AIRPORT PAVEMENT DESIGN
Consideration of New Guidelines

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Abstract
The following dissertation aims to study FAARFIELD, the most recent method of airport pavement design by the Federal Aviation Administration (United States of America). Launched in 2009 with Advisory Circular AC 150/5320-6E, FAARFIELD consists of an automatic calculation software, based on an elastic and linear multilayer structural model for flexible pavements, and tridimensional finite elements for rigid pavements. It was made a presentation of this new method and evaluated its potential applicability to airports in Portugal, performing a comparative analysis between the FAARFIELD results and previous ones achieved through the mechanistic-empirical method currently used in Portugal. The case studies defined were the runways from Lisbon Airport (RWY 03-21) and Faro Airport (RWY 10-28). The data used for traffic and pavement structures comes from a project of Instituto Superior Técnico related to the development of an Airport Pavement Management System for Portuguese international airports. This analysis doesn't compromise under any circumstances the airports manager, neither the reality of its operations, once was required a simplification/adaptation of the database to the use of FAARFIELD. It’s concluded that FAARFIELD is more detailed, but less controllable (with regard to how considers information), than mechanistic-empirical method. The results are more conservative when pavements are at the limit of its service capacity and align reasonably when dealing with new pavements or with high load capacity.

Key words: FAARFIELD; airport pavements; structural analysis; design; mechanistic-empirical method.

INTRODUCTION
There is now a multitude of airport pavement design methods, with varying degrees of disclosure and acceptability in each country. In addition, there is a growing trend in software deployment, such as FAARFIELD (United States), or PCASE (United States), ALIZE-LCPC (France), APSDS 5.0 (Australia), among others.

Comparative analysis of results obtained using different design methods is an essential tool for understanding, evolution and development of the same.

Since its inception in 1958, the Federal Aviation Administration (FAA) of the Department of Transportation of the United States is one of the entities that have studied and promoted the progress of design methodologies for airport pavements [1]. The reputation earned over the decades makes its publications and policies have a global impact.
The latest, released in 2009 - Advisory Circular (AC) 150/5320-6E [2] - introduces the FAARFIELD as the most advanced method of airport pavement design, with new approximate models of reality, the result of further testing to full-scale settings complex landing gear.

**BACKGROUND**

The current airport pavement design procedure used in Portugal is a mechanistic-empirical method (MEM) which is still based on the “design aircraft” concept [3] [4], used by FAA until 1995 [5].

The subgrade failure criteria taken into account is proposed by Chou in 1982 (1), where $N$ is the number of coverages to failure and $\varepsilon_V$ the maximum vertical strain at the top of the subgrade [6]:

$$\varepsilon_V = 0.00539 \times N^{-0.14356}$$  \hspace{1cm} (1)

With the emergence of 3D landing gear configuration on the Boeing B777, the FAA found that due to the high degree of interaction between the individual loads of the wheels, not only the predictability of its previous design methodology was exceeded (AC 150/5320-6D), as well as this had a limited ability to accommodate new aircraft and arrangements of wheel sets.

The introduction of these new aircraft boosted the need to carry out further testing full-scale to improve pavement design methodologies (NAPFT) [7].

As a result of these tests, the FAA developed in 2004 the LEDFAA 1.3 software, which evolution to FAARFIELD consists in small internal improvements, which don’t change the use of the user’s point of view.

The main change to FAARFIELD regarding the mechanistic-empirical methodology above, together with others software mentioned, is related to the end of the “design aircraft” concept, admitting any mixture of traffic and the exact position and geometry of the wheels of each aircraft relative to the pavement centerline [8].

Thus, each aircraft contributes to cumulative damage factor (CDF) - Fig. 1 - according to Miner’s rule, where the effects of each aircraft linearly overlap.

![Fig. 1: Cumulative Damage Factor](image)

The pavement design is performed to $CDF = 1$.

