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Investigation of Runway Pavement Design Software and Determination of Optimization Software*

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ABSTRACT

So far, many pieces of software have been presented by aviation administrations and research and investigation institutions to design airport pavement system. In this paper, five typical pieces of software on the runway pavement design are evaluated, so that first, structure of each piece of software mentioned in the runway pavement design is addressed and then design of the sample airport is performed by each piece of software, and the thickness of the pavement and the cumulative damage factor for each airplane is obtained by each piece of software. According to the results obtained from each software design, the pavement thickness and the share of airplanes from the amount of cumulative damage are measured. The analyses show that the ability of FAARFIELD software to design based on three-dimensional finite element method, makes the prediction of the behavior of airplanes loading on the runway pavement more realistic and designing by this software is more economical. Also, PCASE software considers more precise details and analyses of the materials and conditions behaviors of the desired area.
KEYWORDS: pavements, runways, pavement design software, cumulative damage factor.

1- INTRODUCTION

The presence of new generation of modern airplanes, rapid growth of air travel demand, and consistent and accurate traffic laws and regulations for different phases of flight operations made the airport to be considered as a complex and dynamic system. Airport pavements, which are the passageways of different planes traffic, are rigid, flexible, and composite. Ground facilities are an integral part of the airport, most important of which is airport pavement system. Because the airplane wheels are applied directly to the pavement system, pavement behavior and condition have a significant impact on fleet performance, so having an appropriate pavement system considering all the designing circumstances is necessary.

Thus, numerous pieces of software are designed and released by air administrations in different countries that some related software can be cited such as LEDFAA, PCASE, APSDA, FAARFIELD and TKUAPAV. In this paper, the factors affecting airport pavement thickness and various software capabilities and their output comparison are carried out and the appropriate software is proposed for designing airport pavement.

The goal of the study is a comparison among runway pavement design software and determination of optimization software. The proposed approach compares five software but the old methods only compared two or tree software.

The scientific contributions of this paper are; evaluation new version of software, comparing CDF for any aircraft, similar traffic assumptions and similar structure assumptions.

The remainder of the paper was organized as follows: the section 2 is for literature review, in section 3 some pieces of valid software in designing rigid and flexible pavement of Airport runway are evaluated, in section 4 design process in some pieces of software is applied, in section 5 results of each of these pieces of software and their capabilities are compared, Finally, in section 6 the obtained results from each piece of software for flexible and rigid pavement are compared and the results of total pavement thickness design by each piece of software is shown

2 - Background of the Research

Federal Aviation Administration (FAA) has simulated various types of airplane movement in terms of arrangement of wheels and their weights using field experiments in real scale and through the facilities related to real simulation. Also, some members of the Airport Engineering department of FAA performed some studies on some software of Aviation Administration of America such as LEDFAA and FEDFAA [1]. Brill et al. (2004) performed studies on three pieces of software LEDFAA, FEDFAA, and FAARFIELD and stated the capabilities of each of them in the analysis and design of pavement, and finally validated their work by the results of NAPTF field experiments. This study showed that for airplanes with 4 and 6 wheels system such as Boeing 777 and Airbus 340, obtained design with FAARFIELD software is more consistent with the values obtained from field experiments with real scale [2].

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Wang and Chia-Pei in 2005 conducted a case study using the displacement and strain sensors on crawling band of Chang-Kai-Sheck International Airport to repair concrete slabs pavement. They also conducted extensive field research at the airport in order to generalize the results to three-dimensional environment of finite element software [3]. Their studies showed that the arrangement of wheels has a determining impact on pavement damages and affects the useful life of the pavement and the thickness of the concrete slab. Also Godiwalla and Pokhrel (2011) emphasized the necessity of the use of some capable software to design and analyze runway pavement in a paper presented at pavement systems seminar at Texas Airport and introduced their recommended software based on the results of their research software by presenting brief comparison among the structure, basis of the work, and the results obtained from some software [4].

3- Conventional Software in Designing Runway Pavement

In this section, some pieces of valid software in designing rigid and flexible pavement of Airport runway are evaluated and the basis of their work is described.

