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**U.S. Department
of Transportation**

**Federal Aviation
Administration**

Advisory Circular

Subject: AIRPORT PAVEMENT DESIGN FOR THE BOEING 777 AIRPLANE	Date: 10/22/95	AC No: 150/5320-16
	Initiated by: AAS-200	Change:

1. PURPOSE. The purpose of this advisory circular is to provide thickness design standards for pavements intended to serve the Boeing 777 airplane.

2. APPLICATION.

    a. New Pavements. The guidelines and standards contained herein are recommended by the Federal Aviation Administration (FAA) and are applicable to the thickness design of airport pavements intended to serve the Boeing 777 airplane. Other facets of pavement design are equally important and should be performed in accordance with AC 150/5320-6, Airport Pavement Design and Evaluation. Thickness design for pavements not subject to Boeing 777 traffic should be determined using AC 150/5320-6. This program was specifically developed as a pavement design program. Traffic is assumed to be composed of a mixture of different aircraft. The program is not intended for use as a tool to compare one aircraft with another, i.e., ACN type calculations. Attempts to use the program in this fashion will likely lead to erroneous results. If only one aircraft is input, a warning will appear indicating that the program is designed for a mix of traffic.

    b. Existing Pavements. The ACN/PCN method, as described in AC 150/5335-5, is recommended to determine the adequacy of existing pavements to serve the B-777. Generally speaking, existing pavements which currently serve wide body aircraft should be adequate for Boeing 777 traffic.

3. BACKGROUND. The Boeing 777 airplane is supported by a landing gear arrangement made up of two main gears and a single nose gear. The main landing gears are unique in that they have 6 wheels arranged in a tri-tandem (3 pairs of wheels in a row) configuration. The nose gear is composed of a single dual wheel arrangement. When the main gear assembly is analyzed using the conventional FAA design methodology, the pavement thickness requirements are considered to be unduly conservative. This is particularly noticeable for flexible pavements. A new airport pavement design methodology was adopted for the Boeing 777 to reduce some of the conservatism experienced with the present method and to phase in a more mechanistic approach. The new method is computer based and is code named LEDFAA v1.2 (Layered Elastic Design - Federal Aviation Administration, version 1.2). The methods of design for flexible and rigid pavements and overlays of rigid pavements were originally developed by the U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS and are reported in DOT/FAA/RD-

74/199, DOT/FAA/RD-77/81 and DOT/FAA/PM-87/19, respectively. See Appendix 1. The new design method uses a general purpose layered elastic analysis procedure code named JULEA developed by Dr. Jacob Uzan, Technion at Haifa, Israel.

4. RELATED READING MATERIAL. Appendix 1 provides a listing of documents containing supplemental material relative to the subject. Information on ordering these documents is also provided.

5. METRIC UNITS. The computer program in its present form does not provide metric dimensions. Future revisions will include metric dimensions.

6. AVAILABILITY. The computer program for airport pavement design for the Boeing 777 airplane is available on the Office of Airport Safety and Standards Electronic Bulletin Board (BBS). There is no charge to access the bulletin board or download information. The bulletin board requirements and parameters are listed below:

        Equipment Requirements:
                Computer with modem
                Communications software

        Bulletin Board Parameters:

Telephone number 202-267-5205 (2 lines)	
or 800-224-6287 (FAA Corporate BBS Gateway)	
Data Bits	8
Parity	(N)one
Stop Bits	1
Baud Rate	300/1200/2400/9600/14400
System Operator	Rick Marinelli, AAS-100
	202-267-7669
Co-System Operator	Jeffrey Rapol, AAS-200
	202-267-7474

DAVID L. BENNETT
Director, Office of Airport Safety and Standards

BACKGROUND

1. INTRODUCTION. The Boeing 777 produces an unprecedented airport pavement loading configuration which seems to exceed the capability of the current methods of design. Existing methods incorporate some empiricism and have limited capacity for accommodating new gear and wheel arrangements. A new method of design based on layered elastic analysis has been developed to calculate design thicknesses for pavements for the Boeing 777. The new design method is computationally intense and is thus in the form of a computer program.

2. COMPUTER PROGRAM. The computer program operates under Microsoft Windows. The core program , JULEA, is a Microsoft Windows FORTRAN application. The remainder of the program is written in Visual Basic.

3. HARDWARE AND SOFTWARE REQUIREMENTS. In order to achieve reasonable solution times, an IBM compatible computer with a 486 or Pentium ® central processing unit (CPU) and a math co-processor is recommended. Windows 3.1 is the required software. These requirements are intended to be compatible with the in-house capabilities of most consulting firms. The program will operate with a 386 CPU and a math co-processor, however, solution times may be objectionably long.

4. AIRCRAFT CONSIDERATIONS. A wide variety of aircraft with pertinent pavement design characteristics are stored in the program library. The designer has some latitude in selecting aircraft parameters.

        a. Mixed Traffic. The computer program was developed and calibrated specifically to analyze a mixture of different aircraft. If a single aircraft is used for design, a warning will appear in the Aircraft Window indicating the program was intended for use with a mixture of different aircraft types. Nearly any traffic mix can be developed from the aircraft in the program library. A maximum of 20 aircraft can be analyzed. Solution times are a function of the number of aircraft in the mix. The design procedure described herein deals with mixed traffic differently than previous methods. There is no need to determine a design aircraft. The program calculates the damaging effects of each aircraft in the traffic mix. The damaging effects of all aircraft are summed in accordance with Miner's Law. When the cumulative damage factor (CDF) sums to a value of 1.0, the design conditions have been satisfied.

        b. Boeing 777. In addition to the requirement for mixed traffic, Boeing 777 aircraft must be in the mixture. If a 777 airplane is not in the traffic mix, a warning will appear on the screen and on the printout.

5. PAVEMENT CONSIDERATIONS.

        a. Design Life. The FAA design standard for pavements is based on a 20 year design life. The computer program is capable of considering other design life time frames. Use of a design life other than 20 years constitutes a deviation from standards and will require FAA approval.

b. Design Reliability. The reliability of this method of design should be approximately the same as the reliability of the CBR method of pavement design.

c. Materials. Pavement materials are characterized by thickness, elastic moduli, and Poisson's ratio. Layer thicknesses can be varied at will except where minimum thicknesses are required. Elastic moduli are either fixed or variable depending on the material. The permissible range of variability for elastic moduli is fixed to ensure reasonable values. Poisson's ratio for all material is fixed. Materials are identified with their corresponding FAA specification designations, for example, crushed stone base course is identified as Item P-209. The list of materials contains an undefined layer with variable properties. If an undefined layer is used, a warning will appear in the Structure Window stating that a non standard material has been selected and its use in the structure will require FAA approval.

FLEXIBLE PAVEMENT DESIGN

6. SCOPE. This section presents FAA standards for the design of flexible pavements intended to serve a mix of traffic which includes the Boeing 777 airplane.

7. INTRODUCTION. The design process considers two modes of failure for flexible pavement, vertical strain in the subgrade and horizontal strain in the asphalt layer. Limiting vertical strain in the subgrade is intended to preclude failure by subgrade rutting. Limiting horizontal strain at the bottom surface of the asphalt surfacing layer guards against failure by cracking of the asphalt surface layer.

8. HOT MIX ASPHALT SURFACING. Hot mix asphalt surfacing should meet the requirements of FAA Item P-401. A minimum thickness of 5 inches (127 mm) of hot mix surfacing is required for traffic mixes which include the Boeing 777. The landing gear of the 777 is articulated (rear dual wheels are steerable) thus scrubbing during turns is expected to be no worse than existing dual tandem gears. Item P-401 surfacing should provide adequate surface stability. A fixed modulus value for hot mix surfacing is set in the program at 200,000 psi (1380 MPa). This modulus value was chosen to produce results which closely matched thickness requirements for pavements designed with the CBR methodology.

9. BASE COURSE. A minimum 8 inch (203 mm) thick stabilized base course is required for pavements serving these aircraft. LEDFAA includes two stabilized flexible base options which are designated: P-401 and Variable. The word flexible is used to indicate that these bases have a higher Poisson's Ratio (0.35) and act as flexible layers as opposed to rigid layers and are not likely to crack. P-401 is the standard FAA Item P-401 bituminous base which has a fixed modulus of 400,000 psi (2760 MPa). The variable stabilized flexible base can be used to characterize a bound base which does not conform to the properties of P-401. It has a variable modulus ranging from 150,000 to 400,000 psi (1035 to 2760 MPa). This modulus range was selected to closely duplicate results from using an equivalency factor range of 1.2 to 1.6 in the CBR method of design. Stabilized (rigid) bases, P-304 and P-306 may also be used as base course although they are subject to cracking and can induce reflection cracking in the hot mix asphalt surfacing.   Item P-301 Soil Cement Base is not acceptable for use as a base course for these pavements.

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10. SUBBASE COURSE. Subbases may be aggregate or bound materials. The minimum thickness of subbase is 3 inches (76 mm). Acceptable aggregate materials are P-209, Crushed Aggregate Base Course, P-208 Aggregate Base Course, or P-154, Subbase Course. Acceptable bound materials are P-401, P-304, P-306. Use of Item P-301 is limited to locations not subject to freeze thaw cycles. More than one layer of subbase material may be used, i.e., P-209 over a layer of P-154. Layering must be done so as not to produce a sandwich (granular layer between two bound layers) section.

11. SUBGRADE. The subgrade is assumed to be infinite in thickness and is characterized by either a modulus or CBR value. The computer program converts CBR to modulus by multiplying by 1500. Subgrade compaction and embankment construction should be in accordance with AC 150/5320-6, Airport Pavement Design and Evaluation, and AC 150/5370-10, Standards for Specifying Construction at Airports.

12. SEASONAL FROST AND PERMAFROST. Seasonal frost and permafrost effects should be considered by applying the techniques in AC 150/5320-6.

<div align="center">

RIGID PAVEMENT DESIGN

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13. SCOPE. This section presents FAA standards for the design of rigid pavements intended to serve a mix of traffic which includes the Boeing 777 airplane.

14. INTRODUCTION. The design process considers one mode of failure for rigid pavement, cracking of the concrete slab. Limiting horizontal stress at the bottom surface of the concrete surfacing layer guards against failure by cracking of the surface layer. The computer program iterates on the concrete layer thickness until the CDF reaches a value of 1.0. Once a CDF of 1.0 is achieved, the section satisfies the design conditions. A design life of 20 years is recommended for airport pavements.

15. CONCRETE PAVEMENT SURFACING. Concrete pavement surfacing should meet the requirements of FAA Item P-501. The minimum concrete surfacing thickness is 6 inches   (152 mm).

16. STABILIZED SUBBASE COURSE. Bound materials are required for subbase for rigid pavements serving these aircraft. Acceptable bound materials are: P-304, P-306, P-401, variable stabilized rigid and variable stabilized flexible . The minimum thickness of subbase is 4 inches (102 mm). More than one layer of subbase may be used, i.e., P-306 over a layer of P-209. Layering must be done so as not to produce a sandwich (granular layer between two bound layers) section.

17. SUBGRADE. The subgrade is assumed to be infinite in thickness and is characterized by either a modulus or k value. The computer converts k to modulus by using the logarithmic relationship: $\log E = 1.415 + 1.284 \log k$. Subgrade compaction requirements and embankment construction should be in accordance with AC 150/5320-6 and AC 150/5370-10.

18. SEASONAL FROST AND PERMAFROST. As with flexible pavements, seasonal frost and permafrost effects should be considered by applying the techniques in AC 150/5320-6.

19. JOINTING DETAILS. Jointing details for rigid pavements are presented in AC 150/5320-6 Airport Pavement Design and Evaluation. The limitations on jointing of rigid pavements for wide body aircraft also apply to pavements designed to serve the B-777.

OVERLAY DESIGN

20. INTRODUCTION. Layered system design permits a direct design approach for overlays. The other FAA method relies on an empirically based thickness deficiency approach. The layered system design calculates the thickness of overlay required to provide a 20 year life, which satisfies the layered elastic failure criteria for limiting stress or strain. The 20 year life thickness is defined as the design thickness. The design method for overlays of rigid pavement was developed by Dr. R. S. Rollings under an FAA funded research effort, as listed in Appendix 1. Overlay pavements are grouped into 4 different types as follows:

| Hot Mix Asphalt Overlay of Existing Flexible Pavement | Concrete Overlay of Existing Flexible Pavement | Hot Mix Asphalt Overlay of Existing Rigid Pavement | Concrete Overlay of Existing Rigid Pavement |

21. OVERLAYS OF EXISTING FLEXIBLE PAVEMENTS. The design of an overlay for an existing flexible pavement is essentially the same as designing a new pavement. The existing flexible pavement is characterized by assigning the appropriate thicknesses and moduli of the existing layers. Characterization of the existing pavement layers requires engineering judgment.

    a. Hot Mix Overlay Of An Existing Flexible Pavement. A trial thickness of overlay is then selected and the program iterates until a CDF of 1.0 is reached. The overlay thickness required to achieve a CDF of 1.0 is the design thickness.

    b. Concrete Overlay Of An Existing Flexible Pavement. The design of a concrete overlay of an existing flexible pavement is essentially the same as designing a new rigid pavement. The existing flexible pavement is characterized by assigning the appropriate thicknesses and moduli of the existing layers. A trial thickness of overlay is then selected and the program iterates until a CDF of 1.0 is reached. The overlay thickness required to achieve a CDF of 1.0 is the design thickness. The design process is relatively simple, however, the characterization of the existing pavement layers requires engineering judgment. The interface between the concrete overlay and the existing flexible surface is assumed to be frictionless.

