Introducing FAARFIELD 1.41: Latest Updates to FAA Airport Pavement Design Procedures

Advisory Circular 150/5320-6F & Introduction to FAARFIELD 1.41

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By: David R. Brill, P.E., Ph.D.
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Research conducted at the FAA William J. Hughes Technical Center, Atlantic City, NJ, USA.

Sponsor: FAA Office of Airport Safety and Standards (AAS-100), Washington, DC.

Provide support for development of FAA pavement standards (Advisory Circulars).
FAA Airport Pavement R&D

National Airport Pavement Test Facility (NAPTF)

- Fully enclosed facility for accelerated traffic testing of airport pavements – opened 1999

National Airport Pavement Materials Research Center (NAPMRC)

- Opened August 27, 2015

Heavy Vehicle Simulator for Airports (HVS-A)
Order of Presentation

• AC 150/5320-6F – Changes and Organization
• FAARFIELD – Mechanistic-Empirical Design Concepts
  – Structural Models in FAARFIELD
  – Pass/Coverage Ratio and Wander
  – Cumulative Damage Factor (CDF)
  – Failure Models
• FAARFIELD 1.42 – What’s New
  – Flexible Pavements
  – Rigid Pavements and Overlays
• FAARFIELD 1.42 Technical Requirements
• Library Features
• Future Improvements
• Examples
AC 150/5320-6F
Airport Pavement Design and Evaluation

• Issued Nov. 10, 2016.
  – Replaces AC 150/5320-6E.
  – Incorporates FAARFIELD 1.42 software program.

• General reorganization of contents.

• Download at: https://www.faa.gov/airports/resources/recent_advisory_circulars/
AC 150/5320-6F – Partial List of Changes - General

- Eliminated separate chapter for light-load design (intended to handle aircraft under 13,600 kg / 30,000 lbs. gross weight).
- Consolidated list of minimum thicknesses applicable for various standard layer types.
- New guidance for automated compaction criteria – replaces Table 3-4 in old AC.
- Revised shoulder design criteria.
- Updated all design examples.
- Added appendix on NDT methods for pavement evaluation.
AC 150/5320-6F – Partial List of Changes - Flexible

- Clarified subgrade characterization using CBR.
- Implemented new asphalt fatigue criteria (RDEC energy model).
- Reduced minimum base thickness requirements.
  - Removed previous requirement for additional stabilized base thickness (above 125 mm / 5 inches) when P-209 subbase is used.
Partial List of Changes - Rigid

- Modified conversion from CBR to $k$-value.
- Modified guidance for concrete design strength.
- Added detail on reinforcement at Type A1 joints (reinforced isolation joint).
- Added detail of transition between PCC and HMA Pavement sections.
- Removed CRCP design procedure (rarely used).
- Reduced subgrade compaction requirements for rigid pavements.
AC 150/5320-6F Organization

• Chapter 1: Airport Pavement Function and Purpose
  – Pavement layers & specifications
  – Cost effectiveness analysis
• Chapter 2: Soil Investigations
  – Soil strength testing
  – Subgrade stabilization
• Chapter 3: Pavement Design
  – Flexible Pavement Design
  – Rigid Pavement Design
• Chapter 4: Pavement Rehabilitation (includes overlay design)
• Chapter 5: Pavement Structural Evaluation
• Chapter 6: Pavement Design for Shoulders
• Appendix A: Soil Characteristics (USC Classification)
• Appendix B: Design of Structures
• Appendix C: NDT Using Falling-Weight Type Devices
• Appendix D: Reinforced Isolation Joint
• Appendix E: Variable Section Runway
• Appendix F: Related Reading Material
Chapter 3 – Pavement Design

1. Design Considerations
2. FAA Pavement Design
3. Flexible Pavements
4. Full Depth Asphalt Pavements
5. Rigid Pavements
6. Stabilized Base Course
7. Base/Subbase Contamination
8. Drainage Layer
9. Subgrade Compaction
10. Swelling Soils
11. Pavement Life
12. Pavement Design Using FAARFIELD
13. Flexible Pavement Design
14. Rigid Pavement Design
15. Pre-stressed, Precast, Reinforced & CRCP
16. Aggregate-Turf Pavements
17. Heliport Design
18. Passenger Loading Bridge

