Calculating PCN using the FAA Method

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Introduction

The ACN/PCN system of rating airport pavements is designated by the International Civil Aviation Organization (ICAO) as the only approved method for reporting strength. Although there is a great amount of material published on how an ACN is computed, ICAO has not yet specified regulatory guidance as to how an airport authority is to arrive at a PCN, but has left it up to that agency as to how to perform this task. This is not a result of member states reluctance to agree on an international standardized method of pavement evaluation, but rather an affirmation that they should rely on their own internally developed procedures. Acceptance of the ACN/PCN method itself resulted only from the omission of a uniform evaluation standard in that many states felt that their method was superior, and a change to another method would be costly in terms of study, research, development, field training, staff familiarity, and all other attendant concerns.

As a consequence, it has been discovered through our work and correspondence with airport authorities, engineering consultants, and airlines that there is a great amount of uncertainty among many states that do not have well-established evaluation methodology as to exactly how to arrive at a PCN and still be within the boundaries of whatever ICAO guidelines might exist. Most organizations attempt to follow regulatory guidelines in their operations, but without a specific guidance procedure this uncertainty has developed. Additionally, without published ICAO standard recommendations on this subject, the determination of PCN has most certainly been anywhere from inconsistent to erroneous. This paper presents methods to calculate PCN using the FAA method as described in FAA Advisory Circular 150/5335-5B.

The purpose of an airfield pavement is to provide a surface on which aircraft takeoffs, landings, and other operations may be safely conducted. The purpose of a pavement rating is to allow for adequate pavement utilization at a reasonable cost, with the optimization of pavement economics that vary with local operational conditions. For example, a heavily used runway should have greater strength and a correspondingly greater rating than a lightly used runway, even though they both may have been designed to be served by the same aircraft. Although the PCN does not indicate anything about actual traffic and pavement characteristics, these components are necessary in order to determine the allowable gross weight for a critical airplane, which is then turned into a rating called PCN.

In the most fundamental terms, the determination of a rating in terms of PCN is a process of deciding on the maximum allowable gross weight of a selected critical airplane for a pavement, and knowing its ACN at that weight, reporting it as PCN. This process can be as simple as knowing the operational gross weight of each aircraft that is currently using the pavement and looking up its ACN (referred to as the *Using* aircraft method). This method can be applied with limited knowledge of the existing traffic and pavement characteristics. The second method is more complex and is referred to as *Technical* evaluation. In order to be successfully implemented, *Technical* evaluation requires a more intimate knowledge of the pavement and its traffic, as well as a basic understanding of engineering methods that are utilized in pavement design. In either of these cases, accuracy is improved with greater knowledge of the pavement and traffic characteristics.

There are no precise pavement strength requirements for a given airplane or fleet of airplanes, even though the various design systems in use today can be very accurate in their computational abilities. Pavement structural capability is best determined through a combination of on-site inspection, load-bearing tests, and engineering judgment. Each of these are of importance, and it is for this reason that pavement ratings should not be viewed in precise terms, but rather as nominal estimations of a representative value. The end result of a valid rating process is that an assignment of PCN is enabled which considers the effects of all significant traffic on the pavement.

The strength rating of airport pavements is commonly thought of in terms of conventional structural concepts in which limiting loads are determined based on ultimate strength or failure criteria. However, pavements do not generally experience a loss in serviceability from instantaneous structural failure, but rather from an increase in roughness or gradual deterioration resulting from the accumulated effects of traffic. Structural failure is most often recognized in terms of common pavement distresses such as rutting, cracking, and noticeably intolerable roughness that both pilots and passengers experience. Analysis of the adequacy of a pavement for the intended service, therefore, requires that a pavement rating be assigned that not only considers the significance of load magnitude, but the effects of the traffic volume over the intended life of the pavement.