22. OVERLAYS OF EXISTING RIGID PAVEMENTS. The design of overlays for an existing rigid pavement is complex because deterioration of the underlying pavement as well as

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deterioration of the overlay must be considered. The condition of the existing rigid pavement prior to overlay is important and is expressed in terms of the structural condition index (SCI). The SCI is derived from the pavement condition index (PCI). The PCI is a numerical rating indicating the operational condition of an airport pavement based on visual survey. The scale ranges from a high of 100 to a low of 0, with 100 representing a pavement in excellent condition. The PCI is measured using ASTM standard test method D 5340, Standard Test Method for Airport Pavement Condition Index Survey. For rigid pavements 15 different types of distress are considered in measuring the PCI. These distress types all reduce the PCI of a pavement depending on their severity and relative effect on performance. Not all distress types are indicative of structural distress. Rollings has identified 6 distress types that are indicative of the structural condition of the pavement. The 6 distress types are listed in   Table 1.

TABLE 1. RIGID PAVEMENT DISTRESS TYPES USED TO CALCULATE THE STRUCTURAL CONDITION INDEX, SCI

Corner Break
Longitudinal/Transverse/Diagonal Cracking
Shattered Slab
Shrinkage Cracks[a] (cracking partial width of slab)
Spalling - Joint
Spalling - Corner

[a] Used only to describe a load induced crack that extends only part way across a slab.
The SCI does not include conventional shrinkage cracks due to curing problems.

To illustrate, an SCI of 80 is consistent with the current FAA definition of initial failure of a rigid pavement, i.e., 50% of the slabs in the traffic area exhibiting initial structural cracking. The SCI allows a more precise and reproducible rating of a pavement's condition than previous FAA condition factor ratings, C_b and C_r.

      a. Hot Mix Asphalt Overlays Of Existing Rigid Pavements. The design process for hot mix overlays of rigid pavements considers two conditions for the existing rigid pavement to be overlaid. The SCI of the existing pavement may be equal to, or less than, 100.

            (1). Structural Condition Index Less Than 100. The most likely situation is one in which the existing pavement is exhibiting some structural distress, i.e., the SCI is less than 100. If the SCI is less than 100, the overlay and base pavement deteriorate at a given rate until failure is reached. An overlay thickness is assumed and the program iterates on the thickness of overlay until a 20 year life is predicted. A 20 year predicted life satisfies the design.

            (2). Structural Condition Index Equal to 100. An existing pavement with an SCI of 100 may require an overlay to strengthen the pavement in order to accept heavier aircraft. If the SCI of the base pavement is equal to 100, an additional input is required (CDFU - cumulative damage factor used) which estimates the amount of pavement life used up prior to overlay. The program assumes the base pavement will deteriorate at one rate while the SCI is

equal to 100 and at a different rate after the SCI drops below 100. As before, a trial overlay thickness is input and the program iterates on that thickness until a 20 year life is predicted. The design thickness is that which provides a 20 year predicted life.

       b. Concrete Overlays Of Existing Concrete Pavements. The design of a concrete overlay of an existing rigid pavement is the most complex type of overlay to be designed. Deterioration of the concrete overlay and existing rigid pavement must be considered as well as the degree of bond between the overlay and existing pavement. Two degrees of bond are considered and addressed separately.

           (1). Fully Unbonded Concrete Overlay. An unbonded concrete overlay of an existing rigid pavement is one in which purposeful steps are taken to eliminate bonding between the overlay and existing pavement. Commonly the bond is broken by applying a thin, nominal 1½ inch thick, hot mix layer to the existing rigid pavement. For this case the interface friction coefficient between the overlay and existing pavement is set to reflect an unbonded condition. The interface coefficient is fixed and cannot be changed by the user. As with hot mix asphalt overlays, an SCI is required to describe the condition of the existing pavement. A trial overlay thickness is input and the program iterates until a 20 year service life is predicted. The thickness which yields a 20 year service life is the design thickness.

           (2). Partially Bonded Concrete Overlay. A partially bonded overlay is one in which no particular effort is made to either eliminate or achieve bond between the concrete overlay and the existing rigid pavement. They are normally appropriate for existing rigid pavements which are in good condition, i.e., when the SCI is 77 or greater. For this case the interface coefficient is set to reflect a small degree of friction between the overlay and base pavement. This coefficient is fixed and cannot be changed by the user. An SCI for the existing pavement is required. A trial overlay thickness is input and the program iterates until a 20 year service life is predicted. The thickness which yields a 20 year service life is the design thickness.

APPENDIX 1. RELATED READING MATERIAL

1. The latest issuance of the following free publications may be obtained from the Department of Transportation Utilization and Storage Section, M-443.2, Washington, D.C. 20591. Advisory Circular 00-2, updated triannually, contains the listing of all current issuances of these circulars and changes thereto.

      a. AC 00-2, Federal Register, Advisory Circular Checklist and Status of Federal Aviation Regulations.

2. The following advisory circulars which can be found in AC 00-2 may be obtained from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402. Use the Superintendent of Documents stock number when ordering, along with the AC number and title. Send a check or money order in the amount listed for each document. No c.o.d. orders are accepted.

      a. AC 150/5335-5, Standardized Method of Reporting Airport Pavement Strength PCN, dated June 15, 1983 and Change 1, dated March 6, 1987.

      b. AC 150/5370-10A, Standards for Specifying Construction of Airports, dated February 17, 1989

      c. AC 150/5320-6C, Airport Pavement Design and Evaluation, dated December 7, 1978.

3. Copies of the following reports may be obtained from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

      a. DOT/FAA/RD-74/199, Development of a Structural Design Procedure for Flexible Airport Pavements, November 1974.

      b. DOT/FAA/RD-77/81, Development of a Structural Design Procedure for Rigid Airport Pavements, April 1979.

      c. DOT/FAA/PM-87/19, Design of Overlays for Rigid Airport Pavements, April 1988.

4. Copies of ASTM standards may be obtained from the American Society of Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.

APPENDIX 2. USERS MANUAL

This appendix contains the users manual for LEDFAA. It provides detailed information on proper execution of the computer program LEDFAA v1.2. Note that this design method is considered to be an FAA standard only if a mixture of traffic is considered and the Boeing 777 airplane is a part of that mixture.

LEDFAA User's Manual

Federal Aviation Administration
Airport Pavement Design

October 1995

A computer program for layered elastic based airport pavement design.
Developed by the Federal Aviation Administration

Office of Airport Safety and Standards, AAS-1
Federal Aviation Administration
Washington, D.C.

Contents

INTRODUCTION

LEDFAA is a computer program for airport pavement thickness design. It implements layered elastic theory based design procedures developed under the sponsorship of the Federal Aviation Administration (FAA) for new and overlay design of flexible and rigid pavements. The layered elastic procedures, as implemented in the program, are the FAA airport pavement thickness design standards in Advisory Circular AC 150/5320-16 for pavements intended to serve the Boeing B-777 airplane. The core of the program is JULEA, a layered elastic computational program implemented, in this case, as a Microsoft Windows™ FORTRAN application. The remainder of the program is written in Visual Basic™ and operates under Microsoft Windows. JULEA is loaded and executed by LEDFAA when needed and is not visible to the user.

Design information is entered by means of two graphical screens, one for the structure and one for the traffic. Default values and ranges for the various input parameters have been set so that the designs produced by LEDFAA are compatible with designs produced by the AC 150/5320-6 design procedures for aircraft up to and including the current generation (B-727, DC-8, B-747, DC-10, etc.). Designs for new generation aircraft, starting with the B-777, are not covered by AC 150/5320-6 design procedures. LEDFAA includes the necessary information for thickness design when B-777 aircraft are included in the aircraft mix.

Apart from the procedures being implemented as a computer program instead of as nomographs, the main change in pavement design from the user's perspective is that the "design aircraft" concept has been replaced by design for fatigue failure expressed in terms of a "cumulative damage factor" (*CDF*) using Miner's rule. Also, the major material property of the pavement layers is now uniformly expressed as an elastic modulus instead of the previous CBR (California Bearing Ratio) for flexible pavements or k value for rigid pavements. Formulas for transforming CBR and k values to modulus values are provided where appropriate in the documentation. Automatic conversion is provided in the program.

It should also be borne in mind that, although layered elastic based procedures are normally considered to be mechanistic, and more rational than the previous procedures, a considerable amount of engineering judgment is still required. Designs produced by LEDFAA should comply with the detailed requirements and recommendations of AC 150/5320-16 and AC 150/5320-6. The program does not automatically satisfy all of these requirements and the recommendations in the ACs should be followed in the selection of input parameters. It is the designer's responsibility to use the program and the advisory circulars in conjunction with each other.

A complete description of the design procedures and program structure is not possible within the confines of a user's manual, and these descriptions can be found in other publications. The main intent of the user's manual is

to provide sufficient information for operating the program, selecting input data values, and interpreting the output data. Installation of the program is described first, followed by descriptions of the various parts of the program and its operation. Information is then given on the structure data input requirements and how they relate to the design procedures. Final sections provide a short discussion on program running times, with possible strategies for decreasing design time for a given design case, a description of the structure of external data files so that interested users can access the files and incorporate the data in other applications if desired, and a selection of design examples.

The relationship between the layered elastic design procedures and the AC 150/5320-6 design procedures is not discussed in the manual. However, it should be pointed out that the traffic and failure models are fundamentally different and comparisons between the two sets of procedures are only valid when considering multiple aircraft traffic mixes. Single aircraft comparisons misleadingly indicate a degree of conservatism with the LED procedures which is not present for typical multiple aircraft mixes. The program is also primarily intended for use in designing airport pavements according to a standard procedure. It is not intended to be used to compare the damaging effects of different aircraft by running single aircraft designs or *CDF* computations, i.e., ACN type calculations.

INSTALLATION

Installation of LEDFAA is started by inserting the distribution diskette in an available diskette drive; usually a or b. Then, from Windows Program Manager, select Run from the File menu. Type in a:setup (or b:setup) and press Enter on the keyboard. You will be asked to enter a working directory. The default is C:\LEDFAA. If this is OK, click continue. The directory will be created if it does not already exist. If you want to use a different directory, type in the name with full path. The remainder of the setup is automatic. A new program group will be created called LEDFAA. LEDFAA is run by double clicking the LEDFAA icon in the program group. The icon can be dragged into a different group, such as applications, and the LEDFAA group deleted if you wish.

The following files are installed by setup:

Directory LEDFAA (or user determined directory)

LEDFAA.EXE:	Visual Basic I/O and design program.
JULEAWW.EXE:	Julea compiled as a Windows application.
LEDFAA.HLP:	Help file.

Directory WINDOWS

SETUP1.EXE	Setup executable.

Directory WINDOWS\SYSTEM

VBRUN300.DLL:	Visual Basic run time library.
THREED.VBX:	3-D control library.
GRID.VBX	Grid (table) control library.
SETUPKIT.DLL	Setup dynamic link library.
VER.DLL	System file version dynamic link library.

Most of the files on the installation disk are compressed and are expanded during installation. If you need to reinstall any of the files you can use the EXPAND.EXE program on the installation disk. As an example of reinstalling LEDFAA.EXE from the a: drive, transfer to the a: drive from the DOS prompt and type:

EXPAND LEDFAA.EX_ DestinationPath\LEDFAA.EXE.

OVERVIEW

The program consists of five main windows rigidly linked together as shown in the figure. The essential windows for pavement design are STARTUP , STRUCTURE , and AIRCRAFT . The NOTES and AIRCRAFT DATA   windows are for convenience in entering additional data describing the structure and traffic, and for viewing data.

Operations within a window are executed by clicking the mouse cursor on a "command button." Command buttons are referred to by showing the button name in bold type. For example, "click the command button called Structure" is abbreviated by "click Structure ."
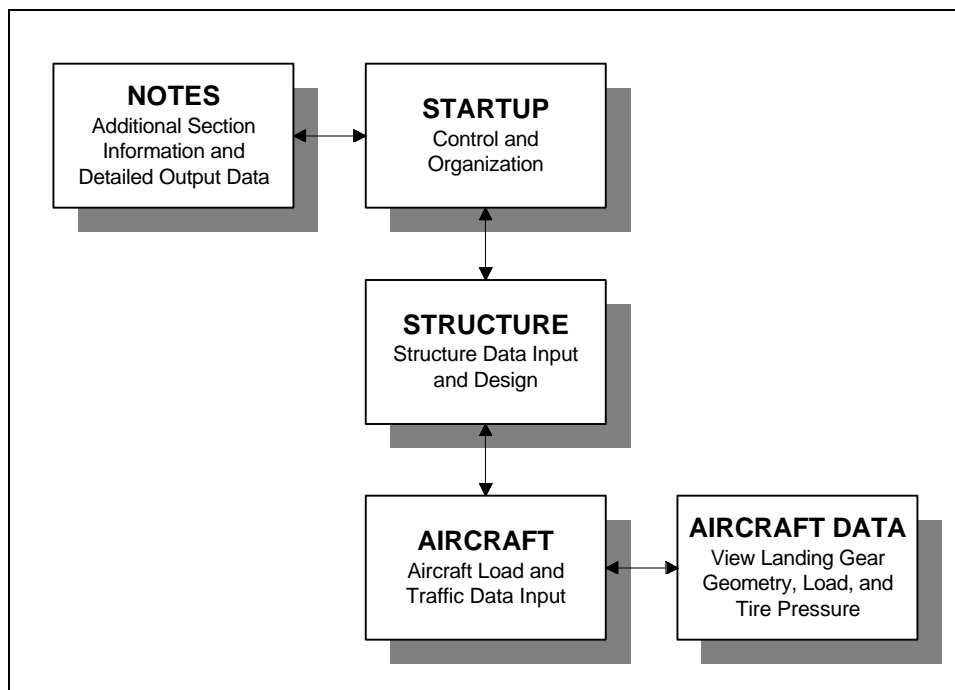
Figure 1. Program Windows and Linkage

STARTUP WINDOW

Introduction

The startup window has two functions. First is to allow selection of either the STRUCTURE or the NOTES window. Second is to organize the basic data storage units, consisting of "Sections" embedded in "Jobs." Jobs are MSDOS ASCII text files containing up to 100 sections. All Job files existing in the working directory are listed on the left of the window. A special Job file called Samples is initialized within the system and does not exist as an external file. It is always available to create new section data. This is necessary if no other Job files are present because new structures cannot be created from scratch. The Samples structures are also typical of current pavement design practice and are a convenient starting point for design. The data in the Samples sections cannot be changed and the structures cannot be "designed." The sections are provided only for starting new designs.