3-1 - LEDFAA Software

Layered Elastic Design Federal Aviation Administration is a computer program for airport pavement design which operates based on elastic layer theory. This software was designed by FAA and its final version was presented in 2004 that is used to design rigid and flexible airport pavement [5]. The method of this program is based on pavement thickness design standards of aviation administration. The inputs data include the initial assumptions that are entered in two distinct pages; one of the pages is related to structural assumptions and the other page is about traffic data. Moreover, a set of default values are available for input parameters in accordance with the standards in the software itself. Pavement design is based on fatigue and rutting - related failures expressed in terms of “damage cumulative factor". Maximum horizontal strain under asphalt layer in fatigue model and maximum vertical strain on pavement substrate in rutting model are controllers which are consistent with Burmester's equations. The ability to transfer loads through joints in this software is 25% which is based on the assumptions of Westergaurd. This software can calculate damaging effect of any plane to the pavement separately using this factor. In addition, main characteristics of the pavement layer materials are stated in the same way that is as a modulus of elasticity like CBR for flexible pavement and k for rigid pavement. The dimensions of concrete slab designing are fixed values of 9 × 9 m [5].

3-2 - FAARFIELD Software

Federal Aviation Administration Rigid & Flexible Iterative Layered Elastic Design is a computer program for airport pavement design which operates based on elastic layer theory and finite element method. This software was developed by FAA and the final version was presented in 2009 and is used for rigid and flexible pavement design. The design method in this program is based on pavement thickness design standards of aviation administration. Thickness design method that is used in the program is FAA design standards which refer to Circular (AC) 150/5320-6E [6]. The core of the program is a response structural model that consists of two programs of LEAF and NIKE3D. LEAF is a multilayered elastic computational program and NIKE3D program is a program which operates based on the finite element method. Both programs can be used when they are needed in FAARFIELD program, but they are not visible to the user. Design information is entered into the program by two graphical pages. One of the pages is for Pavement structure and the other is for traffic [7].

3-3 - PCASE Software

Pavement-Transportation Computer Assisted Structural Engineering software is produced by the U.S. Army Corps of Engineers association and the 2008 version of this software is the latest one which has become available for public use since 2005 [8].

PCASE software has the ability to design and evaluate flexible and rigid road and airport pavement based on empirical methods of K, CBR, and analytical method of LED. This software has collected all evaluation and design criteria and benchmarks of road and airport in a collection.

3-4-APSDS 5.0 Software

Airport Pavement Structural Design System is new software for airport pavement design which operates based on the theory of elastic layer. This software is designed by an Australian company named Mincad, and its latest version was presented in 2010 that is used for flexible pavement design [9].This software is the new version of APSDS 3.0 and APSDS 4.0 software that was produced and entered the market and became available for users in 1995 and 2000. The main capability of the software is calculating the amount of pavement costs according to the volume of materials used in the design. Moreover, economic design is the main advantage of this software.

3-5 - TAPAN Software

Tamkang University Airfield Pavement is the software to design airport rigid pavements thickness. TKUAPAV was developed at Tamkang University in Taiwan by Shao-Tang Yen under the supervision of professor York Ying-Haur [10]. This software is used to design airport rigid pavement based on the theory of Westergaurd page and in choosing the airplanes, based on the list of available airplanes in LEDFAA program. This program was manufactured in 2002.

4 - Design Process of the Software

Design process in some pieces of software is almost similar, so that first the intended airplanes along with their number of annual flight are selected, then the characteristics of pavement materials are determined and design process is performed based on the cumulative damage factor (CDF) of each aircraft to the extent that cumulative value of this factor is equal to one. This ratio represents the pavement failure rate and is dependent on many factors such as aircraft weight, wheel placement, the percentage of aircraft weight on the main wheels, axles distance, and pavement type. The CDF value is from zero to one and is split among the planes in the complex traffic list a cumulative manner and each of the planes has a part in this amount. This factor indicates the amount of damage caused by complex traffic on the pavement and this enables the designer that the plane has the maximum force to the pavement and put the system under loads on the threshold of pavement failure [11]. The CDF value is obtained by the following relations [5, 7]:

$$CDF = \frac{(\text{annual departures}) \times (\text{life in years})}{(\text{pass / coverage ratio}) \times (\text{coverages to failure})}$$

Coverage: The number of times the aircraft passes unit area of flight path, one wheel of a plane main wheels that passes through it.
Pass: The distance a plane passes to the loading location until it flies or the distance from where the aircraft touches the ground to the discharge site.
If CDF<1, it means some time is remained from pavement life and the pavement does not suffer from fatigue.
If CDF=1, all the useful life of the pavement is used.
If CDF>1, the useful life of pavement is finished and pavement suffers from some damages.
Also substrate elasticity modulus calculation in flexible pavement in any software is based on the following relation:

$$E_{SG} = 1500 \times CBR\ (psi) \qquad \text{Eq.1}$$

This method is based on flexible pavement design method which is based on the substrate CBR. For the rigid pavement, modulus value considering the substrate K amount is equal to [5]:

$$E_{SG} = 26k^{1284}\ (psi), \quad k = \left[\frac{1500 \times CBR}{26}\right]^{0/778}\ (psi) \qquad \text{Eq.2}$$