For an aircraft with constant annual departures, CDF may be defined as (2):

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

or

$$CDF = \frac{\text{annual departures} \times \text{life in years}}{P/C \text{ ratio} \times \text{coverages to failure}}$$  \hspace{1cm} (2)

**PROCEDURE**

Due to their relevance and different characteristics in terms of traffic and pavement structure, the case studies defined are the runways from Lisbon Airport (RWY 03-21) and
from Faro Airport (RWY 10-28). The pavement structures adopted for these case studies correspond to those defined in [3] and [4].

In order to be able to insert the elastic modulus of each layer in FAARFIELD determined by falling-weight deflectometer (FWD) tests, all layers of the pavement have to be set to *undefined*. Nevertheless, adoption of the *undefined* type materials in FAARFIELD doesn’t establish considerations when to asphalt fatigue failure criteria, so this has to be omitted in case studies.

**COMPARATIVE ANALYSIS**

In this research a comparison is made between the results of FAARFIELD application and MEM.

**Pavement Remaining Life**

With regard to the subgrade failure criteria, the MEM provides the exhaustion of structural life for RWY 03-21 from Lisbon Airport in a lot longer than 20 years and for RWY 10-28 from Faro Airport in a relatively short period, between 5 and 6 years.

Comparing these results with those obtained in FAARFIELD, Lisbon Airport (Table 1) is in conformity with that. Although oversized for the current traffic, this pavement has a reduction in structural quality towards head 03 to the head 21.

<table>
<thead>
<tr>
<th>RWY 03-21</th>
<th>Subgrade Remaining Life</th>
<th>Zone 1</th>
<th>Zone 2</th>
<th>Zone 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>MEM (2012)</td>
<td>&gt;&gt; 20</td>
<td>&gt;&gt; 20</td>
<td>&gt;&gt; 20</td>
<td></td>
</tr>
<tr>
<td>FAARFIELD (2012)</td>
<td>703.3</td>
<td>155.0</td>
<td>29.3</td>
<td></td>
</tr>
<tr>
<td>FAARFIELD (2013)</td>
<td>648.0</td>
<td>141.6</td>
<td>26.3</td>
<td></td>
</tr>
</tbody>
</table>

In turn, in the case of Faro Airport (Table 2), FAARFIELD application results are very conservative, and despite the pavement is clearly undersized for current traffic and in need of a rehabilitation intervention, the expected time horizon to failure seems too short, of approximately 1 year.

<table>
<thead>
<tr>
<th>RWY 10-28</th>
<th>Subgrade Remaining Life</th>
<th>Zone 1</th>
<th>Zone 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>MEM (2012)</td>
<td>6.0</td>
<td>5.0</td>
<td></td>
</tr>
<tr>
<td>FAARFIELD (2012)</td>
<td>1.2</td>
<td>0.9</td>
<td></td>
</tr>
<tr>
<td>FAARFIELD (2013)</td>
<td>1.0</td>
<td>0.8</td>
<td></td>
</tr>
</tbody>
</table>

**Pass-to-Coverage Ratios**

Regarding the conversion of the number of aircraft departures in coverages (P/C ratios), it’s introduced the concept of effective tire width (Fig. 2 & 3), under which the calculation is performed on top of the foundation of the flexible pavements and not on its surface as MEM.

**Fig. 2: Effective tire width: without overlap [2]**

**Fig. 3: Effective tire width: with overlap [2]**
Consequently, the passage of an aircraft can cause more than a coverage in each plane, so the average P/C ratios (x) computed in FAARFIELD are substantially lower than those presented in ACs 150/5320-6D [5] and 150/5335-5A [9], which are used in MEM (Table 3).

Note that for the same number of annual departures and structural lifetime projection, a lower P/C ratio has a positive contribution to the increase in the number of applied coverages.

Table 3: P/C ratios for case studies

<table>
<thead>
<tr>
<th>Gear</th>
<th>ACs</th>
<th>FAARFIELD*</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>[5]</td>
<td>3.48</td>
</tr>
<tr>
<td></td>
<td>[9]</td>
<td>1.84</td>
</tr>
<tr>
<td>3D</td>
<td>-</td>
<td>1.40</td>
</tr>
</tbody>
</table>

*Statistical analysis from case studies

**SUBGRADE FAILURE CRITERIA**

In this point, it's compared the Chou’s formula for subgrade failure criteria in relation to the internal formulation of FAARFIELD (3):

$$N = \left( \frac{0.004}{\epsilon V} \right)^{0.1} \quad \text{if} \ N \leq 12100$$

$$N = \left( \frac{0.002428}{\epsilon V} \right)^{14.21} \quad \text{if} \ N \geq 12100$$

(3)

The development of both failures models is shown in Fig. 4.