Note: The normal Windows file dialog boxes are not supported in LEDFAA. Backup to floppy disk, or other media, is therefore not possible directly from the program. This was done to simplify the user interface. But, since job files are MSDOS ASCII files, file backup and, where necessary, deletion, can be done using File Manager or from the DOS prompt. (See the Windows or DOS manual for file management procedures.) All job files have the extension .JOB.

Section data consists of pavement structure properties, aircraft names and gross loads, and annual departures and growth for each aircraft. Details of the required information are given when the data entry windows are discussed.

Jobs are listed in the list box on the left of the window. All sections in the selected job are listed in the right hand list box. Scroll bars will appear if there are too many jobs or sections to fit in the boxes. The operations associated with each of the command buttons on the STARTUP window are briefly described under separate headings.

Command Buttons

New Job

New jobs are created by clicking **New Job**. A dialog box will then appear requesting that a name be entered for the new job. The name can have up to 8 characters. Normal letters and numbers are allowed, together with hyphen (-) and underscore (_). Clicking OK or pressing Enter on the keyboard will accept the name, create the file, and close the dialog box. Clicking Cancel will close the dialog box without creating a new file. When first created, job files are completely empty. But new sections cannot be

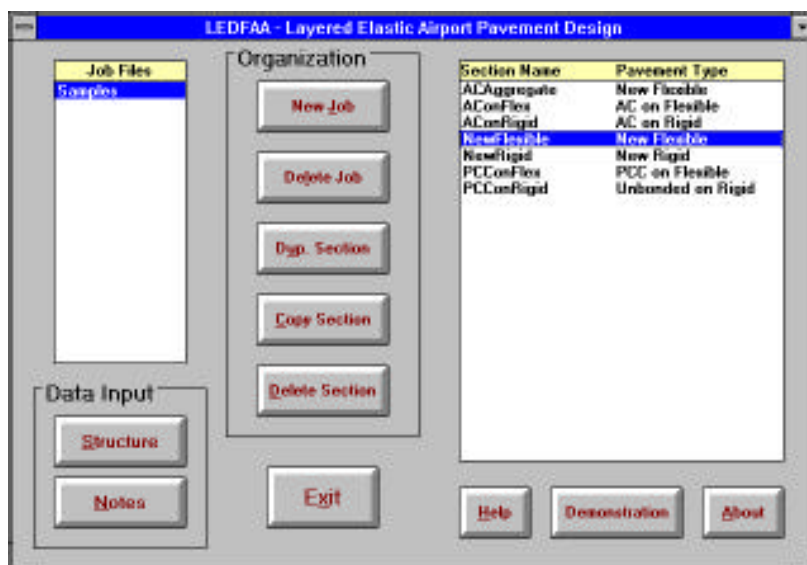created from scratch. Instead, old sections are moved and renamed using Dup. Section or Copy Section .

Figure 2. Startup Window

Delete Job

To delete a job file, first select the job to be deleted by clicking the job's name in the left hand list box. Then click Delete Job . A message box will be displayed asking if you want to continue. Click Yes to delete the file and close the message box. Click No to close the message box without deleting the job. Deleting a job will cause all of the information in a job file to be deleted from the disk. The only way to restore the information is to immediately run undelete in DOS or Windows.

Note: Whenever, as in this case, information can be destroyed by an action, a message box with a No or Cancel option is displayed to reduce the risk of accidentally destroying the information.

Copy Section

New pavement structures cannot be created from scratch in the STRUCTURE window. Instead, existing structures in one job are copied to another job (or duplicated and renamed within a single job as described below). The section list box shows the type of structure for each listed section so that the desired type of structure can be selected before copying without having to check the STRUCTURE window. Six types of structure are included:

1. New Flexible.

2. AC on Flexible (asphalt overlay on an existing flexible pavement).

3. New Rigid.

4. AC on Rigid (asphalt overlay on an existing rigid pavement).

5. Unbonded on Rigid (unbonded concrete overlay on an existing rigid pavement).

6. Part Bonded on Rigid (partially bonded concrete overlay on an existing rigid pavement).

The sequence for copying a section is:

1. Select the job to be copied from by clicking the job name.

2. Click Copy Section . The caption on the button will change to End Copy .

3. Select the section to be copied by clicking the section name in the right hand list box.

Select the job to be copied to by clicking the job name. A dialog box will be displayed asking you to enter the name of the new section. The name can have up to 12 characters, consisting of alphanumeric, hyphen, or underscore. The old name can be kept provided it does not already exist in the job the section is being copied to.

Repeat to copy more sections or click End Copy to end copying.

Copying can be stopped at any time by clicking End Copy .

Dup. Section

A section can be duplicated within any job and given a new name. First select the job. Then select the section and click Dup. Section . Enter the new name in the displayed dialog box.

Delete Section

To delete a section, first select the job. Then select the section and click Delete Section . The section data is completely deleted from the job file and cannot be recovered.

Help

The Help file is loaded by clicking Help in any of the windows except the AIRCRAFT DATA window, or by pressing the F1 key on the keyboard.

Demonstration

An interactive demonstration of the major functions in the STARTUP , STRUCTURE , and AIRCRAFT windows is started by clicking Demonstration . The demonstration can be run through all three windows in succession, or individual windows can be selected.

A time delay is inserted between each distinct operation in the demonstration so that the functions occurring can be observed. The default delay setting is 2 seconds. The delay setting can be changed any time a demonstration specific message box is displayed by clicking Change Delay . The demonstration can also be terminated from any of the demonstration specific message boxes by clicking Cancel .

About

Displays the application "About" box giving a brief description of the application and information on the configuration of the computer system.

Structure

Transfers control to the STRUCTURE window.

Notes

Transfers control to the NOTES window. This allows incidental section information to be entered and attached to the job file and a summary of the section data to be viewed. The NOTES window is described last.

Exit

Closes all files and exits to Windows.

STRUCTURE WINDOW

Introduction

The STRUCTURE window allows a pavement structure to be modified and "designed" to carry the load applied by the selected traffic. On the left of the window is a list of the sections in the current job. On the right of the window is a table showing the structure with all layers illustrated and the values of all changeable parameter values displayed. Clicking a new section name in the list changes the displayed structure to that of the new name.
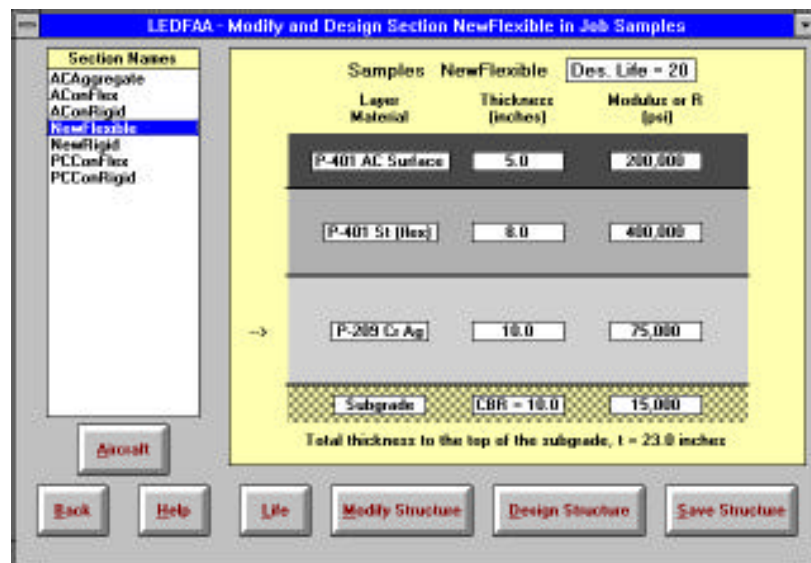
Figure 3. Structure Window

Command Buttons

Modify Structure

A structure is modified from the modify mode, generally entered by clicking Modify Structure . Modify Structure then changes to End Modify and Design Structure changes to Add/Delete . The only operations allowed until End Modify is clicked are modifications to the structure. Alternative ways of entering modify mode are double clicking a section name (also changes the displayed structure) and double clicking the picture of the structure (also starts an associated modification sequence).

Modifications which can be made to a structure are:

1. Change the composition of a layer (change layer type).

2. Change the thickness of a layer.

3. Change the modulus value of a layer (except asphalt and PCC).

4. Change the flexural strength of a PCC layer.

5. Duplicate (add) an existing layer.

6. Delete an existing layer.

7. Change the iteration layer for flexible pavement design.

Layer types and modulus values must be selected for compatibility with the layered elastic design procedures and with FAA pavement design standards and recommendations. The purpose of this section is simply to outline the operation of the program. Detailed guidelines for selection are given in a later section. These must be read before using the program to design pavements to FAA standards. In particular, the use of an undefined layer results in a non-standard structure.

Structure properties are changed by clicking on the picture of the structure over the displayed value or setting. Instructions are then given for changing the value or setting.

Figure 4. Layer Types

Clicking on the picture in the layer type column displays the selection box shown. To change the layer type, click the type you want to select followed by OK. Certain combinations of layers are not allowed in a structure (aggregate on the top, for example). However, the structure is not checked during selection and layers can be changed to anything until End Modify is clicked. A complete check of the structure is then made and a message displayed if the structure is not valid for design. The reason for disallowing the structure is given in the message. You cannot leave modify mode until the structure is valid for design.

When the displayed value of a layer thickness or layer modulus is clicked, an input box is displayed giving instructions on changing the value. In some cases, the modulus value cannot be changed manually and a description is given of how the program assigns the value automatically.

Note: The thickness of the bottom layer is assumed to be infinite and cannot be assigned a value. The thickness display column in the bottom

layer is therefore used to display either the CBR or the k value corresponding to the modulus value of the bottom layer; CBR for flexible pavements and k value for rigid pavements. The conversion factors used are given in the section Layer Types. If the value in either of the two columns is changed, the value in the other column changes automatically.

Design life, in years, is displayed at the top of the picture of the structure and can be given any value within the range 1 to 50 years. However, the standard design life is 20 years. If the design life of a section is different than 20 years the message "Non-Standard Life" is displayed. Clicking on the message displays a longer message explaining why the life is non-standard. A warning message is also printed in the Design Info text box in the NOTES window.

Input data for overlay structures also includes the structural condition index (*SCI*) of the existing pavement before overlay and, under some conditions, the Cumulative Damage Factor Used (*CDFU*) of the existing pavement. (*CDFU* is related to the remaining life of the existing pavement.) Recommendations for selecting appropriate values of *SCI* and *CDFU* are given in the discussion of concrete layers in the Layer Types section.

The small arrow in the left margin of the picture of the structure indicates the layer which will be adjusted during design (see below). The position of the arrow can only be changed when the structure is a new flexible pavement. Clicking in the margin to the left of any layer except for the top or bottom layers will select that layer as the adjustment layer for design.

Add/Delete

Layers can be added or deleted using Add/Delete . After clicking the button you must select a layer in the picture of the structure. A box is displayed requesting the selection of Add or Delete. Selecting Add duplicates the selected layer. The properties of the layer can then be changed as desired. Selecting Delete completely removes the selected layer from the structure.

End Modify

Terminates the modify mode. No functions other than structure modifications can be executed while the modify mode is active.

Design Structure

Clicking this button adjusts the thickness of one of the layers of the structure so that the design criteria for the particular type of structure are satisfied. The structure type is automatically determined from the top two layers and the correct design procedure executed. The layer to be adjusted is indicated by the small arrow in the left margin of the picture of the structure. Except for new flexible pavements, the layer cannot be changed. During design the layer being adjusted is highlighted by changing its display color. In some cases, if a new computed layer thickness is unreasonable (such as negative), the thickness of an adjacent layer is changed. This is only included to prevent unreasonable layer thicknesses and is not intended to try to optimize the design. If it occurs, the structure should be inspected and changed if necessary, followed by a redesign.

Information on the state of the design is displayed at the bottom of the picture of the structure.

Details of the design procedures executed by Design Structure for the different pavement structures are given in the Pavement Thickness Design section.

Interrupt Design

When a design is started by clicking Design Structure , Save Structure changes to Interrupt Design . Clicking this button during design stops the design calculations and leaves the thickness of the layer being adjusted at its value at the time of stopping the design. The design can be restarted with the structure as it existed at the time of interruption by clicking Design Structure again. Or the structure can be changed and a new design started from the changed condition. During design, the structure does not become permanent in the job until the structure is saved (see Save Structure).

Save Structure

The structure is saved in the current section data record by clicking Save Structure . This cannot be done in modify mode or during design. Saving the structure after a design has run to completion marks the section in the data record as being a completed design. Clicking Back without having saved the structure causes a message box to be displayed which prompts for the structure to be saved.