The substrate elasticity Modulus (psi) = E_{SG}
Soil reaction index (psi) = k

In addition, E_{SG} can be obtained from laboratory tests or other non-destructive tests. Equations for converting CBR to modulus are based on empirical data that are used in the method of elastic layers theory [12].

5 - Results of Runway Pavement Design Evaluation through Software

To compare the results of each of these pieces of software and their capabilities, in this section, runway pavement design for a sample airport with the same traffic assumptions and materials has been done and the planes cumulative damage index together with obtained thickness for rigid and flexible pavement are compared in tables and diagrams.

5-1 - Traffic Assumptions of the Airport under Study

Before designing the airport, aircraft type, weight, number of annual flights, flights growth rate and other information related to it must be specified. These assumptions for pavement design of the sample airport for 10 types of aircraft groups such as Airbus, Boeing and other common types in the form of complex traffic are described in the following table.

Table 1- Traffic Assumptions of the Ample Airport

Tire pressure (KPa)	Annual growth %	Gross weight (ton)	Annual departure	Aircraft
1.38	5%	68.039	1200	A320
1.42	5%	272.155	1200	A340-200/300
1.08	5%	272.155	1200	A340-200/300Belly
1.57	5%	367	1200	A340-500/600
1.53	5%	367	1200	A340-500/600 Belly
1.33	5%	562	1200	A380-800
1.35	5%	592	1200	A380-800F
1.37	5%	377.8	1200	B-747-200
1.31	5%	152	1200	B-767-200
1.50	5%	341.2	1200	B-777-300ER
1.22	5%	264.44	1200	DC-10-30
1.05	5%	264.44	1200	DC-10-30 Belly
1.07	5%	81.45	1200	Fokker F100

As it can be seen in Table 1, names of the some aircraft are applied twice in the traffic mix that is because of the type of their wheels arrangement, in a way that once front wheels of the aircraft and in the second time back wheels of the aircraft are investigated.

According to pavement growth rate and annual flight number, the total number of flight operations on the pavement system during the design course is calculated through Equation 3 [7]:

$$N = \left(1 + \frac{b \times L}{200}\right) \times a \times L \qquad \text{Eq.3}$$

In this equation, N represents the total number of flights, b represents an annual growth rate of flights, L represents the life period of a pavement design and a represents the annual number of aircraft flight in their first year. The total number of flight operations on pavement systems during the design course by placing traffic assumptions of Table 1, in Equation 3 is obtained as follows:

$$N = \left(1 + \frac{5 \times 20}{200}\right) \times 1200 \times 20 = 36000 \qquad \text{Total number of flights}$$

5-2- Studying the Design Results

According to the aircraft mentioned in the previous section and for all the same traffic assumptions, rigid and flexible pavement design is undertaken by each software and the results and thickness of each layer is equal to the following tables.

Table 2 - Results of the design using LEDFAA software

Rigid			**Flexible**		
Modulus (Mpa)	**Thickness (mm)**	**Layer**	**Modulus (Mpa)**	**Thickness (mm)**	**Layer**
*R= 4.83	418	PCC	1379	127	AC
4826	152.4	CTB Base	2758	203.2	Stabilized Base
244	152.4	Subbase Cr Ag	376	409.2	Subbase Cr Ag
103.42	**k =38.38	Subgrade	103.42	CBR = 10	Subgrade
total thickness 735.2 mm			total thickness 739.4 mm		

* R represents the flexural strength of concrete.
** K, based on Newton Mega, is cubic meter.

As it is shown in the table above, the total thickness of flexible pavement system and the total thickness of rigid pavement system are obtained 739.4 mm and 735.2 mm, respectively.

Table 3 - Results of the design using FAAEFIELD software

Rigid			Flexible		
Modulus (Mpa)	Thickness (mm)	Layer	Modulus (Mpa)	Thickness (mm)	Layer
*R= 4.83	445.5	PCC	1379	127	AC
4826	152.4	CTB Base	2758	288.4	Stabilized Base
244	152.4	Subbase Cr Ag	321	270.3	Subbase Cr Ag
103.42	**k = 38.4	Subgrade	103.42	CBR = 10	Subgrade
total thickness 750.3 mm			total thickness 685.7 mm		

* R represents the flexural strength of concrete.
** K, based on Newton Mega, is cubic meter.