NOTE: No more separate chapter for light load aircraft design.
Layer Types & Allowable Modulus Values

Table 3-2. Allowable Modulus Values and Poisson’s Ratios Used in FAARFIELD

<table>
<thead>
<tr>
<th>Layer Type</th>
<th>FAA Specified Layer</th>
<th>Rigid Pavement psi (MPa)</th>
<th>Flexible Pavement psi (MPa)</th>
<th>Poisson’s Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface</td>
<td>P-501 PCC</td>
<td>4,000,000 (28,000)</td>
<td>NA</td>
<td>0.15</td>
</tr>
<tr>
<td></td>
<td>P-401/P-403/P-601 HMA</td>
<td>NA</td>
<td>200,000 (1,380)</td>
<td>0.35</td>
</tr>
<tr>
<td>Stabilized Base and Subbase</td>
<td>P-401/P-403HMA</td>
<td>400,000 (3,000)</td>
<td></td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td>P-306 Lean Concrete</td>
<td>700,000 (5,000)</td>
<td></td>
<td>0.20</td>
</tr>
<tr>
<td></td>
<td>P-304 cement treated base</td>
<td>500,000 (3,500)</td>
<td></td>
<td>0.20</td>
</tr>
<tr>
<td></td>
<td>P-301 soil cement</td>
<td>250,000 (1,700)</td>
<td></td>
<td>0.20</td>
</tr>
<tr>
<td></td>
<td>Variable stabilized rigid</td>
<td>250,000 to 700,000 (1,700 to 5,000)</td>
<td>NA</td>
<td>0.20</td>
</tr>
<tr>
<td></td>
<td>Variable stabilized flexible</td>
<td>NA</td>
<td>150,000 to 400,000 (1,000 to 3,000)</td>
<td>0.35</td>
</tr>
<tr>
<td>Granular Base and Subbase</td>
<td>P-209 crushed aggregate</td>
<td>Program Defined</td>
<td></td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td>P-208. aggregate</td>
<td>Program Defined</td>
<td></td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td>P-219. Recycled concrete aggregate</td>
<td>Program Defined</td>
<td></td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td>P-211. Lime rock</td>
<td>Program Defined</td>
<td></td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td>P-154 uncrushed aggregate</td>
<td>Program Defined</td>
<td></td>
<td>0.35</td>
</tr>
<tr>
<td>Subgrade</td>
<td>Subgrade</td>
<td>1,000 to 50,000 (7 to 350)</td>
<td></td>
<td>0.35</td>
</tr>
<tr>
<td>User-defined</td>
<td>User-defined layer</td>
<td>1,000 to 4,000,000 (7 to 350)</td>
<td></td>
<td>0.35</td>
</tr>
</tbody>
</table>

Notes:
1. A fixed modulus value for hot mix surfacing is set in the program at 200,000 psi (1,380 MPa). This modulus value was conservatively chosen and corresponds to a pavement temperature of approximately 90°F (32°C).

- Similar to FAARFIELD v 1.305.
- “Undefined” layer replaced by “User-defined.”
- P-306 econocrete renamed Lean Concrete.
- Added P-219, recycled concrete aggregate, as a standard layer type.
- Rubblized concrete base now handled as user-defined layer.
# Minimum Layer Thickness - Flexible