Modifications made to a pavement structure do not become permanent until the data is saved using Save Structure . You can therefore try different designs and return to the original structure by canceling the save with the following sequence: click Back followed by clicking NO in the displayed message box. This transfers control to the STARTUP window. Returning to the STRUCTURE window restores the original structure and all changes will have been lost.

Life

Computes the life of the current section in years. This function is not required for design, but is provided for convenience in computing *CDFU* and *CDF*. If design for the section has been run to completion, the life computed using Life will equal the design life.

CDF and percent *CDFU* are computed for new pavement design based on the current setting of design life.

Aircraft

Transfers control to the AIRCRAFT window.

Back

Returns control to the STARTUP window.

AIRCRAFT WINDOW

Introduction

The AIRCRAFT window allows for the creation and modification of an aircraft list for the currently selected section in the currently selected job. Other sections or jobs cannot be selected from the AIRCRAFT window. If you want to change to another section, return to the STRUCTURE window. If you want to change to another job, return to the STARTUP window.

Aircraft are selected from a library and placed in a list of design aircraft. Except for gross load, annual departures, and percent annual growth (defined below), all necessary aircraft information for design is stored internally as part of the library and cannot be changed. At the top left of the window is a list of library aircraft groups. Selecting one of these groups will display all of the aircraft in that group in the list box located below the aircraft group box.
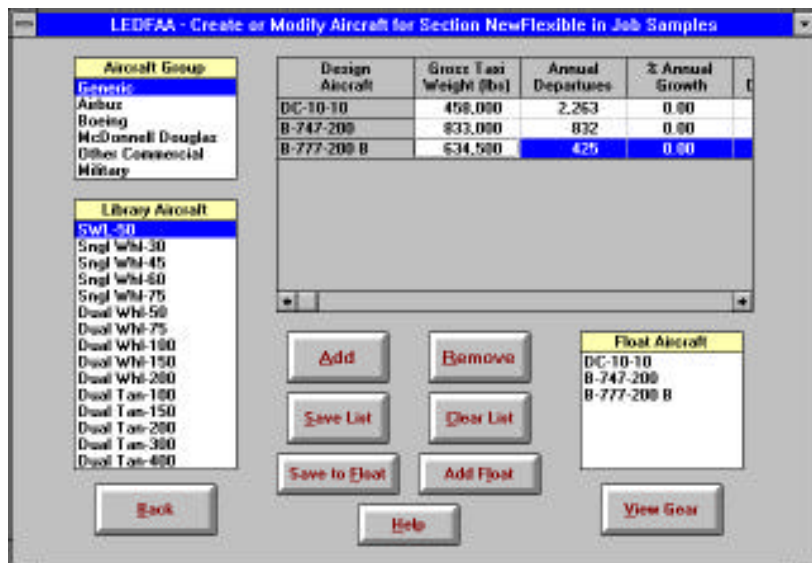
Figure 5. Aircraft Window

At the top right of the window is a table which lists the design aircraft for the currently selected section, with associated data. Aircraft are transferred from the library list to the design list by selecting an aircraft in the library list (by clicking the name once) and clicking Add, or by double clicking the aircraft name in the library list. Aircraft are removed from the design list by selecting an aircraft in the design list (by clicking the name once) and clicking Remove , or by double clicking the aircraft name in the design list.

Values in the first three data columns of the design aircraft list table (gross load, annual departures, and percent annual growth) can be changed by

clicking on the value to be changed. An input box is displayed which gives instructions and the allowed ranges for data entry. Scrolling the table columns to the left shows columns for: total lifetime departures, tire pressure, percent gross load on the design gear, dual-wheel spacing, tandem-wheel spacing, tire contact width, and tire contact length. None of these can be changed.

For all aircraft in the library, the fraction of the gross load carried by the main gear has been set at 95 percent to make the LEDFAA design procedures compatible with those of AC 150/5320-6. The tire contact lengths and widths are those used in the calculation of pass-to-coverage ratio for the aircraft. An elliptical contact patch is assumed, with its area equal to the tire load divided by the tire pressure. (In contrast, circular tire contact patches are used in JULEA because the layered elastic model is axisymmetric.)

Aircraft with dual-wheel belly gear (DC-10-30, MD-11, and A-340) are treated as two aircraft for design; a two-gear dual-tandem aircraft and a single-gear dual-wheel aircraft. For example, adding a DC-10-30 to the design list places the two aircraft for design in the list automatically, and removing one of the two aircraft from the design list removes the other automatically. The data for the two aircraft is also tied - changing the data for one changes the data for the other automatically.

A maximum of 20 aircraft can be included in the design list.

The library list contains aircraft representative of the most common commercial and military aircraft. Substitutions can be made for aircraft not in the list, either by a similar aircraft or from the "Generic" group list. Data for the Generic group is from AC 150/5320-6.

Annual departures is defined as the aircraft departure rate in departures per year. The displayed value is the annual departures for the selected aircraft at the start of the pavement's design life. Percent annual growth is defined as the percent change in annual departures per year over the design life of the pavement. Negative values represent a decrease in annual departures. The total number of departures for the selected aircraft over the design life of the pavement is given by the equation:

$$N = \left(1 + \frac{b \times L}{200}\right) \times a \times L$$

where:

N = total departures

L = pavement design life

a = initial annual departures

b = percent annual growth

Large negative percent annual growth can result in negative aircraft departures before the end of the design life has been reached. The program automatically detects this condition if it occurs, and assumes zero departures for the aircraft from the time at which the departure rate becomes zero to the end of the design life.

Non-Standard Aircraft Lists

If the design aircraft list does not contain a Boeing 777, or contains only one aircraft, the message "Non-Standard Aircraft List" is displayed. Clicking on the message displays a longer message explaining why the list is non-standard. The long message is also displayed in the Design Info text box in the NOTES window.

Command Buttons

Add

An aircraft is transferred from the library list to the design list by selecting an aircraft name in the library list and clicking Add. The same operation can also be performed by double clicking an aircraft name in the library list.

Remove

An aircraft is removed from the design list by selecting the aircraft name and clicking Remove , or by double clicking the aircraft name in the design list.

Clear List

Deletes all aircraft from the design list.

Save List

Saves the data for all of the aircraft in the design list into the data record for the currently selected section in the currently selected job. All changes made to a design list must be saved, or discarded, before returning to the STRUCTURE window. The Save operation permanently changes the aircraft data stored in the section data record.

Save to Float

An independent, "floating," list of aircraft is provided to allow an existing list to be transferred easily to a different section. Clicking Save to Float transfers the current design list and aircraft data to the floating list, replacing the existing floating list. The new floating list will remain available until the next Save to Float operation or the program is terminated. The floating list is displayed in the list box at the bottom right of the window and is always empty when the program starts.

Add Float

Adds the aircraft in the floating list to the current design list up to the maximum of 20 aircraft.

View Gear

Transfers control to the AIRCRAFT DATA window (discussed under separate heading).

Back

Returns control to the STRUCTURE window. If changes have been made to the design list and the list has not been saved, a message box is displayed requesting that the changes be saved or discarded, or that the Back operation be canceled. Control cannot return to the STRUCTURE window until the changes have been saved or discarded.

NOTES WINDOW

Introduction

The NOTES window is provided for viewing a summary of the design information for the currently selected section and for entering and saving notes on the currently selected section, such as size, location, maintenance history, etc.

On the left of the window is a list of the sections in the currently selected job. On the right of the window is a text box which contains either the design information or the notes for the currently selected section. The design information is fixed and is taken from the section data record. The notes are entered by the user and can contain up to 30,000 characters for each section (5 to 20 pages). Text is entered and edited as it would be in the Windows Notepad text editor.
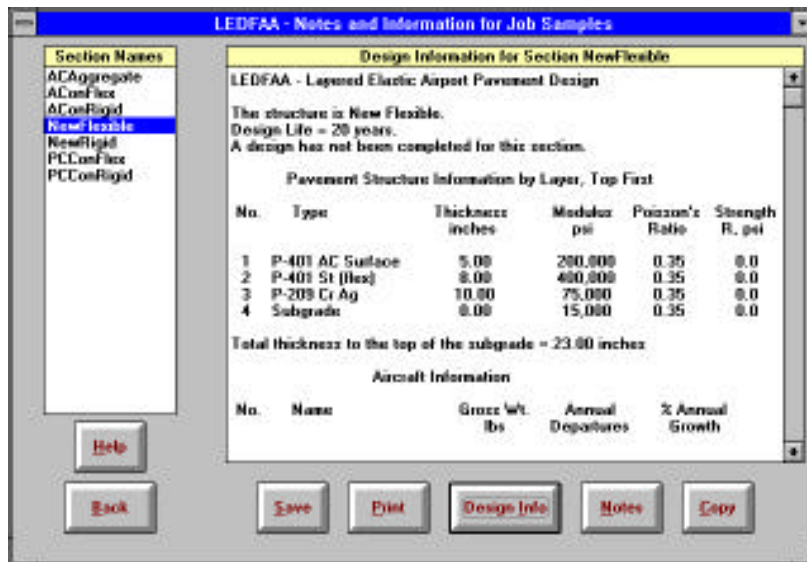
Figure 6. Notes Window

Command Buttons

Design Info

Displays in the NOTES window text box the design information for the currently selected section.

Notes

Displays in the NOTES window text box the notes for the currently selected section.

Copy

Copies the design information and the notes from the NOTES window to the Windows clipboard. The text can then be pasted into another application, such as a text editor or word processor.

Print

Prints the design information and the notes from the NOTES window to the currently selected default Windows printer.

Save

Saves the notes for the currently selected section in the .NTS file for the currently selected job. (Each .JOB file has a corresponding .NTS file. When initialized, the notes for a section contain only the section name unless the section was created using Copy Section in the STARTUP window, in which case the old notes are copied into the new section.)

AIRCRAFT DATA WINDOW

The AIRCRAFT DATA window primarily shows the main gear layout for the aircraft currently selected in the design list. The gear layout and the tire contact patches are drawn to scale. An image of the picture can be copied to the clipboard by clicking the right mouse button on the picture. An image of the window is printed by clicking Print . Gross load can also be changed by clicking the Gross Load data display box.
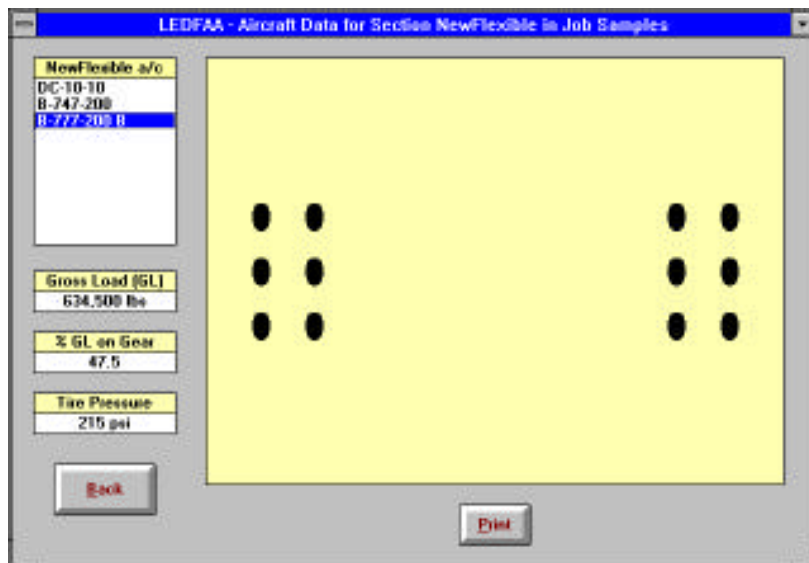

Figure 7. Aircraft Landing Gear Data

CUMULATIVE DAMAGE FACTOR

Cumulative damage factor (*CDF*) is the amount of the structural fatigue life of a pavement which has been used up. It is expressed as the ratio of applied load repetitions to allowable load repetitions to failure, or, for one aircraft and constant annual departures:

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

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

$$= \frac{\text{applied coverages}}{\text{coverages to failure}}$$

When *CDF* = 1, the pavement will have used up all of its fatigue life.

When *CDF* < 1, the pavement will have some life remaining, and the value of *CDF* will give the fraction of the life used.

When *CDF* > 1, all of the fatigue life will have been used up and the pavement will have failed.

Note: In these definitions, failure means failure in a particular structural failure mode according to the assumptions and definitions on which the design procedures are based. A value of *CDF* greater than one does not necessarily mean that the pavement will no longer support traffic, but that it will have failed according to the definition of failure used in the design procedure, and within the constraints of uncertainties in material property assumptions, etc. Nevertheless, the thickness design is based on the assumption that failure occurs when *CDF* = 1.

Multiple aircraft types are accounted for by using Miner's Rule instead of the "design aircraft" concept as in the current procedures, or:

$CDF = CDF_1 + CDF_2 + \dots CDF_N$

Where CDF_I is the *CDF* for each aircraft type in the mix and *N* is the number of aircraft types in the mix.

Note: The same aircraft model with two different gross loads represents two different aircraft types. This is because a different pavement load will be applied by each gross load.

Each failure mode included in the design procedure will have a separate *CDF*. For example, in flexible pavement design, the thickness is adjusted to make the *CDF* for subgrade failure equal to 1. An additional computation is then made to find the *CDF* for asphalt surface cracking. If the asphalt *CDF*

is less than 1, the asphalt is predicted not to fail in cracking before the subgrade fails. But if the asphalt *CDF* is greater than 1, the asphalt is predicted to fail before the subgrade, and adjustments should be made to base and subbase layers so that asphalt *CDF* is less than 1 in the final design.