As it can be viewed in the above table, the total thickness of flexible pavement system and the total thickness of rigid pavement system are obtained 685.7 mm and 750.3 mm, respectively.

So, this process is performed in APSDS software and results are described in the following table. It is necessary to explain that as mentioned in the introduction of the software, this software has only the capability to design flexible pavement of airport runway.

Table 4 - Results of the design using APSDS software

Flexible		
Modulus (Mpa)	**Thickness (mm)**	**Layer**
1379	127	AC
2758	280	Stabilized Base
321	332	Subbase Cr Ag
103.42	CBR = 10	Subgrade
total thickness 739 mm		

Results of the flexible pavement design of runway using APSDS software shows that the total thickness of pavement system in this sample is 739 mm. The curves corresponding to the cumulative damage factor for each aircraft is drawn by the software.

In Figure 1, features and material of the layers in flexible pavement design of runway using PCASE software is shown.

Layers

Layer Type	Analyze	Minimum Thickness (mm)	Required Thickness (mm)	Non-Frost Design Thickness (mm)	Equivalent Subbase Thickness (mm)	Calculate at this depth	Base Equivalency Factor	Subbase Equivalency Factor
Asphalt	Manual	102	0	127	0	Yes	1.15	2.30
Base	Manual	152	0	200	0	N/A	1.00	2.00
Stabilized Subbase	Comput	102	787	787	0	N/A	1.15	2.30
Natural Subgrade	N/A	0	0	0	0	Yes	1.00	1.00

Figure 1: Characteristics and materials of the layers in flexible pavement by PCASE

As can be seen in the figure above, surface concrete asphalt layer thickness and the basis thickness are selected 127 mm and 200 mm by default, respectively. After design processes, the underneath layer thickness of base is achieved 787 mm. In runway pavement design using LED method, thicknesses of surface and basis asphalt layer are selected by default and the design is done based on the underneath basis by the software. The final thickness of flexible pavement is achieved 1114 mm by PCASE software.

Similarly in Figure 2, specifications and layers materials in rigid pavement design of runway are shown by PCASE software.

PAVER 5.2.2; PCASE 2.08

Layers

Layer Type	Material Type	Dry Weight (kg/m3)	Flexural Strength (MPa)	% Steel	Analyze	Minimum Thickness (mm)	Required PCC Thickness (mm)	Non-Frost Design Thickness (mm)	Calcul at thi dept
PCC	N/A	0.00	4.80	0.00	Comput	152	0	896	N/A
Stabilized Base	PCC Stab-SC,SM	0.00	0.00	0.00	Manual	102	0	152	N/A
Base	Unbound Base	0.00	0.00	0.00	Manual	102	0	152	N/A
Natural Subgrade	Cohesive Cut	0.00	0.00	0.00	N/A	102	0	0	No

Figure 2: Specifications and layers materials in the pavement rigid by PCASE

As depicted in Figure 2, the dense basis layer thickness is equal to 152 mm and the underneath layer thickness of basis is equal to 152 mm which are selected by default. After design stages, surface concrete thickness is achieved equal to 896 mm. The runway rigid pavement design based on LED method and basis and underneath basis layers thicknesses are selected according to the default and the design is performed based on surface concrete slab thickness by the software. The final thickness of runway rigid pavement is achieved 1200 mm by PCASE software.

Runway rigid pavement design is performed by TKUAPAV software likewise. In the software there is no possibility to create basis or underneath basis layers and the software has only considered the natural properties, modulus of elasticity, and flexural strength of concrete in the assumptions part. Based on these data and the given traffic data, the thickness of the surface concrete slab is calculated by the software. This has been done for the sample airport with the mentioned assumptions and the results are shown in Figure 3.