The PCN rating process is not related to the pavement design process. Pavement design cannot be determined from a PCN rating in that the PCN is a rating of pavement strength in terms of ACN. The PCN does not indicate anything about traffic volume, design loads, or pavement thickness, which are major components in pavement design. Flexible pavement ACN is no more than the weight of a standard single wheel at a standard tire pressure that has the same thickness requirements as the airplane in question at an arbitrary 10,000 coverages. Rigid pavement ACN is likewise the weight of a standard single wheel load that has the same thickness requirements as the airplane in question at an arbitrary 399 psi (2.75 Mpa) concrete working stress. (The values of 10,000 coverages and 399 psi working stress were chosen in the ACN/PCN development process as representative values of typical airfield pavements). The ACN is therefore a relative number based on chosen pavement design parameters, and the PCN is the ACN of the critical airplane at its allowable gross weight. It is for these reasons that conversions of other rating methods to PCN, such as LCN, cannot be developed.

The steps outlined in this document can be used by a pavement engineer to determine the rating of a runway pavement in terms of PCN. These steps can also be utilized for taxiways, but evaluation of parking aprons is somewhat more difficult due to the lack of detailed traffic pattern information. Both rigid (concrete) and flexible (asphalt) runway types are included, along with a discussion of composite pavements. Additionally, methods that go beyond the simplified methods presented in Annex 14 are given that will allow the assignment of a PCN in overload conditions where the pavement is not strong enough to handle current or future traffic.

The ACN/PCN method is based on design procedures that evaluate one aircraft against the pavement structure. In other words, calculations necessary to determine the PCN are performed for one aircraft at a time. In pavement design, the FAA has used the equivalent annual departure concept to consolidate entire traffic mixtures into equivalent annual departures of one representative aircraft. This concept is carried over into the PCN procedure in which equivalent annual departures for a given aircraft from a traffic mixture are based on the cumulative damage factor (CDF).

The Cumulative Damage Factor (CDF)

The CDF method is based on the principle of Miner's Rule, which states that the damage induced in a structure or pavement is proportional to the number of load applications divided by the number of load applications required to fail the pavement. In the PCN analysis the CDF of each aircraft is simply its 20-year coverages divided by the number of failure coverages. The failure models are the CBR method for flexible pavements and Westergaard edge case method for rigid pavements.

A single aircraft is not initially designated as critical in this method, but each one in the traffic mix is considered critical and evaluated using the equivalent coverages of all the remaining traffic. Equivalent coverages are computed by ratioing the coverages to failure of each individual critical aircraft to all the other aircraft in the mix and then multiplying by that aircraft's 20-year coverages. The total summation determines the equivalent coverages and is different for each aircraft in the mix.

For each aircraft's total equivalent coverages a pavement design thickness can be calculated using the COMFAA software. If the resulting required design thickness for all aircraft in the mix is less than the actual pavement thickness, then the pavement can handle all the traffic, and the resulting PCN should be greater than the highest ACN values. Conversely, if the actual pavement thickness is less than that required by the COMFAA design thickness computation, then the PCN would be lower than some of the ACN values, thereby possibly restricting some operations.

The PCN values for each aircraft in the mix are automatically calculated by the COMFAA program. The PCN is merely the aircraft ACN at its maximum allowable weight. The maximum allowable weight is based on the total equivalent coverages of each aircraft and the actual pavement thickness, and it is an indication of the true bearing strength of the pavement.

This document provides a number of PCN calculation examples that will cover a variety of situations. Although these examples are comprehensive, the engineer will soon experience a pavement that is not covered. It is therefore prudent that the solutions arrived at must make sense for the problem at hand, with the realization that judgment obtained over years of experience is a necessary part of the solution.

The examples presented herein are all taken from existing airport data.

First Things First

The very first thing to do when calculating a PCN for a runway, a runway segment, or any other pavement is to create a new folder on your computer for that project. This includes copying the COMFAA and support spreadsheet files to this new folder. Always run COMFAA from this folder for that particular job. By doing so, you will be able to keep each project's input and output files separate. For a given airport create an airport traffic file (.ext) using COMFAA in the same folder.