In the program implementation, *CDF* is calculated for each 10 inch wide strip along the pavement over a total width of 820 inches. Pass-to-coverage ratio is computed for each strip based on a normally distributed aircraft wander pattern with standard deviation of 30.5 inches (equivalent to aircraft operation on a taxiway) and used in the above equation for Miner's rule. The *CDF* for design is taken to be the maximum over all 82 strips. Even with the same gear geometry, therefore, aircraft with different main gear track widths will have different pass-to-coverage ratios in each of the 10 inch strips and may show little cumulative effect on the maximum *CDF*. Removing the aircraft with the lowest stress or strain may then have little effect on the design thickness, depending on how close the gear tracks are to each other.

LAYER TYPES

Introduction and LED References

Sixteen layer types are included for building pavement structures. Some of the types can be placed at any position in a structure, while others can only be placed in specified positions. The reason for specifying placement, and specifying types, is that the design procedure executed by the program is automatically determined by the layer types of the top two surface layers, and the presence of aggregate layers. Control of default parameter values is also easier when placement is controlled. Some flexibility is allowed by the inclusion of an "undefined" layer type. The only restrictions on this type are that Poisson's ratio is fixed at 0.35 and modulus must be in the range 1,000 to 4,000,000 psi. (Default values and ranges for all layer types are displayed in the Modify Structure data entry dialog boxes.) However, undefined layer types do not meet FAA standards for airport pavement design.

All layer types except undefined are related in some way to layer types identified or specified in AC 150/5320-6. The following includes information for making the relationship between the LEDFAA and AC 150/5320-6 layer types and for selecting appropriate layer properties as input data for LEDFAA.

The requirements and guidelines of AC 150/5320-6 should be followed whenever there is a discrepancy between LEDFAA and the advisory circular. For example, minimum thicknesses should always be set according to the requirements of the circular for the particular pavement type under design and not the default minimum thicknesses built into LEDFAA.

References for specific details of the LEDFAA design procedures are:

1. Barker, W.R., and W.N. Brabston, Development of a Structural Design Procedure for Flexible Pavements , Report No. FAA-RD-74-199, September 1975.

2. Parker, F., Jr., W.R. Barker, R.C. Gunkel, and E.C. Odom, Development of a Structural Design Procedure for Rigid Airport Pavements , Report No. FAA-RD-77-81, April 1977.

3. Rollings, R.S., Design of Overlays for Rigid Airport Pavements , Report No. DOT/FAA/PM-87/19, April 1988.

4. Barker, W.R., and C.R. Gonzalez, Pavement Design by Elastic Layer Theory .

Subgrade Layers

Subgrade modulus values for flexible pavement design can be determined in a number of ways. The procedure which will be applicable in most cases is to use available CBR values and substitute in the relationship:

E = 1,500×CBR psi

This method will provide designs compatible with the current design procedure based on subgrade CBR. Resilient modulus and non-destructive test (NDT) data may also be used where the reliability of the measurements is felt to be high.

Similarly, for rigid pavement design, where values of foundation modulus (k value) for the subgrade are available, the following relationship can be used:

$$\log_{10}(E_{SG}) = 1.415 + 1.284 \log_{10}(k)$$

$$\text{or, } E_{SG} = 26\, k^{1.284}$$

where:

E_{SG} = Resilient modulus of the subgrade, psi

k = Foundation modulus of the subgrade, pci

Otherwise, resilient modulus values from laboratory tests or NDT tests can be used.

The equations for converting CBR and k to modulus are based on empirical data and were used in the development of the failure models for the layered elastic design procedures. The failure models represent the relationship between computed pavement response (strain or stress) and coverages to failure measured in full-scale tests. But resilient modulus of the subgrade was not typically measured during the full-scale tests (most were run before 1974) and the conversions were required to estimate resilient modulus for use in the layered elastic computations of strain and stress. CBR was used for flexible pavements and k value for rigid pavements. The conversion equations are therefore an integral part of the design procedures when measured values of CBR or k are used for design. A consequence of the separate developments is that the conversion for CBR to modulus should not be used when designing a rigid pavement based on measurements of CBR. The recommended method is to convert the CBR value to k using any preferred method, and then use the equation given above for converting from the intermediate k value to modulus. This will almost certainly not give the same modulus as the direct CBR relationship, but, considering the empirical nature of the relationships, the lack of correspondence is to be expected. Details of the development of the conversion equations is given in references 1 and 2.

Asphalt Layers

Two types of asphalt layers are included: asphalt surface and asphalt overlay. Both have the same properties, with modulus fixed at 200,000 psi and Poisson's ratio fixed at 0.35. The asphalt overlay type can be placed over asphalt surface or PCC surface types. The asphalt surface type can only be placed on the top of a structure, or under an asphalt overlay.

Concrete Layers

Four types of concrete layers are included: PCC surface, PCC unbonded overlay on a rigid pavement, PCC partially bonded overlay on a PCC pavement, and PCC overlay on a flexible pavement. The PCC surface type can be placed on the top of the structure for new designs or next to the top for overlays. The overlay types can only be placed on the top of the structure. PCC overlay on flexible pavement can be placed on an asphalt or undefined layer.

The modulus of all PCC types is fixed at 4,000,000 psi except for PCC surface when it is part of an overlay structure (see below). Poisson's ratio is fixed at 0.15 in all cases. Flexural strength can be varied in the range 650 to 800 psi. (PCC modulus is considered to be independent of flexural strength.)

Overlaid rigid pavement designs require the *SCI* of the existing pavement as an input. For unbonded overlays, it is assumed that the existing pavement may have suffered serious deterioration before the overlay and *SCI* can be given values in the range 100 (none to negligible structural cracking) to 40.

For partially bonded overlays, it is assumed that the existing pavement is in sound to barely failed condition before the overlay and *SCI* can be given values in the range 100 (none to negligible cracking) to 77 (slightly worse than the LEDFAA definition of end-of-design-life of *SCI* = 80).

Cumulative Damage Factor Used (CDFU)

When *SCI* = 100 for overlay design of an existing rigid pavement, an additional input is required to define the amount of life that has been used by the existing pavement up to the time of the overlay. The input is in terms of "*CDF* used to first crack" (*CDFU*) and is equivalent to equation 42, p 98, in reference 3. For aggregate base layers, and assuming that traffic on the pavement has been constant over time, a good estimate of *CDFU* can be obtained from:

$$CDFU = \frac{L_U}{0.75\,L_D} \quad \text{when } L_U < 0.75\,L_D$$

$$= \quad 1 \quad \text{when } L_U \geq 0.75\,L_D$$

where:

L_U = number of years of operation of the existing pavement until overlay

L_D = design life of the existing pavement in years

This equation was derived from the empirical relationship between coverages and *SCI* given in reference 3. But layered elastic stress computations show much lower sensitivity to base material quality than the procedure used in AC 150/5320-6 and a modification was made to the layered elastic failure model to make the two design procedures more compatible. The modification essentially increases the percent design life remaining after *SCI* starts to drop from 100 if the base and subbase layers are of higher quality than an 8 inch aggregate subbase (aggregate base thicker than 8 inches or stabilized base thicker than 4 inches). The simple

relationship given above is not valid for such structures and percent *CDFU* is computed and displayed when Life is clicked in the STRUCTURE window.

The procedure for computing percent *CDFU* for a rigid pavement with *SCI* = 100 is as follows:

1. Setup the structure based on the original design assumptions.

2. Estimate the traffic which has been applied to the pavement and enter into the aircraft design list.

3. Set design life to the amount of time the pavement will have been in operation up to the time of overlay.

4. Run Life .

Percent *CDFU* will be displayed when the computation is completed. Values of percent *CDFU* greater than 100 indicate that the procedure predicts that the *SCI* of the pavement should be less than 100. A value of 100 should then be entered for percent *CDFU* as input data for the overlay design. However, since the computation of percent *CDFU* will be based on estimated structure properties and traffic, the value is likely to be unreliable. An alternative procedure is to run Design Structure for the original structure with design life set to the actual design life. Then repeat the steps given above and use the new value of percent *CDFU*.

If it is suspected that the pavement has been subjected to more, or heavier, traffic than assumed in the Life computation, percent *CDFU* should be increased from the computed value. Setting percent *CDFU* to 100 will give the most conservative design.

For both partially bonded and fully unbonded concrete overlays, the modulus of the base pavement is varied as a function of *SCI* of the base pavement when *SCI* is less than 100 according to the relationships given in reference 3. The computation is automatic and transparent to the user.

Structure Condition Index (SCI)

The ranges of the *SCI* inputs correspond to specific ranges of the factors c_b and c_r used in overlay design by the AC 150/5320-6 method.

For a concrete overlay on rigid pavement the following, taken from reference 3, can be used to relate the *c* factor in the current FAA procedure with *SCI* required for input in LEDFAA:

$$SCI = 100\left(\frac{c_r + 0.076}{1.073}\right) = 93.2\, c_r + 7.1$$

Asphalt overlays on rigid pavements also require the input of a value for *SCI* of the existing pavement. The range is 100 to 50. The following, taken from reference 3, can be used to relate the *c* factor in the current FAA procedure with *SCI* required for input in LEDFAA:

$$SCI = 100\, c_b - 25; \qquad 0.75 \le c_b \le 1$$

The range for *c* is specified in AC 150/5320-6. Note that the relationship is not valid when *SCI* is between 75 and 100.

Aggregate Layers

Crushed Aggregate

Crushed Aggregate in LEDFAA corresponds to Item P-209, Crushed Aggregate Base Course.

The modulus of crushed aggregate layers is computed automatically and cannot be changed manually.

Uncrushed Aggregate

Uncrushed Aggregate in LEDFAA corresponds to Item P-154, Subbase Course.

The modulus of uncrushed aggregate layers is computed automatically and cannot be changed manually.

Modulus Values of Aggregate Layers

The modulus values of aggregate layers are calculated automatically. The WES "Modulus" procedure included with LEDNEW is followed, with sublayering performed automatically (maximum sublayer thicknesses are 8 inches for uncrushed aggregate and 10 inches for crushed aggregate). The modulus values of the sublayers decrease with increasing depth of a sublayer within the aggregate layer, and are also dependent on the modulus of the layer below the aggregate layer.

Aggregate layers can be placed anywhere in the pavement structure except at the top or bottom. The following additional restrictions also apply:

1. Only one crushed layer and one uncrushed layer may be present in a structure. This is for compatibility with the Modulus procedure. (Sublayering by the Modulus procedure accounts for thick layers, and multiple layers of a single aggregate type are not necessary.) The maximum number of aggregate layers which may be present in a structure is therefore two, one of each type.

2. If crushed and uncrushed layers are adjacent, the crushed layer must be above the uncrushed layer (to be compatible with the modulus procedure).

For efficiency in iterating to a valid thickness design, a two-stage process is used during design with thick aggregate layers. When *CDF* is outside the range 0.5 to 2.0, the aggregate layers are not sublayered for Julea, but are treated as a single layer with modulus equal to the average modulus of what would be the sublayers. When *CDF* is within the range 0.5 to 2.0, full sublayering is used according to the Modulus procedure. One consequence of this is that the *CDF* can increase when sublayering first occurs, apparently indicating an error in the procedure.

The modulus value displayed in the structure table for an aggregate layer is the average value of the sublayer modulus values. The only exception is for newly created layers, in which case the "defaults" of 75,000 and 40,000 are

displayed for crushed and uncrushed respectively. These defaults are never used in calculations.

Sublayering by the Modulus procedure also causes a discontinuity in computed *CDF* when the number of sublayers changes as the total thickness of an aggregate layer crosses over the threshold during design. For example, if the thickness of an uncrushed aggregate layer increases from 15.99 inches to 16.01 inches the number of sublayers increases from 2 to 3, and the CDF may jump from a value above 1 to a value below 1. This can result in a condition in which a given combination of structure and traffic does not have a *CDF* of 1, whatever the thickness of the iteration layer may be, and the thickness of the iteration layer changes back and forth across the threshold continuously. To stop the continuous iteration, the number of sublayers in a structure is fixed when *CDF* is within the range 0.7 to 1.4. The condition can be detected by running Design Structure again after a design has been completed. If the second design gives a different thickness than the first, then the condition exists. A further consequence is that pavement life computed using Life will not agree with the design life, and sudden changes in AC layer *CDF* may occur for flexible pavements.

Stabilized Layers

Two types of stabilized layers are included, classified as stabilized (flexible) and stabilized (rigid). The classifications are derived from the fact that the modulus values correspond to current procedure (AC 150/5320-6) equivalencies when comparing designs made by current and LED procedures. Variable modulus types are provided as well as fixed modulus types corresponding to standard material items. Property values are:

Type	Modulus, psi	Poisson's Ratio
Stabilized (flexible)		0.35
Variable Minimum	150,000	
Variable Maximum	400,000	
P-401 Asphalt	400,000	
Stabilized (rigid)		0.20
Variable Minimum	250,000	
Variable Maximum	700,000	
P-301 Soil Cement Base	250,000	
P-304 Cement Treated Base	500,000	
P-306 Econocrete Subbase	700,000	

Because the modulus values were determined on the basis of producing thickness designs comparable with the current design procedures, typical laboratory test data for stabilized materials should not be used in preparing input data for LEDFAA designs. Instead, the material recommendations and equivalencies given in AC 150/5320-6 should be followed and related to the modulus values as follows.

For flexible pavement design, the minimum modulus value of 150,000 psi corresponds to a base course equivalency factor of 1.2, and the maximum value of 400,000 psi corresponds to a base course equivalency factor of 1.6 (paragraph 36. b. in AC 150/5320-6). The choice of base course modulus value can have a significant effect on total thickness of a flexible pavement.