The intersection between the FAARFIELD functions occurs for very high value of $\epsilon_V$ for international airports, $1250 \times 10^{-6}$.

It should be noted that FAARFIELD formulation is only more conservative than Chou for strains greater than $1125 \times 10^{-6}$, in
other words, for situations that already exists the possibility of significant deterioration of the pavements.

In the case of Faro Airport, that pavement has low structural capacity, the strains presented in are greater than 1125 x 10^6, so FAARFIELD formulation is more prejudicial than Chou’s, what is in agreement with the results obtained.

For values lower than, usual in recent pavements or with high load capacity, as the case study of Lisbon Airport, there is a remarkable difference between the subgrade failure criteria of Chou and FAARFIELD “>12100”, being Chou the most conservative approach (allowing fewer repetitions to failure).

CONCLUSIONS

The latest AC 150/5320-6E (2009) from FAA, developed with FAARFIELD, represents a breakthrough in relation to airport pavement design methods, being able to consider the degradation of structural quality of a pavement to the new generations of aircrafts, heavier and with complex landing gear configurations.

This software enables the user to obtain quick results in a simple interface.

However, it is essential to meet that results obtained in the software are function of the input parameters considered in the method.

Thus, despite the apparent ease that one provides software, it remains a major engineering component in the correct determination of parameters and its interpretation.

The case studies analyzed were the flexible pavements of RWY 03-21 from Lisbon Airport and RWY 10-28 from Faro Airport, on which the FAARFIELD adopts an layered elastic-based design procedure (LEAF) without direct access to calculated strains.

The main change of FAARFIELD in relation to MEM, as other existing software, is the end of “design aircraft” concept, assuming the entire traffic mix and the exact placement and geometry of each aircraft landing gear in relation to the pavement centerline.

Thus, each aircraft contributes to a cumulative damage factor (CDF) according to Miner’s rule.

The main limitation of FAARFIELD to the application of case studies in Portugal is the very little correlation between the standard materials available in the software, with deformability modules automatically set and unalterable, and the materials used in the Portuguese paving technology.

It’s therefore necessary to admit undefined materials for the pavement layers, which prevents any consideration with regard to asphalt fatigue failure criteria.

Moreover, there are limitations inherent to the structural model adopted, and there is no direct access to the strains calculated. It was also found, in the course of the study, other less important limitations, namely: (i) traffic mix with a maximum of 40 aircrafts; (ii) Absence in internal library of Embraer aircraft manufacturer; (iii) Minimum 2” thickness (5.8 cm) per layer (iv) doesn’t allow to consider non-adherence interfaces between layers; (v) does not allow changes to the Poisson’s ratio of the layers.

MEM provides a remaining life for RWY 03-21 from Lisbon Airport in a much longer period than 20 years and for RWY 10-28 from Faro Airport in a relatively short time, between 5 and 6 years.
When comparing these results to FAARFIELD, the Lisbon Airport is accordingly. This pavement is oversized for the current traffic, although it presents a reduction in its structural quality towards the head 03 to 21.

In turn, in Faro Airport, FAARFIELD application results are very conservative, and despite being undersized for current traffic, the expected time horizon to failure, in about 1 year, seems too short. This pavement requires an overlay or rehabilitation.

This difference, negligible in a practical situation, is related not only with a more determinant consideration of the traffic in FAARFIELD, but also with the differences between subgrade failure models.

It’s concluded that FAARFIELD is more detailed, but less controllable with regard to how it considers information, than mechanistic-empirical method currently used in Portugal.

The results are more conservative when pavements are at the limit of its service capacity and align reasonably when dealing with new pavements or with high load capacity.

REFERENCES