<table>
<thead>
<tr>
<th>Layer Type</th>
<th>FAA Specification Item</th>
<th>Maximum Airplane Gross Weight Operating on Pavement, lbs (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>&lt;12,500 (5 670)</td>
</tr>
<tr>
<td>HMA Surface</td>
<td>P-401, Hot Mix Asphalt (HMA) Pavements</td>
<td>3 in. (75 mm)</td>
</tr>
<tr>
<td>Stabilized Base</td>
<td>P-401 or P-403; P-304; P-306</td>
<td>Not Required</td>
</tr>
<tr>
<td>Crushed Aggregate Base</td>
<td>P-209, Crushed Aggregate Base Course</td>
<td>3 in. (75 mm)</td>
</tr>
<tr>
<td>Aggregate Base</td>
<td>P-208 Aggregate Base Course</td>
<td>3 in. (75 mm)</td>
</tr>
<tr>
<td>Subbase</td>
<td>P-154 Subbase Course</td>
<td>4 in. (100 mm)</td>
</tr>
</tbody>
</table>
## Minimum Layer Thickness - Rigid

<table>
<thead>
<tr>
<th>Layer Type</th>
<th>FAA Specification Item</th>
<th>Maximum Airplane Gross Weight Operating on Pavement, Lbs (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>&lt;12,500 (5,670)</td>
</tr>
<tr>
<td>PCC Surface</td>
<td>P-501, Portland Cement Concrete (PCC) Pavements</td>
<td>5 in. (125 mm)</td>
</tr>
<tr>
<td>Stabilized Base</td>
<td>P-401 or P-403; P-304; P-306</td>
<td>Not Required</td>
</tr>
<tr>
<td>Base</td>
<td>P-208, P-209, P-211, P-301</td>
<td>Not Required</td>
</tr>
<tr>
<td>Subbase&lt;sup&gt;3,4&lt;/sup&gt;</td>
<td>P-154, Subbase Course</td>
<td>4 in. (100 mm)</td>
</tr>
</tbody>
</table>
FAARFIELD 1.42

• Accompanies new AC 150/5320-6F.
• Many significant changes.
• Reduces excess design conservatism.
• New design-based compaction procedure.
• Incorporates results of full-scale tests at the National Airport Pavement Test Facility.
• Download:

http://www.airporttech.tc.faa.gov/Download/Airport-Pavement-Software-Program
FAARFIELD – What Is It?

• **FAARFIELD** is the standard FAA airport pavement thickness design program.

• **FAARFIELD** design procedure for:
  – Flexible
  – Rigid
  – Overlay

• Current version is **FAARFIELD 1.42** (posted 18 Sep 2017)
Mechanistic-Empirical Design

- Structural Model (Mechanistic)
- Traffic Model (Statistical)
- Failure Model (Empirical)
Key Concepts in FAARFIELD

- Layered Elastic Analysis
- Wander
- Pass/Coverage Ratio (P/C)
- Miner’s Rule (linear summation of damage)
- Cumulative Damage Factor (CDF)
Structural Models in FAARFIELD

• Both layered elastic (LEAF) and 3D-FEM (NIKE3D) are used in FAARFIELD.

• Flexible pavement design
  - LEAF is used for all structural computations.
  - For flexible, no advantage to using 3D-FEM.

• Rigid pavement design
  - LEAF is used to generate a preliminary thickness.
  - Final iterations are done using a 3D finite element model (3D-FEM).
Pass/Coverage Ratio Concept

• **Coverage** = application of the maximum stress or strain at a point on the pavement.

• **Pass/Coverage Ratio** = the number of aircraft passes resulting in one coverage on a given strip.

• **Wander** = the width over which the centerline of the aircraft is distributed 75% of the time.
P/C Ratio in FAARFIELD

- Assume tire has a normal lateral distribution with wander width = 1.78 m (70 in.).
- The probability that, for a given pass, any part of the effective tire width covers point P, is defined as the coverage/pass ratio (C/P) for point P.
- P/C is the reciprocal of C/P.
- On a pavement strip of width w, P is the center point of the strip, and we define P/C as applying to the whole strip.
Cumulative Damage Factor (CDF)

- Sums the damage contributed from each aircraft - not from equivalent aircraft.
- \[ \text{CDF} = \sum \left( \frac{n_i}{N_i} \right) \text{, where:} \]
  - \( n_i \) = actual passes of individual aircraft \( i \)
  - \( N_i \) = allowable passes of individual aircraft \( i \)
- When CDF = 1, design life is exhausted.
- In FAARFIELD:
  - The gear location and wander are considered separately for each aircraft in the total mix.
  - CDF is calculated for each 25.4 cm (10 inch) wide strip over a total 20.83 m (820 inch) width.
  - Use Miner’s rule to sum damage for each strip.

