represent medium intensity level, and 100,000 annual departures to represent high intensity level. Table 3 shows the four analysis scenarios of annual departure levels using Hurghada Airport air fleet composition.

Table 3. Annual departure levels for analysis scenarios

Aircraft		Hurghada 2006 traffic		Annual departure for analysis Scenarios			
No.	Type	Annual departures	Share in traffic mix (%)	Scenario I	Scenario II	Scenario III	Scenario IV
1	A320-200	6,972	29.24	2,924	7,310	14,621	29,241
2	A321-200	5,100	21.39	2,139	5,347	10,695	21,390
3	B737-200	4,700	19.71	1,971	4,928	9,856	19,712
4	A310-300	3,600	15.10	1,510	3,775	7,549	15,099
5	A310-200	1,435	6.02	602	1,505	3,009	6,019
6	MD83	427	1.79	179	448	896	1,791
7	A300-B4	371	1.56	156	389	778	1,556
8	B777-300	266	1.12	112	279	558	1,116
9	A340-200	248	1.04	104	260	520	1,040
10	B757-200	146	0.61	61	153	306	612
11	MD90	103	0.43	43	108	216	432
12	DC9	97	0.41	41	102	203	407
13	B767-200	91	0.38	38	95	191	382
14	A330-300	85	0.36	36	89	178	356
15	B737-400	72	0.30	30	76	151	302
16	B757-300	50	0.21	21	52	105	210
17	B747-200	28	0.12	12	29	59	117
18	LJ35	21	0.09	9	22	44	88
19	B737-500	18	0.08	7	19	38	75
20	G-IV	13	0.05	5	14	27	55
Total		23,843	100.00	10,000	25,000	50,000	100,000

3.1.3 Subgrade strength categories

Four subgrade strength categories are assumed to represent different standard subgrade soil types. These categories are CBR = 3% to represent ultra-low strength soil, CBR = 6% to represent low strength soil, CBR = 10% to represent medium strength soil, and CBR = 15% to represent high strength soil. The chosen subgrade strength categories in this research are consistent with the categories defined by ICAO for PCN reporting.

3.1.4 Typical flexible pavement cross sections

Sixteen typical cross sections were designed using FAArfield software at the four assumed subgrade strength categories, and the four scenarios of annual departures levels shown in Table 3. Asphalt thickness is taken as a constant and equals to 180.0 mm, and bituminous treated base thickness is also taken as constant and equals to 130.0 mm for all cases. Crushed aggregate base course thickness and characteristics shown in Table 4 are variable to achieve design life of 20 years for the different CBR and annual departure scenarios. The required thickness and Modulus of Resilient for the crushed aggregate base course layer for each case are shown in Table 4.

Table 4. Base course characteristics for different CBR and annual departure scenarios.

CBR Categories	Assumed Annual departures levels	Base course characteristics	
		Thickness (mm)	Modulus of Resilient (MPa)
A (CBR = 3%)	10,000	1,021	443
	25,000	1,127	458
	50,000	1,189	462
	100,000	1,242	468
B (CBR = 6%)	10,000	565	374
	25,000	635	392
	50,000	683	402
	100,000	565	374
C (CBR =10%)	10,000	300	334
	25,000	339	350
	50,000	370	361
	100,000	401	372
D (CBR = 15%)	10,000	153	322
	25,000	186	340
	50,000	211	352
	100,000	236	363

4. Results and analysis

The study presents the impacts on pavement life due to introduction of A380-800 as a percent share in the traffic mix. The impact on pavement life is studied for four subgrade strength categories and four annual departure levels which were formed using Hurghada Airport air fleet composition. Table 5 shows the results of pavement life analysis scenarios using FAArfield for the sixteen typical pavement sections, after the introduction of A380-800 at five percentage share in the traffic mix.