Example 1 - Rigid Pavement

Description

This airport consists of two runways – one is a rigid pavement and the second is a flexible pavement. Both are of typical design and construction for the traffic encountered. Runway 15/33, analyzed in Example 1A, is well designed and the derived PCN is adequate. Example 1B shows the effect of altering the Modulus of Rupture and its affect the PCN. Example 1C shows the effect of reducing slab thickness.

The flexible runway, 11/29, is analyzed in Example 2, is marginally acceptable and may require an overlay.

Annual Traffic

The airport authority has reported the average annual traffic, as seen in Table 1. Runway 15/33 has 60% of the traffic and Runway 11/29 has the remainder. Note that the Maximum Taxi Weight (MTW) of each aircraft is shown rather than actual operating weights; however, weights at less than MTW may be used at the option of the engineer.

There are at least two reasons for using maximum weights:

1. The COMFAA program lists each aircraft at MTW, and the construction of the traffic file for that program is less tedious when MTW is used.
2. The use of MTW rather than actual weights is more conservative.

Table 1 - Examples 1 and 2 Traffic

				Departures	
Aircraft	Gear Type	MTW (lb)	Average Annual Departures	Rigid Runway 15/33 60%	Flexible Runway 11/29 40%
B747-400ER	2D/2D2	913,000	3,800	2,280	1,520
B747-8	2D/2D2	978,000	300	180	120
B787-8	2D	503,500	6,800	4,080	2,720
B717	D	122,000	6,100	3,660	2,440
B727-200	D	185,200	200	120	80
B737 (300/400/500)	D	150,500	22,000	13,200	8,800
B737 (700/800)	D	174,700	26,000	15,600	10,400
B757-200	2D	256,000	41,000	24,600	16,400
B767-300ER	2D	413,000	7,800	4,680	3,120
B777-300ER	3D	777,000	3,300	1,980	1,320
MD-11ER	2D/D1	633,000	1,200	720	480
MD-83	D	161,000	700	420	280
A319	D	150,800	12,000	7,200	4,800
A320	D	172,800	19,000	11,400	7,600
A321	D	181,200	5,500	3,300	2,200
A300/310	2D	365,700	2,100	1,260	840
A340-200	2D	515,600	800	480	320
A380-800	2D/3D2	1,234,500	500	300	200
		Totals	**177,100**	**106,260**	**70,840**

Construct the traffic file in COMFAA as follows:

1. Open COMFAA.
2. If an external traffic file (.ext) has not yet been created, then
   a. Click the Open Aircraft Window box.
   b. Add aircraft from the Aircraft Group. Note the Position to Insert Aircraft radial buttons.
   c. Remove aircraft by clicking the No. and then the Remove (Cut) the Selected Aircraft box.
   d. Save the List as a New External File with an appropriate name such as "Example 1A Rigid Pavement Runway 15/33".
3. If an external file exists, either:
   a. Click Load Ext File from the main COMFAA screen, or
   b. Click Open Aircraft Window and Open an External File
4. Using the Departures columns in Table 1, there should be separate files for each runway with the designated traffic numbers. Use one file for the rigid pavement analysis and the other for the flexible pavement analysis.
5. Save the traffic files with descriptive names.

Example 1A - Rigid Pavement Runway 15/33

Pavement Characteristics

Runway properties relevant to the analysis are shown in Table 2 for runway 15/33. This table contains FAA 5010 ratings, and the goal is to replace them with PCN's. There are many reasons for doing this, but the main one is that the FAA 5010 rating system does not allow for the determination of allowable gross weights such as the B777, MD-11 and A380 aircraft. Furthermore, neither runway is strong enough to accommodate the B747-8 aircraft at MTW, as indicated by the DDT ratings. Finally, there is no gross weight credit given to the 2D widebody aircraft such as the B767, B787 and A330. Each of these has superior landing gear characteristics as compared to the FAA standard DT gear, which should allow them to operate at a higher gross weight than as indicated by the DT rating. The PCN rating will fully determine the capability of these aircraft.