**Important:** Input the fleet mix, NOT equivalent departures of design aircraft.
Cumulative Damage Factor (CDF)

Difference in Gear Location

25.4 cm (10 in.)

Damage from Airplane A

Damage from Airplane B
Cumulative Damage Factor (CDF)

25.4 cm (10 in.)

Damage from Airplane A

Damage from Airplane B

Total Damage
Large Airplane Traffic Mix Gear Locations

![Diagram showing gear locations for various airplane types](image-url)
FAARFIELD – CDF Graphical Display
Failure Models in FAARFIELD

• This is the “empirical” part of mechanistic-empirical.
  – Derived from full-scale traffic tests at NAPTF.
  – Relates strain or stress to allowable coverages (fatigue).
  – Tied to CDF through P/C ratio.

• Flexible: Function of maximum vertical strain at the top of the subgrade.

• Rigid: Function of maximum horizontal stress in concrete slab.
FAARFIELD 1.4 – What’s New?

General Improvements:

• Updated aircraft library aligned with COMFAA 3.0.
• Added non-aircraft vehicles (trucks) to library.
• Automatically generates PDF design report.
• Automated, software-based compaction criteria.
• Support for user-defined gear configurations.
• All data files now stored in document directories.
• Minimum thickness in convenient metric units (100 mm; 125 mm)
• Updated Help file with new examples.
Aircraft Libraries

- Aligned the aircraft libraries in COMFAA and FAARFIELD to the extent possible.
- Used the most current data from manufacturers.
- Includes new aircraft:
  - A350-900/1000
  - B747-8
  - B787-9
  - Embraer Fleet
Automated Compaction Criteria

Computes compaction control points for rigid & flexible pavements.

<table>
<thead>
<tr>
<th>Percent Maximum Dry Density (%)</th>
<th>Depth of compaction from pavement surface (in)</th>
<th>Depth of compaction from top of subgrade (in)</th>
<th>Critical Airplane for Compaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>0 - 16</td>
<td>--</td>
<td>B777-200 ER</td>
</tr>
<tr>
<td>95</td>
<td>16 - 70</td>
<td>0 - 43</td>
<td>B777-200 ER</td>
</tr>
<tr>
<td>90</td>
<td>70 - 183</td>
<td>43 - 156</td>
<td>B747-2008 Combi Mixed</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Percent Maximum Dry Density (%)</th>
<th>Depth of compaction from pavement surface (in)</th>
<th>Depth of compaction from top of subgrade (in)</th>
<th>Critical Airplane for Compaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>95</td>
<td>0 - 16</td>
<td>--</td>
<td>B777-200 ER</td>
</tr>
<tr>
<td>90</td>
<td>16 - 28</td>
<td>0 - 1</td>
<td>B777-200 ER</td>
</tr>
<tr>
<td>85</td>
<td>28 - 96</td>
<td>1 - 69</td>
<td>B747-2008 Combi Mixed</td>
</tr>
<tr>
<td>80</td>
<td>96 - 178</td>
<td>69 - 151</td>
<td>B747-2008 Combi Mixed</td>
</tr>
</tbody>
</table>

Existing subgrade densities
Depth of additional compaction (red areas)
Top of subgrade
Computed compaction requirement (cohesive soils)
Changes in Data File Storage

- All data files are now stored in document directories by default.
  - Job files
  - External aircraft library files
  - Output files.
  - C:\Users\[User Name]\Documents\FAARFIELD

- Previously, data files (including job files) were stored in the program directory.
  - Required unrestricted read/write access for user.
  - Risk of data loss when changing/upgrading PC.
What’s New?

Flexible Designs:

• Revised flexible failure model now includes direct evaluation of tandem gear damage.

• Advanced, energy-based asphalt fatigue models. Fatigue damage (HMA CDF) is now computed at the bottom of all asphalt layers.