For rigid pavement design, the maximum modulus value of 700,000 psi corresponds to Item P-306, Econocrete Subbase, or similar. Lower quality materials should be given lower modulus values if the variable type is being used.

When a variable modulus layer is first created, the modulus is automatically set to the minimum value.

Undefined Layer

This layer type is included to allow the use of layers not covered by the most common structural materials and to investigate the effects of using new, or otherwise nonstandard, materials. Properties of the layer type are:

minimum modulus	= 1,000 psi
maximum modulus	= 4,000,000 psi
Poisson's ratio	= 0.35 (fixed)
minimum thickness	= 2 inches

There are no restrictions on placement of the undefined layer. If an undefined layer is the topmost layer of a pavement structure, either the new flexible or an asphalt overlay pavement design procedure is automatically selected, depending on the composition of the second layer. For flexible pavements, and using the Life option, this allows for computing estimated asphalt *CDF* values with asphalt modulus different than the fixed value of 200,000 psi. It is very important to recognize that flexible pavement thickness designs made with the top layer modulus value greater than 200,000 psi will result in nonconservative designs compared with the current FAA design procedure.

The modulus value for asphalt layers as a function of temperature can be estimated using the relationship (Witczak, M.W., Report II, Asphalt Mixture Material Characterization, University of Maryland, May 1989):

$$Log_{10}(E) = 1.53658 - 0.006447\,T - 0.00007404\,T^2$$

where E = asphalt modulus with units of 10^5 psi
and T = asphalt temperature in degrees Fahrenheit.

Rearranging gives:

$$E = 10^{(6.53658 - 0.006447\,T - 0.00007404\,T^2)}\ \text{psi}$$

The design procedures executed when an undefined layer is present in one of the top two layers of a pavement structure are summarized below.

Top Layer	Second Layer	Design Procedure

Top Layer	Second Layer	Design Procedure
Undefined	Asphalt Surface	Asphalt Overlay on Flexible
Undefined	PCC Surface	Asphalt Overlay on Rigid
Undefined	Any Overlay	Not valid for design
Undefined	Any except the above	New Flexible
Asphalt Surface	Undefined	New Flexible
PCC Surface	Undefined	New Rigid
Asphalt Overlay	Undefined	Asphalt Overlay on Flexible
PCC Overlay	Undefined	PCC on Flexible (New Rigid)

If a structure contains one or more undefined layers, the message "Non-Standard Structure" is displayed. Clicking on the message displays a longer message explaining why the structure is non-standard. The long message is also displayed in the Design Info text box in the NOTES window.

PAVEMENT THICKNESS DESIGN

General Design Procedure

Thickness designs can be made for seven different types of pavement structure:

1. New flexible.

2. Bituminous overlay on existing flexible.

3. New rigid.

4. Concrete overlay on existing flexible.

5. Unbonded concrete overlay on existing rigid.

6. Partially bonded concrete overlay on existing rigid.

7. Bituminous overlay on existing rigid.

New flexible, bituminous overlay on flexible, and new rigid pavements are designed with the following general procedure:

1. Create a structure, a design aircraft list, and set the design life.

2. Click Design Structure in the STRUCTURE window. This causes the thickness of a prescribed layer to be automatically adjusted by the program until the design criteria are satisfied.

3. Inspect the structure when the design program has stopped running and, if necessary, manually adjust the thickness of other layers in the structure and click Design Structure again. Repeat until the thickness design is satisfactory.

4. Click Save Structure . This permanently saves all the information for the new structure in the job file and marks the section as being a completed design.

The automatic adjustment of the thickness of the prescribed layer in step 2 is done as follows:

1. Calculate the maximum stress or strain at a layer interface in the structure for each aircraft in the design list.

2. Calculate the allowable number of aircraft departures to failure for each aircraft based on a defined relationship between allowable departures and stress or strain.

3. Find the ratio of actual departures to allowable departures for each aircraft. This is the *CDF* for each aircraft.

4. Add the aircraft *CDF*s together to find the *CDF* for the structure.

5. Adjust the thickness of the prescribed layer until structure *CDF* = 1. (Increasing thickness decreases *CDF*.)

Design for overlays on rigid pavements is generally similar in terms of structure definition, aircraft list selection, and program execution, but the

New Flexible and Bituminous Overlay on Flexible

Subgrade vertical strain and horizontal strain at the bottom of the top layer are the design criteria for both pavement types. With the fixed default asphalt modulus value of 200,000 psi, horizontal strain only becomes the dominant criterion when the structure is very deep and is heavily loaded. Under these conditions the horizontal strain also has a tendency to increase as the pavement depth increases, the opposite of the trend for subgrade strain. Overlap of the *CDF*s can therefore occur and a proper design never realized. For these reasons, and to save run time, the subgrade strain is used to iterate to a subgrade *CDF* of one. Only one evaluation depth needs to be sent to Julea and the run time is approximately halved for deep, many layered, structures (compared to computing subgrade and asphalt strain each time). When the subgrade criterion has been satisfied, a final calculation is made to find the asphalt *CDF* (again using only one evaluation depth). If the structure is saved after design without making any modifications, the section data is marked as being a completed design and the asphalt *CDF* stored in the .JOB file section data record. The value of the asphalt *CDF* can be viewed in the Design Info text box in the NOTES window. One consequence of delaying asphalt *CDF* calculation until after satisfying the subgrade criterion is that the design continues to run after the displayed (subgrade) *CDF* has reached its terminal value. A message is displayed stating that asphalt *CDF* is being computed. The value of asphalt *CDF* is displayed when the computation is complete.

For new flexible design, the thickness of the layer next to the subgrade is adjusted to make the subgrade *CDF* approximately equal to one. The current error control is that the design will terminate when *CDF* is in the range 0.995 to 1.005. If the layer next to the subgrade becomes thinner than its specified minimum thickness, the thickness of the layer above is halved, or set at its minimum thickness, and the procedure continued. If the *CDF* is less than one with both of the adjusted layers at their minimum thicknesses, the *CDF* is displayed and the design terminated. This procedure is not intended to "optimize" a design. It is intended only to protect from inappropriate input data.

For overlay design, the thickness of the top layer is adjusted to make the subgrade strain *CDF* equal to one. The procedure is also terminated, with a message, if the top layer becomes thinner than its minimum thickness.

The failure model used to find the number of coverages to failure for a given vertical strain at the top of the subgrade is:

$$C = 10{,}000 \times \left(\frac{0.000247 + 0.000245 \times \log_{10}(E_{SG})}{\boldsymbol{e}_v} \right)^{0.0658 \times E_{SG}^{0.559}}$$

where:

C = number of coverages to failure

E_{SG} = subgrade modulus, psi

e_v = vertical strain at the top of the subgrade

Subgrade modulus is included in the equation for subgrade failure and has the effect of decreasing the number of coverages to failure, for any given strain, as the modulus value decreases. This is intended (reference 1) to simulate the effects of the increasing degree of plasticity generally encountered as soil strength decreases.

The failure model used to find the number of coverages to failure for a given horizontal strain at the bottom of the surface asphalt layer is:

$$\log_{10}(C) = 2.68 - 5 \times \log_{10}(e_h) - 2.665 \times \log_{10}(E_A)$$

where:

C = number of coverages to failure

E_A = asphalt modulus, psi

e_h = horizontal strain at the bottom of the surface asphalt layer

New Rigid Pavement

Rigid design is the same as for flexible over flexible overlay design except that *CDF* is calculated using the horizontal stress at the bottom of the PCC layer. To make the layered elastic design procedure compatible with the AC 150/5320-6 procedure (which uses 0.75 of the Westergaard edge stress for design), an adjustment is made to the calculated layered elastic interior stress to provide an equivalent edge stress. Without this adjustment, the interior layered elastic stress for a dual-wheel landing gear relative to a dual-tandem is too low when compared to the Westergaard edge stress for dual-wheel relative to dual-tandem. But, for the six-wheel B-777 gear, and similar, the interior stress can be higher than 75 percent of the equivalent edge stress. The complete procedure is therefore to compute the interior stress, compute 75 percent of the equivalent edge stress, and then select the higher of the two as the working stress for design.

An adjustment is also made to the layered elastic failure model so that the sensitivity of design thickness to base/subbase material quality is compatible with that of the AC 150/5320-6 procedure.

The basic equation used to find the number of coverages to failure (*C*) for given concrete strength (*R*) and working stress for design (σ) is, as given in reference 3:

$$SCI = \frac{R/_s - 0.2967 - (0.3881 + 0.000039 \times SCI)\log C}{0.002269}$$

Two extra coefficients (F_S and F_{SC}) have been added to this equation to apply the compensation:

$$SCI = \frac{R/_s - 0.2967 - F_S(0.3881 + F_{SC} \times 0.000039 \times SCI)\log C}{0.002269}$$

where: $F_{SC} = \dfrac{0.392 - 0.3881 \times F_S}{0.0039 \times F_S}$

For any given value of R/s, the computed value of F_{SC} maintains the number of coverages for $SCI = 100$ constant as F_S varies. When the concrete slab is placed on an 8 inch crushed aggregate layer or a 4 inch stabilized layer (at 500,000 psi), F_S and F_{SC} both have a value of 1 and the basic failure model is unchanged. But if the thickness or quality of the base/subbase structure is higher than either of these two conditions, F_S decreases and the number of coverages to failure increases. The procedure is similar to that used in the design procedure for concrete overlay on rigid pavement as described in reference 3.

Failure is defined as the number of coverages for $SCI = 80$ at any given value of R/s (reference 2).

Concrete Overlay on Flexible Pavement

When the PCC overlay on flexible layer is placed over an asphalt surface or undefined layer, the new rigid pavement design procedure is automatically executed. This is analogous to the use of the new PCC design curves in AC 150/5320-6 as described in paragraph 71 of the AC.

Concrete Overlay on PCC Pavement

Two types of concrete overlay on PCC pavement are considered in the program: fully unbonded and partially bonded. Different interface coefficients between the overlay and the existing pavement are used to simulate the behavior of the different types of structure. For the fully unbonded case, an interface coefficient of 100,000 is used as required by the layered elastic program JULEA. An interface coefficient of 700 is used for the partially bonded concrete overlay, based on numerical comparisons between the current design procedures and the layered elastic based design procedures. For both cases, the maximum tensile stress at the bottom of the overlay is used as the critical response in the calculation of *CDF*.

The design starts with a trial overlay thickness selected by the user. *CDF* is calculated for the concrete overlay layer using the same model as that used in new rigid pavement design. But the elastic modulus of the existing pavement is assumed to decrease during the period of time when the *SCI* of the existing pavement is less than 100. The tensile stress of the overlay layer therefore varies during the life of the overlaid pavement and the *CDF* of the structure must be computed by numerical integration. This results in solution times which are typically much longer than those for the other pavement types. After the *CDF* has been calculated, the thickness of the overlay is adjusted to bring the next calculated *CDF* closer to a value of 1 for the correct design life. The design is terminated when the calculated value of *CDF* is in the range 0.995 and 1.005 and the difference between the calculated and desired design life is less than 0.1 year.

Asphalt Overlay on PCC Pavement

The design of asphalt overlay on PCC pavement is basically the same as that of the concrete overlay on PCC pavement. However, the integrated life of the overlaid pavement has two parts: (1) the number of years needed to reduce the *SCI* of the existing pavement from the initial value at the time of overlay to the minimum value at the end of the life of the overlay structure, and (2) the number of years needed to cause reflection cracks to propagate through the asphalt overlay (the propagation rate is assumed to be one year per inch of overlay thickness).

RUNNING THE PROGRAM

Solution Times

The execution time required to design a structure is almost completely dependent on the floating point performance of the computer when performing the layered elastic strain and stress calculations. Execution time is roughly proportional to the total number of "design" wheels for all of the aircraft in the design list, and is proportional to a small power of the number of layers in the structure. (The inner loop in JULEA consumes almost all of the solution time.) The next most important factor is disk access time, but this mainly affects the response of Windows when performing other tasks while a design is in progress and not the total solution time.

The most effective strategy for reducing solution times is to use an abbreviated aircraft list, consisting of the most damaging aircraft, to produce a first approximation to the pavement design. The full aircraft design list can then be used to finalize the design.

Thick aggregate layers increase the solution time more than would be expected because of the sublayering used to represent variation of modulus with depth. Thin concrete overlays on rigid pavements have the longest solution times of all the structure types.

Options

A batch option has been included in the program so that a number of time consuming designs can be executed unattended. The option is activated by double clicking anywhere on the gray background of the structure window. A check box appears which, when clicked, changes the caption of the Life button to Batch. The first section to be designed is then selected and Batch clicked. Each section in the list starting at the one selected to the last will then, in turn, be designed and the results stored in the .JOB file. The "already designed" and "saving structure" messages are suppressed. However, if any other message, such as "minimum thickness for a layer," is displayed, the batch job will halt until the message is cleared. The results can be viewed in the NOTES window after the batch job has finished.

An additional option called "No AC CDF" is included to disable the computation of asphalt surface *CDF* at the end of a flexible pavement design. This option is most effective during initial design of pavement sections with thick aggregate layers and many aircraft in the design list.

If a lengthy design computation is underway, a second instance of LEDFAA can be started from Program Manager and section data edited. Design computation is only allowed from the first instance of the program because JULEA cannot be run from two programs at once. Alternatively, any other application can be run from Windows while a design is in progress. The

elapsed time window will always remain on top of the desktop so that the progress of the design can be monitored.