Table 2 - Example 1A Pavement Properties

Construction date:	2011		
PCC depth	17	in.	P-501
Base	6	in.	P-306
PCC Modulus Elasticity	4,000,000	psi	
Modulus of Rupture	700	psi	
Subgrade k	193	pci	
Effective k-value*	310	pci	Code B
Design life	20	years	
FAA 5010 rating	D200	DT400	DDT800

* See discussion following on equivalent k calculation

For rigid pavement, the effective subgrade k-value can be improved if there are any superior base materials below the slab. This could include many types of stabilized layers such as P-401, P304, P-209, and also non-stabilized layers such as P-154. COMFAA works with only one layer of pavement on the subgrade, so these stabilizing layers must be converted to effective subgrade strength, and this will be entered into COMFAA as the subgrade k-value. From the Standard support sheet under the Rigid Pavement k-value worksheet, Figure 1, enter the P-501 thickness, the P-306 thickness and the subgrade strength subgrade modulus, k. The P-501 slab flexural strength is also entered here, but it has no effect on the calculation of the effective k-value. The spreadsheet formulas will calculate an effective k-value of 310 pci, which is the value to enter into the COMFAA "k" location.

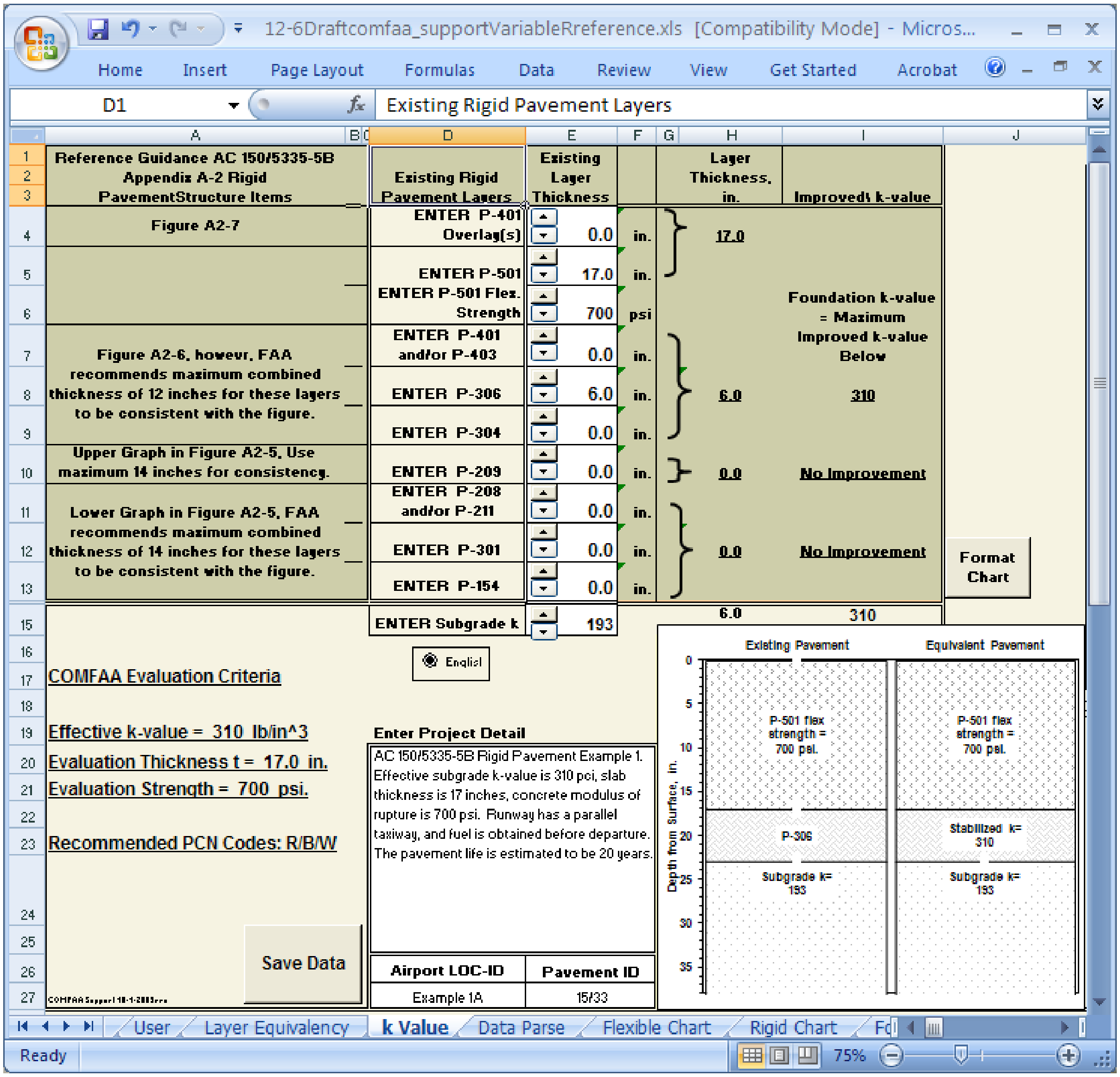


Figure 1 - Example 1A Effective k-value

PCN Calculation of Runway 15/33

Ensure that the "PCA Thick" box is not checked in COMFAA. Although rigid ACN's are calculated using a variation of the PCA program, PCN's are determined by using an adaptation of the FAA edge loading method as found in AC 150/5320-6C/D.

After entering the traffic and pavement characteristics into COMFAA (as shown in Figure 2) and clicking the "PCN Rigid Batch" button, select the Details button when the calculation steps have finished. Alternatively, open the file "PCN Results Rigid-date-time.txt”. This file is generated by selecting the “Save PCN Output to a text file” box in Details before the PCN calculation.