• Reduced excess stabilized base thickness requirement.

• Automatic base layer thickness design feature extended to all standard flexible pavement designs.

• Improved sublayering of aggregate layers.
Flexible Pavements

- New thickness designs are generally less conservative than FAARFIELD 1.305 designs for the same inputs.
- More compatible with COMFAA 1.3 (ACN-PCN method).
New Aggregate Modulus Model

- FAARFIELD 1.4 implements a new sublayering and modulus computation procedure for aggregate subbase (P-154 & P-209).

- **Why?**
  - Previous procedure (WES Modulus subroutine) has gaps that can cause illogical results under some circumstances.
  - New model provides a continuous function of modulus with changes in P-154 thickness.
  - Better overall agreement with the P-209/P-154 equivalency factor used in PCN computations.
Flexible Base Thickness

- The minimum stabilized base thickness is still 5 in.
- No additional stabilized base thickness requirement when improved subbase material (P-209) is used.
- Additional thickness requirement applies only if standard subbase (P-154) is used.
Direct Evaluation of Tandem Gear Damage (Flexible)

- Old method was a two-part P/C ratio consisting of a wander-related factor multiplied by a tandem factor.
- New method: Compute CDF for multiple wheels in tandem by numerical integration of the longitudinal strain profile.
- Similar to method used in Alizé-LCPC (DGAC-France).
- New P/C ratio relates only to wander.
FAARFIELD 1.4 – What’s New?

Rigid Designs:

• Completely revised rigid failure model based on newest full-scale test data.

• Design stress is the larger of:
  – 75% of computed free edge stress; or
  – 95% of computed center slab stress.

• Completely rewritten concrete overlay design procedure.

• Improved, more accurate 3D finite element model.

• New Visual Basic.NET mesh generation procedure replaces legacy Fortran code.
Rigid Pavements

- New thickness designs are generally less conservative than FAARFIELD 1.305 designs for the same inputs.
- New calibrations incorporate CC6 failure data.

**Effect of Subgrade Modulus $E$**

![Graph showing the relationship between subgrade modulus and PCC design thickness]

**Rigid Design Example**

<table>
<thead>
<tr>
<th>Layer Material</th>
<th>Thickness (in)</th>
<th>Modulus or R (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCC Surface</td>
<td>15.09</td>
<td>700</td>
</tr>
<tr>
<td>P-30E E-concrete</td>
<td>6.00</td>
<td>700,000</td>
</tr>
<tr>
<td>P-209 Gr. Ag</td>
<td>6.00</td>
<td>40,383</td>
</tr>
</tbody>
</table>

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30 May 2018
AC 150/5320-6F & FAARFIELD 1.4
Improved Rigid Failure Model

- Sensitivity to factors such as concrete strength, traffic level and subgrade support is similar to current version.

**Effect of Concrete Flex Strength**

![Graph showing the effect of concrete flexural strength on PCC design thickness.]

**Effect of Traffic**

![Graph showing the effect of traffic scale factor on PCC design thickness.]

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AC 150/5320-6F & FAARFIELD 1.4
Improved 3D Finite Element Mesh

- More accurate stress results.
- Improved infinite foundation model.
- Still one slab model with assumed 25% load transfer.

FAARFIELD 1.305

FAARFIELD 1.41
Rigid Overlay Design Procedure

• Completely rewrote overlay life program module.
• Eliminated gaps and illogical results, especially for overlays on new or undamaged PCC.

FAARFIELD 1.305

FAARFIELD 1.41
FAARFIELD – Technical Background

- Computer program for Windows operating systems.
- Main program drives three subprograms:
  - LEAF (layered elastic analysis).
  - NIKE3D (3D finite element analysis).
  - FAAMesh (3D mesh generation).
- NIKE3D information:
  - Modified for FAARFIELD by the FAA.
  - Distributed in compiled form under a software sharing agreement with Lawrence Livermore National Laboratory (LLNL).
FAARFIELD 1.4
System/Software Requirements

Minimum
• Windows XP or higher
• 2 GHz processor
• 2 GB RAM
• 200 MB of available space on hard drive.