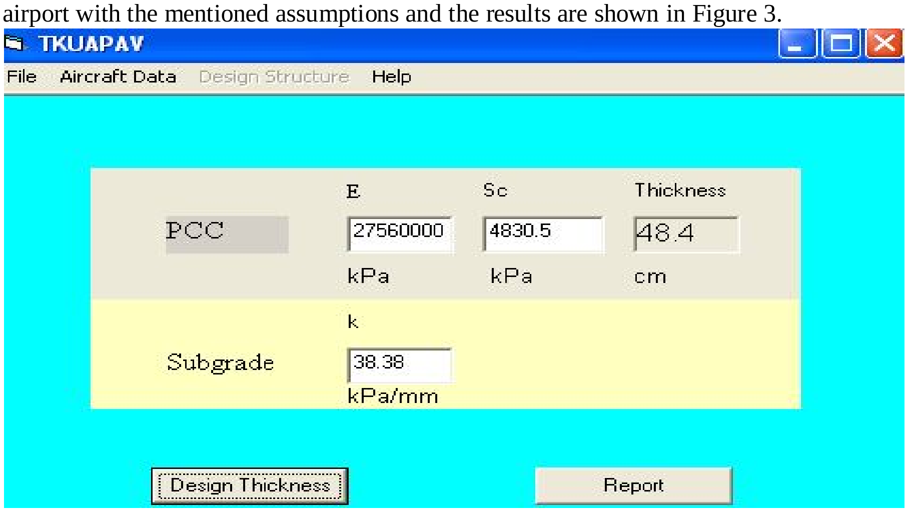

Figure 3 - Runway Rigid Pavement Design by TKUAPAV Software

As can be seen in Figure 3, the coefficient of modulus of subgrade reaction resilience for rigid pavement is assumed 38.38 KPa/mm and according to it; concrete slab thickness is obtained 484 mm.

6 – Comparison of Software Results

Following the runway pavement design of the sample airport with the same traffic assumptions, the obtained results from each piece of software for flexible and rigid pavement are compared and the results of total pavement thickness design by each piece of software is shown in Figure 4.

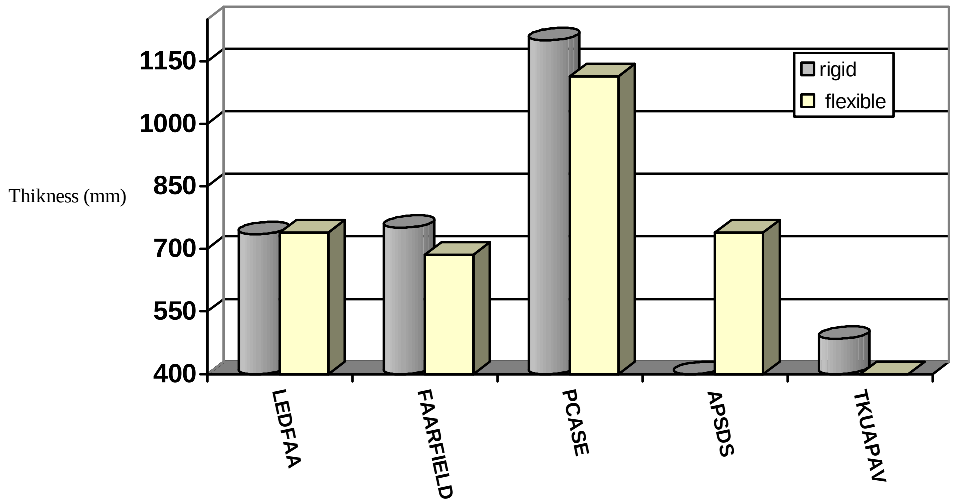

Figure 4 - Comparison of Runway Pavement Design Results

As can be seen in Figure 4, in flexible pavement system design, the obtained thickness by PCASE software is significantly higher than other pieces of software. The results of flexible pavement thickness design by APSDS software are approximately equal to the results of FAARFIELD and LEDFAA software. And obtained rigid pavement thickness in TKUAPAV software was much less than other pieces of software but about this software, this fact should be considered that the obtained thickness is only for the surface concrete slab, in the case, the obtained value is almost equal to the results of FAARFIELD and LEDFAA software. Moreover, the final thickness obtained from LEDFAA software is about 6 cm more than the thickness obtained by FAARFIELD software. The situation is reversed in the case of rigid pavement design so that the obtained total thickness of the system from LEDFAA software is about 25 mm less than the thickness obtained from FAARFIELD Software. Although it is tried to consider design parameters such as age, type of traffic, number of flights per year, the annual growth in flights and the number and characteristics of pavement layers constant, there are some differences. The causes of the difference can be related to differences in a series of assumptions available in the software such as some differences in the weight of airplanes and the first definitions of substrate layers, basis and underneath basis.