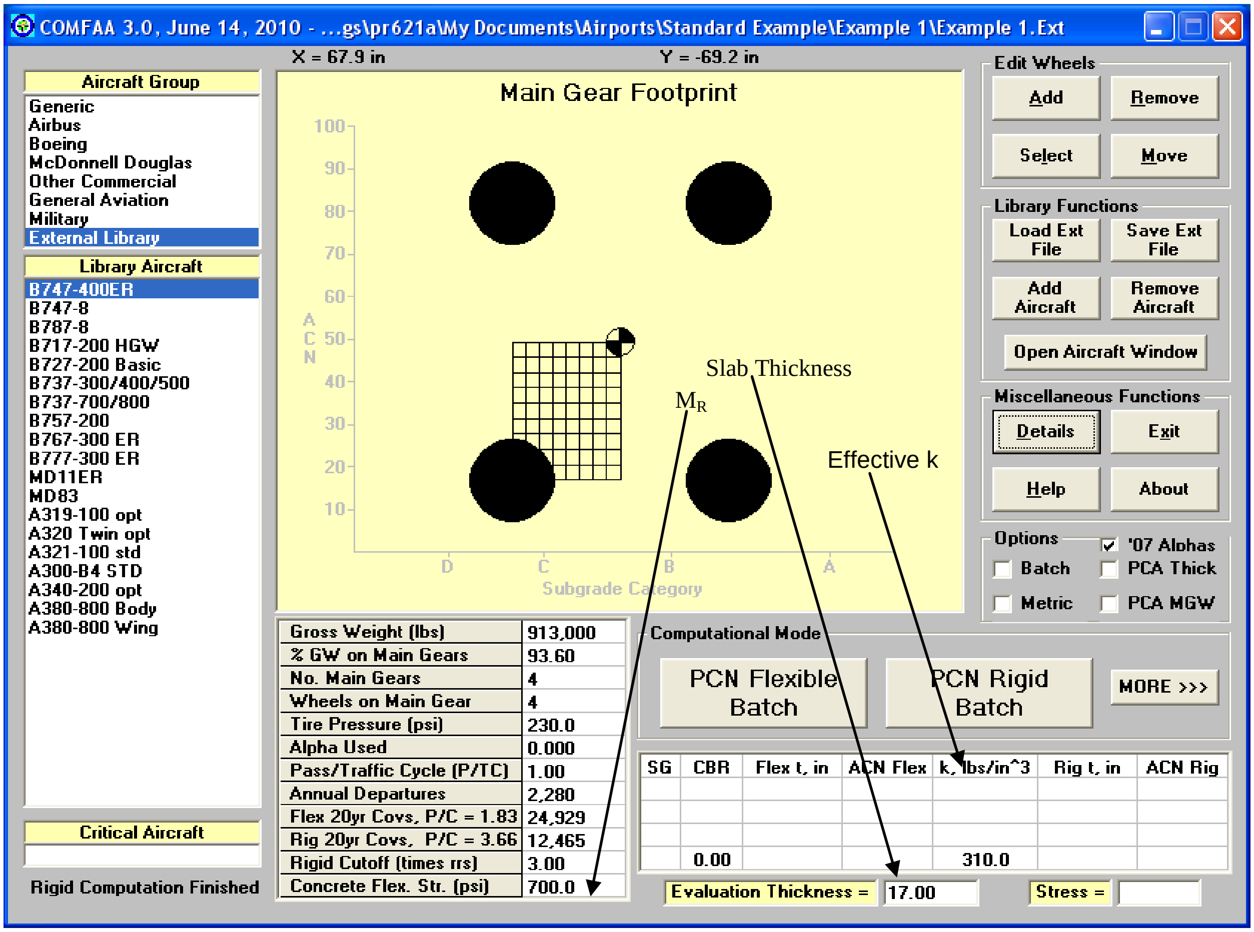


Figure 2 - Example 1A COMFAA Input Screen

Initially the pavement and traffic characteristics are displayed as output, such as in Figure 3, along with the recommended subgrade category.