Table 5. Results of pavement life analysis scenarios

CBR% categories	Annual departure levels	Pavement life using FAArfield (years)					
		A380-800 percentage share					
		0%	1%	2%	3%	4%	5%
A (CBR = 3%)	10,000	20.0	12.2	6.3	4.3	3.2	2.6
	25,000	20.0	8.9	4.6	3.1	2.3	1.8
	50,000	20.0	6.3	3.2	2.1	1.6	1.3
	100,000	20.0	4.2	2.1	1.4	1.1	0.8
B (CBR = 6%)	10,000	20.0	17.4	15.5	13.9	12.6	11.3
	25,000	20.0	17.5	15.5	13.9	12.6	11.2
	50,000	20.0	17.5	15.5	13.9	12.6	11.1
	100,000	20.0	17.3	15.3	13.7	12.3	11.0
C (CBR =10%)	10,000	20.0	17.9	16.2	14.8	13.5	12.4
	25,000	20.0	18.0	16.2	14.8	13.6	12.4
	50,000	20.0	18.0	16.3	14.8	13.5	12.4
	100,000	20.0	17.9	16.3	14.8	13.5	12.4
D (CBR = 15%)	10,000	20.0	17.5	15.5	13.8	12.5	11.3
	25,000	20.0	17.6	15.7	14.0	12.6	11.5
	50,000	20.0	17.6	15.7	14.1	12.7	11.6
	100,000	20.0	17.6	15.7	14.1	12.8	11.6

4.1 Impact of subgrade strength categories

This section presents the study and analysis of results concerning the NLA impact of subgrade strength categories on pavement life. Figure 5 shows the relation between the introduction of A380-800 on four different subgrade strength categories, and reduction in pavement life as a percentage of original pavement life before introduction of A380-800, for four different annual departure levels. Analysis of the results shown in figure 5 reveals that the impact of the introduction of A380-800 is almost the same for the four different annual departure levels. Analysis of the relation between A380-800 share and pavement life reduction in case of the four different annual departure levels, shows the following:

a) Figure 5 displays two different impact trends of pavement life reduction, the two trends are noticed to be almost the same for the four annual departure levels, the trends are explained below:
    1. First impact trend is related to weak subgrade with CBR equal to 3%, where a steep slope is shown to represent high rate of pavement life reduction.
    2. Second impact trend is related to strong subgrade with CBR categories equal to 6%, 10%, and 15%. These subgrades with high CBR values show mild slope to represent the limited loss in pavement life.
b) In case of introduction of A380-800 at 5% share in the traffic mix, weak subgrade with a 3% CBR (first impact trend) experiences a pavement life reduction no less than 87%, while the second impact trend displays pavement life reduction about 40%.