6-1 - Evaluation of the CDF in Each Piece of Software

FAARFIELD, LEDFAA, and APSDS software have the capability to calculate cumulative damage index which are displayed as related graphs or tables. Therefore, after the end of flexible pavement design by software, the cumulative damage factor for each aircraft is obtained that this factor for the four sample airplanes having the highest CDF value in flexible pavements has been shown in Figure 5.

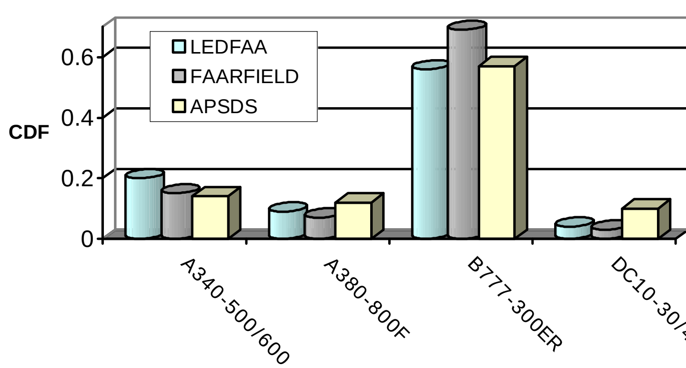

Figure 5 - Airplanes with the highest CDF value in flexible pavements design

As can be seen in Figure 10, the highest CDF value is allocated to B777-300ER airplane in all the three pieces of software. In addition, this amount in the designing by FAARFIELD software is more than the others which is due to the wheels arrangement of this aircraft model and its high destructive effect that has been considered by FAARFIELD software.

Also, in a report from aviation administration consultant published in 2010, not using LEDFAA software in the airport complex traffic design including Boeing 777 aircraft has been emphasized due to the destructive effects of the Boeing 777 which is caused by the type of its wheel arrangement [6]. In Figure 6, the cumulative damage factor for five sample airplanes with the largest CDF value in rigid pavements has been shown. It should be clarified that this section only discussed LEDFAA and FAARFIELD software and APSDS software is not able to design rigid pavement.

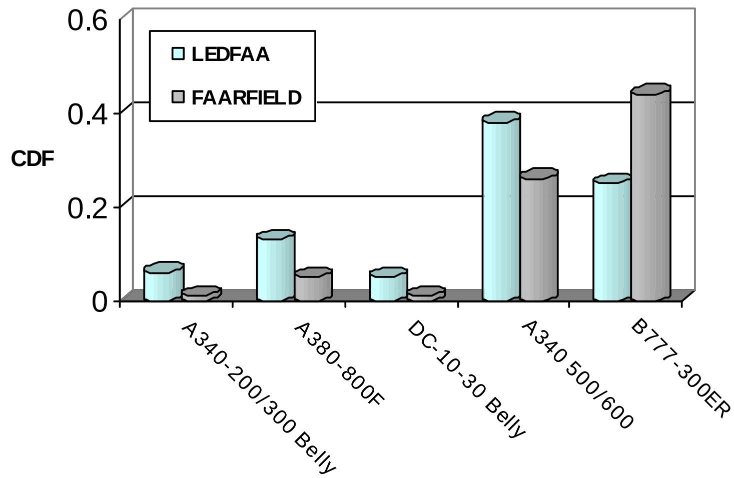

Figure 6 - Aircraft with the highest CDF value in rigid pavement design

As can be seen in Figure 6, like the previous section, the results obtained from FAARFIELD Software indicate Boeing 777 aircraft has the largest CDF value. But in LEDFAA software design, Airbus 340 has the largest share.

7 - Summary and Conclusions

The results from sample airport design with software show that the use of FAARFIELD software to design flexible pavement and regarding that it has provided additional facilities for precise definition of layers and prediction of pavement behavior, it leads to a more economical design compared with LEDFAA software. According to Figure 4, the use of FAARFIELD Software because of having finite element analysis for flexible pavements shows more precise pavement modeled behavior and based on the results of the issued field experiments and reports, behavior of the pavement designed by this software is more realistic [13]. Therefore, finite element analysis and pavement design not only prevents conservative designs, it will also save on materials. Thus, the necessity of using the FAARFIELD software considering its capabilities in designing flexible airport pavement is more considerable than before.

It is worth mentioning that the results presented in this paper are based solely on a case study and to generalize the results to more samples and implement various structural and traffic conditions on the software. Finally, as a conclusion we can say that designing by LEDFAA software at this sample airport is more conservative than FAARFIELD software.

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