Copying to the Clipboard

In addition to copying the design and notes information to the clipboard from the NOTES window, any of the program windows can be copied to the clipboard as a bitmap using the Windows Alt-PrintScreen function. The bitmap can then be pasted into another application and printed or saved. First make sure that the window to be copied is the active window by clicking the mouse within the window area. Then hold down the Alt key and press the PrintScreen key. If the window is not copied to the clipboard, check your computer documentation for the equivalent function.

The picture of the structure in the STRUCTURE window can also be copied to the clipboard by placing the mouse pointer within the area of the picture and clicking the right mouse button. Similarly, the picture of the gear layout in the AIRCRAFT DATA window can be copied by right clicking on the picture.

DATA FILES

Communication Files

Information is passed to and from JULEA in the following data files:

1. JULEA.STR
2. JULEA.LOA
3. JULEADAT.OUT
4. JULEASG.OUT
5. DAMTMP.DAT
6. DAMTMPSG.DAT

JULEA.STR and JULEA.LOA are structure and aircraft data files written by LEDFAA for input to JULEA each time JULEA is executed. They are ASCII files in exactly the same format as used in the LEDNEW collection of programs. The data can be examined in a text editor if more detail is required than given in the LEDFAA windows.

JULEADAT.OUT and JULEASG.OUT are ASCII files written by JULEA and have exactly the same format as used in the LEDNEW collection of programs. They contain all of the structure, aircraft, stress, and strain data read or produced by JULEA. Stresses and strains are given for each evaluation point for each aircraft in the traffic mix. Principal and octahedral stresses are included. For rigid pavements, only JULEADAT.OUT is written. For flexible pavements, JULEASG.OUT contains the data for stresses and strains computed at the top of the subgrade, and JULEADAT.OUT contains the data for stresses and strains computed at the bottom of the asphalt layer. The files are overwritten each time JULEA is executed.

DAMTMP.DAT and DAMTMPSG.DAT are written by JULEA and contain the stresses or strains used by LEDFAA to compute *CDF*. For rigid pavements, DAMTMP.DAT contains the maximum principal stress at the bottom of the concrete slab for each aircraft in the mix. (These are interior stresses and are transformed to equivalent edge stresses by LEDFAA before computing *CDF*. The relative magnitudes of the stresses in DAMTMP.DAT for different aircraft are therefore not a reliable indication of the relative stress levels used in the design procedure.) For flexible pavements, DAMTMPSG.DAT contains the vertical strains at the top of the subgrade and DAMTMP.DAT contains the horizontal strains at the bottom of the surface asphalt layer.

If data in any of these files needs to be stored permanently, it should be copied to a new file immediately after a design has been completed.

Storage Files

Permanent information for layered elastic design is stored in *.JOB and *.NTS files. *.JOB files contain all of the data required by LEDFAA for all of the sections in one job. *.NTS files contain user entered information not needed by LEDFAA but which may be useful in identifying features of the pavement sections, tracking design history, etc. Both are ASCII files and can be read by other applications if necessary.

*.JOB File Format

```
0           1           2           3           4           5           6
01234567890123456789012345678901234567890123456789012345678901234567890
Format#
SectionName
     Date      Time              DateTime        ACCDF
Life     SCI    %CDFU  NL   NA
   Thick(1)  Modulus(1)   LC(1)
   Thick(2)  Modulus(2)   LC(2)
   Thick(3)  Modulus(3)   LC(3)
   Thick(I)  Modulus(I)   LC(I)
   Thick(NL) Modulus(NL)  LC(NL)
 ACName(1)                GL(1)  Rps(1)  %Growth(1)
 ACName(2)                GL(2)  Rps(2)  %Growth(2)
 ACName(J)                GL(J)  Rps(J)  %Growth(J)
 ACName(NA)               GL(NA) Rps(NA) %Growth(NA)
Blank Line (for expansion)
Blank Line (for expansion)
Next set of section data, starting with the name
```

Explanation of *.JOB File Field Names

Format# = File format identifier;   Type = string; current = "Format3"
SectionName = section name;   Type = string
Date = date of completed design;   Type = string; Format = XX/XX/XX
Time = time of completed design;   Type = string; Format = XX:XX:XX
DateTime = date and time of completed design in VB format;
                                        Type = double precision real
                                        Field Width = 20
Note: When a design has not been completed for the section,
      Date = 11/01/71, Time = 00:00:00, DateTime = 26238

Name	Description	Type	Field Width
ACCDF	Asphalt Layer *CDF*	Real	12
Life	Design Life	Integer	4
SCI	Structure Condition Index	Real	8
%CDFU	Percent *CDFU*	Real	8
NL	Number of Layers	Integer	4
NA	Number of Aircraft	Integer	4
Thick(I)	Thickness of Layer I	Real	12
Modulus(I)	Modulus of Layer I *	Integer	12
LC(I)	Layer Code for Layer I	Integer	8
ACName(J)	Aircraft Name for Aircraft J	String	21
GL(J)	Gross Load for Aircraft J	Integer	9
RPS(J)	Annual Repetitions for Aircraft J	Integer	8
%Growth(J)	Percent Annual Growth for Aircraft J	Real	12

* Flexural strength when the layer is PCC.

Example of a *.JOB File with 2 Sections

```
Format3
NewFlexible
 03/30/95 13:50:38    34790.5768287037     0.000000
  20    0.00  100.00    4    3
      5.0000       200000        1
      8.0000       400000       14
     11.2892        47583        6
      0.0000        15000        4
DC-10-10              458000    2263   0.000000
B-747-200             833000     832   0.000000
B-777-200 B           634500     425   0.000000


NewRigid
 11/01/71 00:00:00              26238     0.000000
  20    0.00  100.00    4    3
     14.0000          700        5
      6.0000       700000       17
      6.0000        75000        6
      0.0000        15000        4
DC-10-10              458000    2263   0.000000
B-747-200             833000     832   0.000000
B-777-200 B           634500     425   0.000000
```

Layer Codes

   0 = Undefined

   1 = P-401 Asphalt Surface

   2 = Not Used

   3 = Not Used

   4 = Subgrade

   5 = P-501 PCC Surface

   6 = P-209 Crushed Aggregate Base Course

   7 = Variable Stabilized Base (rigid)

   8 = P-154 Subbase Course (uncrushed aggregate)

   9 = Variable Stabilized Base (flexible)

 10 = P-401 Asphalt Overlay

 11 = P-501 PCC overlay fully unbonded

 12 = P-501 PCC overlay partially bonded

 13 = P-501 PCC overlay on flexible

 14 = P-401 Stabilized Base (flexible)

 15 = P-301 Soil Cement Base Course

 16 = P-304 Cement Treated Base Course

 17 = P-306 Econocrete Subbase Course

*.NTS File Format

*.NTS files contain user entered information about sections in a job stored as strings. The format consists of a sequential list of each section name, the length of the notes string for that section, followed by the notes string. A Visual Basic routine to read the data for a specified section (ISECT) in a *.NTS file is as follows:

```
NFNo = FreeFile
Open FileName$ For Input As #NFNo

For I = 1 To ISect
  Line Input #NFNo, S$     ' Section name.
  Input #NFNo, SLen        ' Length of NotesString.
  NotesString$ = Input$(SLen, #NFNo)
  Input #NFNo, SS$         ' Get CRLF.
Next I

Close NFNo
```

All data in the notes for section ISect is left in the string NotesString$.

DESIGN EXAMPLES

Introduction

Four design examples are given: new flexible, new rigid, concrete overlay on rigid, and asphalt overlay on rigid. In the first 2 examples, it is assumed that external job files have not been created and the designs are started from the internal Samples job. Examples are also given to illustrate overlay design on composite pavements and the effects of sublayering in aggregate layers.

All of the design examples have the same traffic mix, representing a very heavily loaded pavement as would be found at a major port:

Aircraft	Gross Weight, lbs	Annual Departures
B-737-400	150,000	360
B-747-400	873,000	4,200
B-757	250,000	360
B-767-200	335,000	720
B-777-200 B	634,500	720
MD-82/88	150,000	600
DC-10-30	583,000	360
MD-11	621,000	700
L-1011	496,000	320

Percent annual growth is assumed to be zero in all of the examples. Also, layer thickness results are all given to 1 decimal place. Rounding would be done before writing the final design specifications.

New Flexible Design Example

The pavement in the new flexible pavement design example is to service aircraft of greater than 100,000 lbs gross weight and must therefore have stabilized base and subbase as specified in AC 150/5320-6. Item P-401, Plant Mix Bituminous Pavement, is selected for the base course and Item P-209, Crushed Aggregate Base Course, is selected for the subbase. A B-777 aircraft is included in the mix and the asphalt surfacing, also Item P-401, must have a minimum thickness of 5 inches as specified in AC 150/5320-16. Subgrade CBR for the example is 8. Design life is 20 years, complying with AC 150/5320-16. The determination and selection of suitable base and subbase thicknesses is discussed below after describing the initial setup of the example.

When LEDFAA is first started, the STARTUP window is displayed and, if there are no external .JOB files, a message is displayed stating that there are no job files in the working directory.

1. Clear the message by clicking OK and press the New Job command button.

2. Enter a name for the new job in the displayed dialog box and click OK.

3. Reselect the Samples job by clicking on its name in the left hand list box.

4. Click Copy Section to start the procedure for copying from the Samples job to the new job.

5. Select the new flexible sample section in the right hand list box by clicking on the NewFlexible section name.

6. Copy the selected section to the new job by clicking on the new job file name in the left hand list box and entering, in the displayed dialog box, the section name to be used in the new job.

7. End the copy procedure by clicking End Copy .

8. Select the new job file in the left hand list box and double click on the section name in the right hand list box (or click Structure) to transfer to the STRUCTURE window.

The new flexible pavement structure from the Samples job will be displayed after transfer to the STRUCTURE window. But before starting design of the structure, information for the traffic mix listed in the introduction to the design examples must be entered in the AIRCRAFT window. To do this:

1. Click Aircraft to transfer control to the AIRCRAFT window.

2. Click Clear List and answer Yes in the displayed message box. All aircraft stored in the new flexible section of the Samples job will be deleted from the table of design aircraft.

3. Select one of the aircraft groups in the top left hand list box to display the aircraft contained in that group in the lower left hand Library list box.

4. Select the first aircraft in the group to be added to the table of design aircraft by clicking on its name in the library list. Transfer the aircraft to the table by clicking Add. (Double clicking the name will also transfer the aircraft.)

5. "Default" values of gross weight, annual departures, and percent annual growth will be displayed in the table. Any of these values can be changed within a specified range by clicking on the number in the table. An input box is displayed which also gives the default value and the range within which a new value can be entered. Enter the new value and click OK.

6. Select the rest of the aircraft to be added to the design aircraft table from the group one at a time and change the default data values as required. If a mistake is made and the wrong aircraft added to the table, the aircraft can be removed by selecting its name and clicking Remove (or by double clicking its name).

7. Repeat the process for each group until all aircraft in the traffic mix have been added to the table. Note that the L-1011 in this example is contained in the Other Commercial group.

8. Click Save List and answer OK to the displayed message.

9. Click Back to return to the STRUCTURE window.

Suitable base and subbase thicknesses can now be determined by running design cases. However, there is no explicitly defined procedure for doing this and judgment is required on the part of the design engineer to make a selection within two limiting cases. The first case is to select the minimum base course thickness of 8 inches as specified in AC 150/5320-16 for B-777 service and run a design:

1. The new flexible structure in the Samples job has the correct base and subbase materials for this example, the base thickness is set at 8 inches, and the surface thickness is set at 5 inches. All that has to be done before running the design is to change the subgrade modulus by clicking Modify Structure and clicking the "CBR =" box. Enter a value of 8 in the displayed input box and click OK.

2. Click End Modify .

3. Make sure that the arrow on the left of the structure points to the subbase and click Design Structure .

4. Wait until the program has changed the subbase thickness to give a *CDF* of 1 for vertical strain in the subgrade and computed the asphalt surface *CDF*. In this case, the design subbase thickness is 21.1 inches and asphalt *CDF* is negligible.

The second limiting case is to assume that the base course must protect a subbase having a CBR of 20. To do this:

1. Remove the subbase from the structure by clicking Modify Structure followed by Add/Delete Layer (the caption on the Design Structure button changes to Add/Delete Layer in modify mode). Click anywhere within the subbase and select delete in the displayed box. (Alternatively, return to the STARTUP window, duplicate the section with another name, use the new section for temporary working, and return to the first section for final design.)

2. Change the subgrade CBR to 20.

3. Click End Modify , followed by Design Structure . The thickness of the base will be changed until the *CDF* for vertical strain in the 20 CBR "subgrade" has a value of 1. In this case, the revised base thickness is 8.3 inches.

A base thickness of 8 inches is therefore not quite sufficient for the design. But increasing the base thickness decreases the total pavement thickness for a subgrade CBR of 1, and adjustments to the base course thickness can be made at the judgment of the engineer provided that the minimum requirements are satisfied.