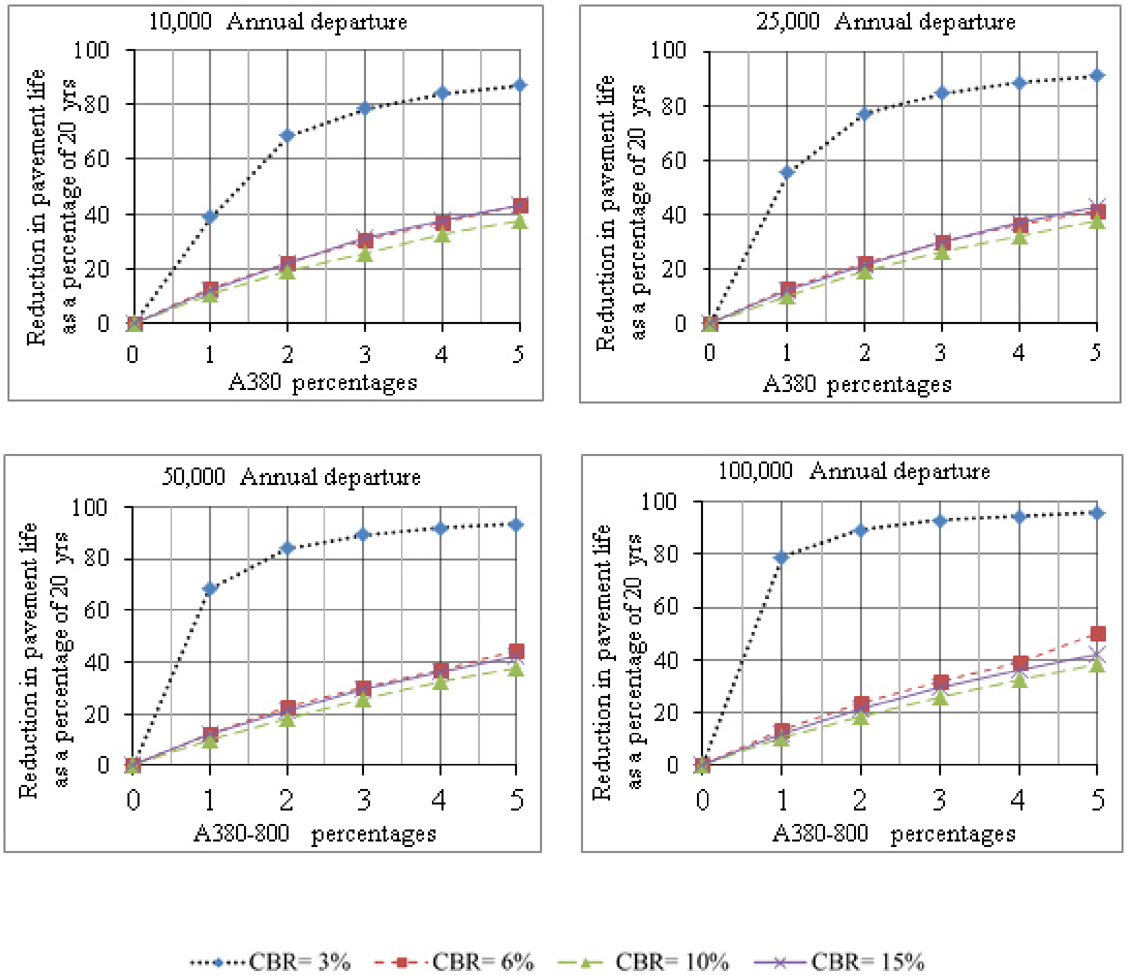

Figure 5. Impact of A380-800 introduction on pavement life for different subgrade strength categories at four annual departure levels

4.2 Impact of annual departure levels

This section presents the study and analysis of introducing A380-800 as a share of four different annual departures traffic mix impact on reduction in pavement life. Figure 6 shows the relation between A380-800 share of four different annual departures traffic mix, and reduction in pavement life as a percentage of original pavement life before introduction of A380-800, for four subgrade strength categories. Analysis of the results shown in figure 6 reveals that there are two types of impact due to introduction of A380-800. First impact trend is the impact on pavement life in the case of low subgrade strength (CBR equal to 3%). Second impact trend is the impact on pavement life in the case of high subgrade strength (CBR higher than 6% and up to 15%). The two impact trends are discussed below:

a) First impact trend which represent the impact of A380-800 introduction on pavement sections with ultra-low subgrade strength shows that there is increase in rate of reduction in pavement life with the increase of annual departure level.
b) The loss in pavement life is nearly the same for the pavement sections with subgrade strength that have CBR of 6% or higher (up to 15%). The reduction in pavement life due to introduction of A380-800 up to 5% have a linear behavior with slope about 8.2.