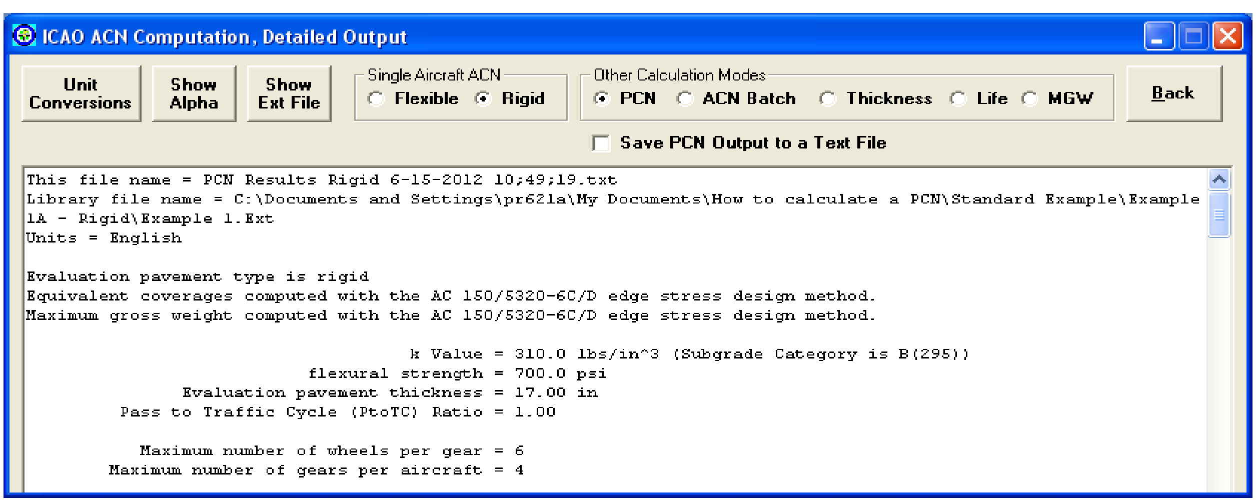
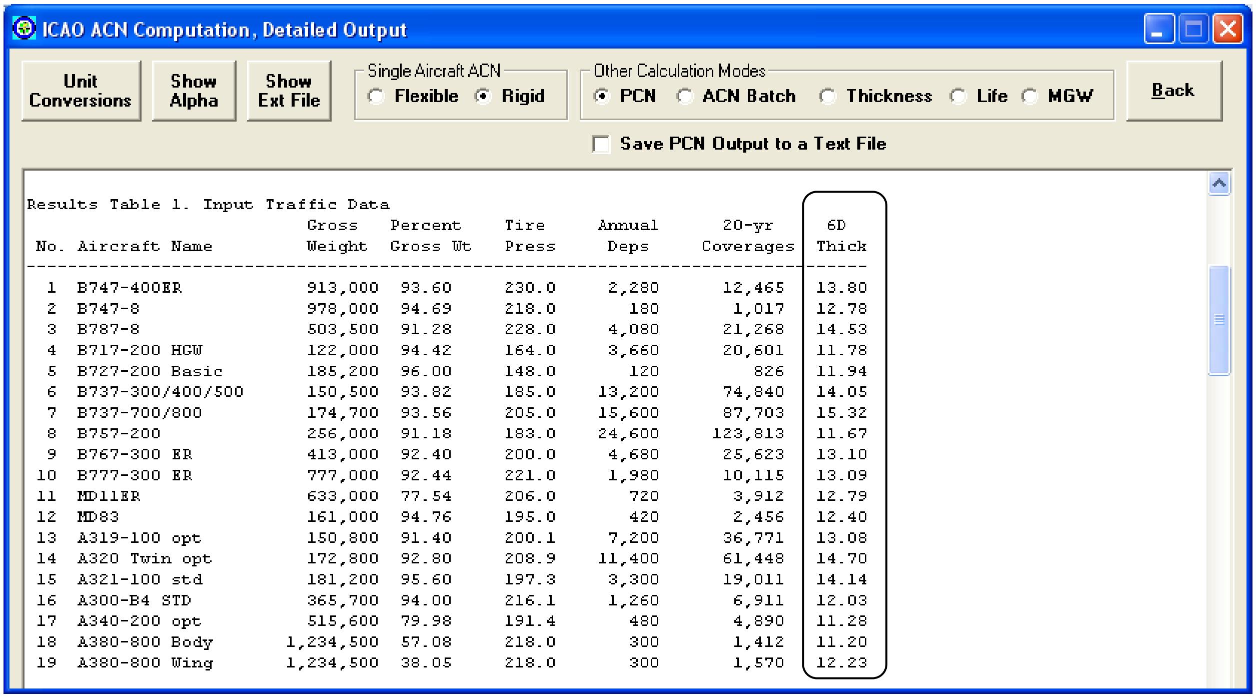


Figure 3 - Example 1A Initial Rigid Pavement Output Details

Next the input traffic data is shown as Figure 4 (Table 1 in the Detailed Output). Note the value of the -6D thicknesses, which are those calculated individually for each model according to the methods in AC 150/5320-6D. These numbers have no relation to the PCN calculation and are only shown for comparison to the evaluation thickness. However, it is expected that each of these values will be less than the evaluation thickness for a properly designed pavement.