For this example, a base thickness of 10 inches was finally selected. Giving, after a final design run, a subbase thickness of 18.2 inches and a total pavement thickness of 33.2 inches. From the NOTES window, Design Info button, the design information for the final design is:

```
          The structure is New Flexible. Asphalt CDF = 0.0000.

          Design Life = 20 years.


                    Pavement Structure Information by Layer, Top First


   No.   Type                 Thickness   Modulus   Poisson's
Strength

                              inches        psi       Ratio      R, psi
     1   P-401 AC Surface       5.00      200,000      0.35         0

     2   P-401 St (flex)       10.00      400,000      0.35         0

     3   P-209 Cr Ag           18.17       50,845      0.35         0

     4   Subgrade               0.00       12,000      0.35         0

Total thickness to the top of the subgrade = 33.17 inches


                              Aircraft Information


   No.       Name           Gross Wt.      Annual      % Annual

                               lbs       Departures     Growth
     1   B-737-400           150,000         360        0.00

     2   B-747-400           873,000       4,200        0.00

     3   B-757               250,000         360        0.00

     4   B-767-200           335,000         720        0.00

     5   B-777-200 B         634,500         720        0.00

     6   MD-82/88            150,000         600        0.00

     7   DC-10-30            583,000         360        0.00

     8   DC-10-30 Belly      583,000         360        0.00

     9   MD-11               621,000         700        0.00

    10   MD-11 Belly         621,000         700        0.00

    11   L-1011              496,000         320        0.00
```

Note that the wing gear and the belly gear for the DC-10-30 and MD-11 are treated as separate aircraft in the design procedure. Also, the thickness of the subgrade is given as 0.00 inches, whereas the assumption in the layered elastic representation of the structure is that the subgrade is infinitely thick.

New Rigid Design Example

The new rigid design example uses the same traffic mix as the new flexible design example, and the pavement for the new rigid design example must therefore have a stabilized subbase course to satisfy the requirements of AC 150/5320-6. A 2-layer subbase has been selected with Item P-304, Cement Treated Base, at the top and Item P-209, Crushed Aggregate Base Course below. Subgrade k value is 120 pci and the surface is Item P-501, Portland

Cement Concrete Pavement, with a design flexural strength of 725 psi. Design life is 20 years.

The design can be started by copying the NewRigid section in the Samples job to the same job file as used in the new flexible example. Since the aircraft mix is the same as in the flexible example, some time can be saved by using the floating aircraft list:

1. Select the NewFlexible design example while in the STRUCTURE window and transfer to the AIRCRAFT window by clicking Aircraft .

2. Click Save to Float to copy all of the aircraft in the design aircraft list to the Float Aircraft list.

3. Click Back to return to the STRUCTURE window and select the NewRigid section.

4. Go to the AIRCRAFT window and clear the design aircraft list with the Clear List command button.

5. Click Add Float to copy the aircraft in the float list to the design aircraft list.

6. Save the newly created aircraft list and return to the STRUCTURE window with the Back button.

All of the information for the Samples job structure is correct for this example except for the upper subbase layer, the subgrade modulus value, the PCC flexural strength, and, depending on the design engineers judgment, the subbase layer thicknesses (the Samples job values are 6 inches for each layer). Start the design by changing the subbase material:

1. Click Modify Structure .

2. Click the box containing the name of the material for the upper subbase layer (P-306 Econocrete in this case). The Layer Type Selection box will be displayed. Click on P-304 Cement Treated Base under the heading Stabilized (rigid) and click OK. The box will close and the layer in the pavement change to P-304.

The subgrade k value and the PCC flexural strength are both changed by clicking in their respective boxes and entering the new values in the input boxes.

Clicking End Modify , followed by Design Structure causes the thickness of the top layer to be changed until the *CDF* for tensile stress at the bottom of the surface layer has a value of 1. In this case the surface thickness is 16.0 inches for a *CDF* of 1.

Various design options for subbase thicknesses can be tried, with the Design Structure function executed after each change. The design in this case was finalized with a Cement Treated Base layer thickness of 8 inches, a lower subbase thickness of 6 inches, and a surface thickness of 15.8 inches. The final design information from the NOTES window, Design Info button, is given below for the structure only (the aircraft information is the same as in the new flexible example).

```
The structure is New Rigid.
Design Life = 20 years.
```

```
              Pavement Structure Information by Layer, Top First


     No.   Type              Thickness   Modulus   Poisson's
Strength
                              inches       psi       Ratio      R, psi

      1   PCC Surface          15.79     4,000,000    0.15        725

      2   P-304 CTB             8.00      500,000     0.20          0

      3   P-209 Cr Ag           6.00       30,518     0.35          0

      4   Subgrade              0.00       12,152     0.40          0

Total thickness to the top of the subgrade = 29.79 inches
```

Concrete Overlay on Rigid Design Example

Design of an overlay on a rigid pavement normally starts with an existing pavement structure having a known *SCI*. In the design example, an unbonded overlay is to be applied over an existing rigid pavement which has an *SCI* of 70. The same traffic mix as used in the new pavement design examples is to be applied for 20 years after overlaying. The properties of the existing structure are:

```
     No.   Type              Thickness   Modulus   Poisson's
Strength
                              inches       psi       Ratio      R, psi

      1   PCC Surface          14.00     4,000,000    0.15        725

      2   P-304 CTB             8.00      500,000     0.20          0

      3   P-209 Cr Ag           6.00       30,518     0.35          0

      4   Subgrade              0.00       12,152     0.40          0
```

After setting up the structure to match the information above and setting the traffic information, as described in the new pavement design examples, an overlay layer is added in the STRUCTURE window as follows:

1. Click Modify Structure .

2. Click Add/Delete Layer .

3. Click anywhere within the PCC surface layer in the picture of the structure. A duplicate of the surface layer will be added to the structure adjacent to the original surface layer.

4. Click on the layer material box in the new surface layer, while still in modify mode, and select Overlay fully unbonded from the Layer Type Selection box under the heading PCC: All P-501. After clicking OK to close the Layer Type Selection box, the new surface layer will change to an overlay and two additional data entry boxes will appear to the right of the design life box, *SCI* and %*CDFU* (percent cumulative damage factor used).

5. Click on the *SCI* box and change the value to 70. % *CDFU* will default to a value of 100. % *CDFU* cannot be changed in this example because *SCI* is less than 100.

6. If Life is not already set to 20, click in the Des. Life box and enter a value of 20. This will give the pavement a life of 20 years after overlaying.

7. Click End Modify to leave the modify mode.

Run the design by clicking Design Structure . Initially, the thickness of the overlay layer will change in increments of 4 inches. After 2 successive thicknesses have bracketed the correct design thickness, the thickness of the overlay layer will iterate to the correct thickness. This process will take considerably longer than in the new pavement designs.

From the NOTES window, Design Info , the final structure is:

```
The structure is Unbonded PCC Overlay on Rigid.
Design Life = 20 years.


            Pavement Structure Information by Layer, Top First


  No.   Type                Thickness   Modulus   Poisson's
Strength

                            inches       psi       Ratio     R, psi
   1   PCC Overlay Unbond   10.22     4,000,000    0.15        700
   2   PCC Surface          14.00     4,000,000    0.15        725
   3   P-304 CTB             8.00       500,000    0.20          0
   4   P-209 Cr Ag           6.00        30,518    0.35          0
   5   Subgrade              0.00        12,152    0.40          0
Total thickness to the top of the subgrade = 38.22 inches
```

In the output from the NOTES window, the modulus of the PCC surface layer of the existing structure is given as 4,000,000 psi. But this is not the value used during design when the *SCI* of the layer is less than 100. The value used is calculated from the relationship (given in reference 3):

$$E_{Exist} = E_{100} \times (0.02 + 0.064 \times SCI_{Exist} + (0.00584 \times SCI_{Exist})^2)$$

where:

SCI_{Exist} = *SCI* of the existing PCC layer as it deteriorates during the life of the overlaid structure

E_{Exist} = modulus of the existing PCC layer at SCI_{Exist}

E_{100} = modulus of the existing PCC layer when its *SCI* is 100 (4,000,000 psi in this case)

The modulus of the CTB layer is also set at its default value of 500,000 psi, which is appropriate for design of new structures. But if, from field surveys, the layer is known to be seriously deteriorated, it can be replaced in the

representation of the structure by a lower quality layer type or by the variable stabilized layer type with its modulus value set to less than 500,000 psi.

Asphalt Overlay on Rigid Design Example

Asphalt overlays on existing rigid pavements are designed in exactly the same way as concrete overlays except that the Asphalt Overlay layer type is selected from the Layer Type Selection box. The modulus of the existing PCC surface layer is adjusted during the design and does not have the value reported in the design information from the NOTES window. Subbase material substitutions are also appropriate where there is evidence of serious deterioration from field surveys.

For the same existing pavement and aircraft traffic as used in the concrete overlay design example, the final structure from the NOTES window, Design Info , is:

```
The structure is AC Overlay on Rigid.
Design Life = 20 years.


          Pavement Structure Information by Layer, Top First


 No.   Type                 Thickness   Modulus   Poisson's
Strength

                            inches       psi       Ratio       R, psi

   1  P-401 AC Overlay        8.63      200,000     0.35          0

   2  PCC Surface            14.00    4,000,000     0.15        725

   3  P-304 CTB               8.00      500,000     0.20          0

   4  P-209 Cr Ag             6.00       30,518     0.35          0

   5  Subgrade                0.00       12,152     0.40          0

Total thickness to the top of the subgrade = 36.63 inches
```

Overlays on Composite Pavements

Design of overlays on existing rigid pavements which already have an asphalt overlay cannot be done directly using LEDFAA because a PCC surface layer cannot be placed further down than the second layer in a structure. One method of representing such a structure is to replace the PCC layer in the existing pavement with an undefined layer or a variable stabilized layer. The modulus of the substitute layer can be selected based on the design engineers judgment of the *SCI* of the existing PCC layer and application of the equation for PCC layer modulus given in the concrete overlay design example.

Effects of Sublayering in Aggregate Layers

As discussed in the section on aggregate layers, sublayering of aggregate layers is included in the design procedures. The maximum sublayer thicknesses are 8 inches for uncrushed aggregate and 10 inches for crushed aggregate (except when the number of layers is fixed to avoid continuous iteration). The following example illustrates the effects of the sublayering caused by changes in effective stiffness of an aggregate layer when the number of sublayers changes. The example structure has a 6 inch thick asphalt surface layer over aggregate base and subbase layers and a 9 CBR subgrade (modulus of 13,500 psi). Aircraft in the mix are B-747-400, MD-80/82, and B-777-200 A.

```
The structure is New Flexible. Asphalt CDF = 0.3096.
Design Life = 20 years.


          Pavement Structure Information by Layer, Top First


 No.   Type                  Thickness   Modulus   Poisson's
Strength

                             inches        psi       Ratio      R, psi

  1  P-401 AC Surface          6.00       200,000    0.35          0

  2  P-209 Cr Ag              13.00        71,950    0.35          0

  3  P-154 UnCr Ag            15.91        26,875    0.35          0

  4  Subgrade                  0.00        13,500    0.35          0

Total thickness to the top of the subgrade = 34.91 inches


                      Aircraft Information


 No.       Name            Gross Wt.      Annual      % Annual

                              lbs        Departures     Growth

  1  B-747-400             873,000         4,200       0.00

  2  MD-82/88              150,500        16,000       0.00

  3  B-777-200 A           537,000          500        0.00
```

The design was run by setting the subbase as the iteration layer and starting from an arbitrary subbase thickness. But running Life after the design was completed gave a life of 18.9 years, a subgrade CDF of 1.06, and an asphalt CDF of 0.36, which do not agree with the design information. Then, without changing any of the properties of the structure or the aircraft mix, Design was run again, resulting in the following structure:

```
The structure is New Flexible. Asphalt CDF = 0.3543.
Design Life = 20 years.
```

```
                    Pavement Structure Information by Layer, Top First


      No.   Type                 Thickness   Modulus   Poisson's
      Strength

                                  inches       psi       Ratio       R, psi

       1   P-401 AC Surface         6.00     200,000      0.35          0

       2   P-209 Cr Ag             13.00      70,002      0.35          0

       3   P-154 UnCr Ag           16.05      26,471      0.35          0

       4   Subgrade                 0.00      13,500      0.35          0
  Total thickness to the top of the subgrade = 35.05 inches
```

From the first to the second design, the thickness of the subbase increased from 15.91 to 16.05 inches and crossed the threshold for sublayering from 2 sublayers to 3. The modulus values of both aggregate layers also changed, as did the asphalt CDF. The changes in the structure are summarized in the table below, with the sublayer modulus values included (read from the JULEADAT.OUT file).

Property	Design 1	Design 2
Subbase thickness	15.91	16.05
Modulus of base sublayer 1	83,778	82,220
Modulus of base sublayer 2	60,121	57,784
Average modulus of the base	71,950	70,002
Modulus of subbase sublayer 1	32,510	30,446
Modulus of subbase sublayer 2	27,409	22,496
Modulus of subbase sublayer 3	20,705	no sublayer
Average modulus of the subbase	26,875	26,471
Design life after Life	18.9	21.3
Subgrade CDF after Life	1.06	0.94
Asphalt CDF	0.31	0.35
Asphalt CDF after Life	0.36	0.31

All of the values given are for the structure at the end of design except where noted that they were obtained after running Life . For the first design the subbase has 3 sublayers instead of the 2 required by its thickness of less than 16 inches. This is because, during the final stages of design, the number of sublayers was fixed when the thickness of the subbase was greater than 16 inches. Then, when Life was run, the correct number of 2 sublayers was created and the life computations made for a slightly different structure. Also, when the second design was run, the structure started with the correct number of 3 sublayers, the number of sublayers was fixed at 3, and the design completed with 3 sublayers and a thickness of less than 16 inches. If the number of layers had not been fixed at some stage, the design would have cycled back and forth across the threshold

thickness of 16 inches with CDF values of 1.06 and 0.94 repeated endlessly.

Two other interesting aspects of this example are:

1. Removing the MD-82 from the aircraft list and running Life on the second design decreases the subgrade CDF from 1.06 to 0.98 (7.5 percent), but decreases the asphalt CDF by a much larger relative amount, from 0.35 to 0.19 (51 percent).

2. Changing the base material to variable stabilized at 150,000 psi on the second design decreases the subgrade CDF to 0.28 and decreases the asphalt CDF to 0.003 (a negligible amount).