Recommended
• Windows 7 or higher
• 3 GHz processor
• 4 GB RAM
• 64-bit operating system*

Notes:
*FAARFIELD 1.4 supports 32-bit or 64-bit Windows operating systems.
Running FAARFIELD: Program Windows and Linkage

- **NOTES**
  - Additional Section Information and Detailed Output Data
- **STARTUP**
  - Control and Organization
- **OPTIONS**
  - Set User Options and Tolerances
- **STRUCTURE**
  - Structure Data Input and Design
- **AIRCRAFT**
  - Aircraft Load and Traffic Data Input
- **AIRCRAFT DATA**
  - View Landing Gear Geometry, Load, and Tire Pressure
- **Export XML**
FAARFIELD Input Requirements

**Structure Window**
- For each structural layer:
  - Material type (FAA specification)
  - Layer Thickness
  - Modulus or R-value (if applicable)
- There are built-in restrictions on the layer types, including relative position and layer properties.
- For subgrade, can enter CBR or k and FAARFIELD will convert to E.

**Aircraft Window**
- Select airplane from library.
- For each airplane in the mix:
  - Aircraft Name
  - Gross Taxi Weight
  - Annual departures and percent annual growth if applicable
- Enter data for all airplanes in the mix.
FAARFIELD External Airplane Library

- FAARFIELD includes >190 airplanes in the internal library.
- FAARFIELD allows users to define additional airplanes in the external library.
- Add or modify external library airplanes by editing the file: FAAairplaneLibrary.xml
- XML (Extensible Markup Language) format.
- Edit the file using Microsoft Word or other XML editor.
Example Airplane Info in XML File

- <AirplaneInfo>
  
  • GrossWt = weight of airplane, lbs.
  • MGpcnt = % of GrossWt on 1 main gear
  • CP = tire contact pressure, psi
  • Gear = gear designation letter code
  • IGear = gear ID no. (see next slide)
  • TT, TS, TG, B = gear parameters (see Help File)
  • NTires = no. of tires in 1 gear
    – TX, TY: Enter 1 pair of coordinates for each tire (1 through NTires), in.
  • NEVPTS = no. of evaluation points for LEAF
    – EVPTX, EVPTY: Enter 1 pair of x,y coordinates for each evaluation point (1 through NEVPTS), in.
  
  • Note: You have to enter the data in U.S. units (inches, psi).
## Codes for Various Gear Types

<table>
<thead>
<tr>
<th>Gear Type</th>
<th>Example</th>
<th>Code</th>
<th>ID No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>DC3</td>
<td>B</td>
<td>2</td>
</tr>
<tr>
<td>D</td>
<td>B737</td>
<td>D</td>
<td>3</td>
</tr>
<tr>
<td>2D</td>
<td>B767</td>
<td>F</td>
<td>3</td>
</tr>
<tr>
<td>3D</td>
<td>B777</td>
<td>N</td>
<td>3</td>
</tr>
<tr>
<td>User-Defined*</td>
<td>A380 (20 wheels)</td>
<td>X</td>
<td>13</td>
</tr>
</tbody>
</table>

*See help file for information on user-defined gear geometries.
User-Defined Gear Geometries

- A new feature allows users to specify arbitrary gear geometries in the external library.
  - Coded as “X” in the external library.
  - Allows multiple wheel groups to be defined.
- Uses rewritten internal pass/coverage computation routine.
- New user guidance for the external library – see FAARFIELD Help File.

In this example, the externally defined A380 main gear gives the identical result as the internally stored airplane.
FAARFIELD 2.0 is Coming!

- Modernized graphical user interface (GUI).
  - Job and section entry.
  - Improved start-up screen.
  - Improved screen re-sizing and appearance.
  - Improved flow between screens.
- Support for new ACN-PCN.
- Rational data file structure.
- Web compatible:
  - Data file sharing
  - On-demand report generation
Thank You!

http://www.airporttech.tc.faa.gov/
david.brill@faa.gov

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