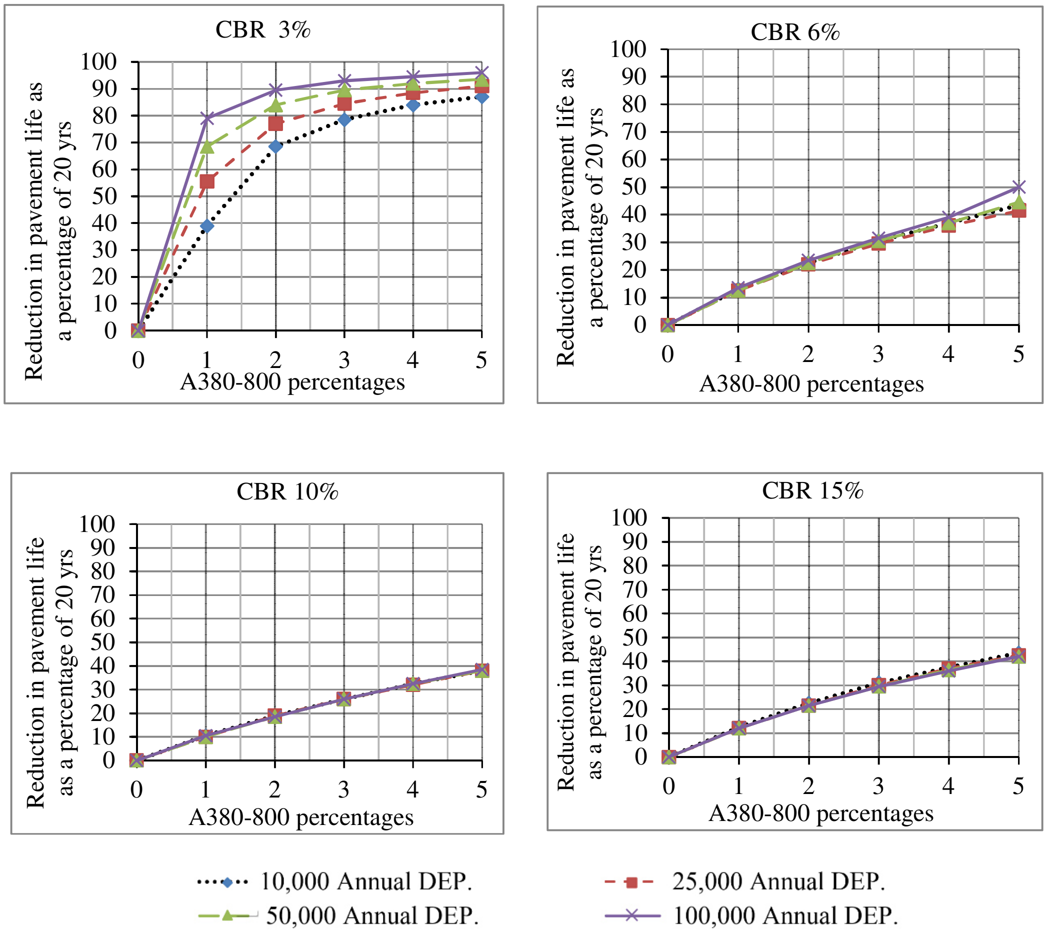

Figure 6. Impact of A380-800 introduction on pavement life for different annual departure levels at different subgrade strength categories

4.3 Summary

Based on previous analysis, the impact of NLA on pavement life has the same trend for all examined annual departure levels. Subgrade strength with CBR 3% (first impact trend) has a steep slope, while for the remaining CBR categories 6%, 10%, and 15% (second impact trend) the slope is mild. For first impact trend with subgrade strength CBR less than 6%, there is a high rate of pavement life reduction due to A380 percentages up to 2% share of the traffic mix, however, there is a low rate of pavement life reduction due to introduction of A380 percentages from 2% and up to 5% share in the traffic mix. Second impact trend has almost the same trend under different annual departures levels. Also, second impact trend has a linear trend with an average slope equal to 8.2. For airports with CBR categories less than 6%, a significant reduction in pavement life as high as 40 to 90 % should be anticipated in case of introducing the A380 at 3 or more percent share in the traffic mix.

5. Conclusions and recommendations

The main purpose of the study was to estimate the effects of New Large Aircraft (NLA) on airport flexible pavement, to clarify the impact of NLA on flexible pavement life. The study was conducted using Hurghada Airport air fleet composition to form four annual departure levels; and four standard subgrade strength categories, as a consequence sixteen different pavement sections were formed that are used for the analysis of the expected impact. NLA was introduced at five different percentages share in the traffic mix to evaluate the NLA impact on pavement life using FAArfield.

5.1 Conclusions

Based on the study results and analysis the following conclusions were obtained from this research:

1. Introduction of A380-800 on all examined annual departure levels have the same impact on pavement

life.

2. NLA has a severe impact on subgrade with CBR less than 6%, while the impact on subgrade with CBR higher than 6% is mild.
3. For airports with CBR categories less than 6%, a significant reduction in pavement life as high as 40 to 90% should be anticipated in case of introducing the A380 at 3 percent share in the traffic mix or more.
4. In case of subgrade strength CBR less than 6%, there is a high rate of pavement life reduction due to introduction of A380 up to 2% share in the traffic mix. However, there is a low rate of pavement life reduction due to introduction of A380 from 2% and up to 5% share in the traffic mix.

5.2 Recommendations

Based on the study results and analysis the following recommendations can be considered:

1. Airports which have subgrade with CBR value higher than 6%, these airports authority can permit NLA operations up to 3 percent share in the traffic mix without losing more than 30 percent of the original pavement life.
2. In case of weak subgrade soils with CBR value equal to or less than 3%, if airport is already accommodating NLA operations at 3 percent share in the traffic mix, airport authority can increase NLA percent share up to 5 without expecting a significant loss in pavement life.

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