Results Table 1. Input Traffic Data

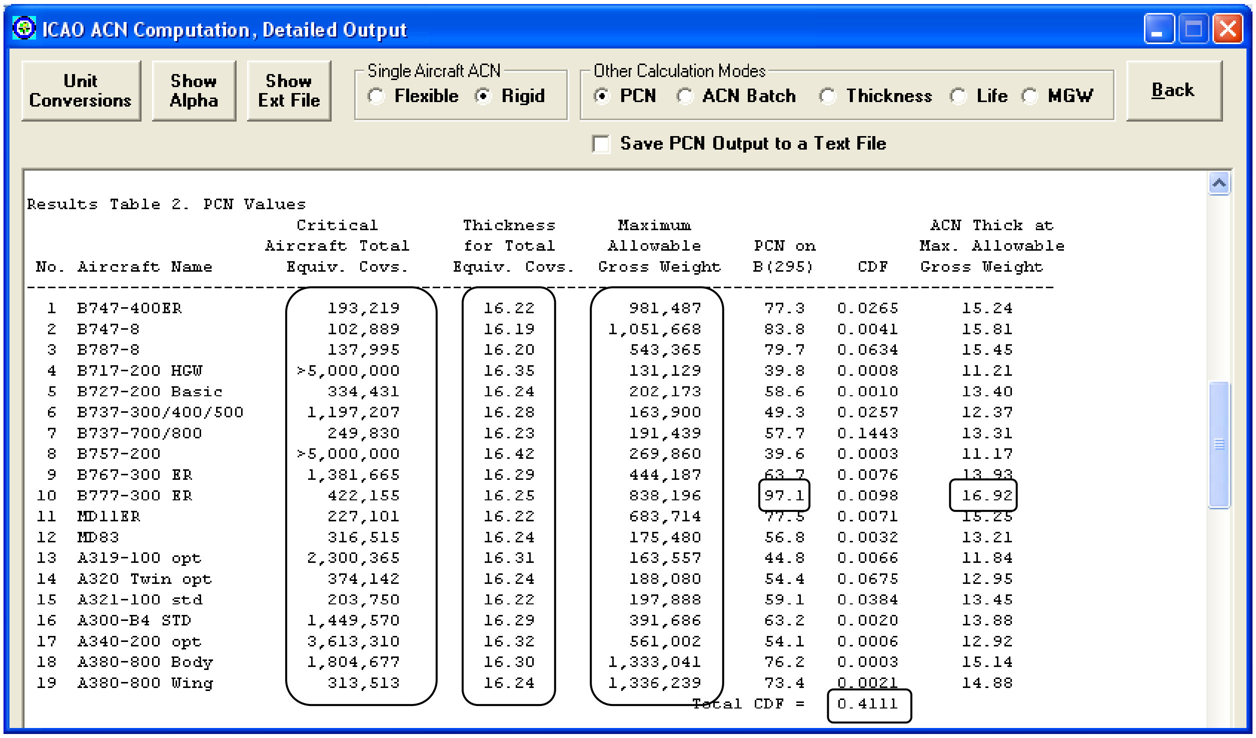
No.	Aircraft Name	Gross Weight	Percent Gross Wt	Tire Press	Annual Deps	20-yr Coverages	6D Thick
1	B747-400ER	913,000	93.60	230.0	2,280	12,465	13.80
2	B747-8	978,000	94.69	218.0	180	1,017	12.78
3	B787-8	503,500	91.28	228.0	4,080	21,268	14.53
4	B717-200 HGW	122,000	94.42	164.0	3,660	20,601	11.78
5	B727-200 Basic	185,200	96.00	148.0	120	826	11.94
6	B737-300/400/500	150,500	93.82	185.0	13,200	74,840	14.05
7	B737-700/800	174,700	93.56	205.0	15,600	87,703	15.32
8	B757-200	256,000	91.18	183.0	24,600	123,813	11.67
9	B767-300 ER	413,000	92.40	200.0	4,680	25,623	13.10
10	B777-300 ER	777,000	92.44	221.0	1,980	10,115	13.09
11	MD11ER	633,000	77.54	206.0	720	3,912	12.79
12	MD83	161,000	94.76	195.0	420	2,456	12.40
13	A319-100 opt	150,800	91.40	200.1	7,200	36,771	13.08
14	A320 Twin opt	172,800	92.80	208.9	11,400	61,448	14.70
15	A321-100 std	181,200	95.60	197.3	3,300	19,011	14.14
16	A300-B4 STD	365,700	94.00	216.1	1,260	6,911	12.03
17	A340-200 opt	515,600	79.98	191.4	480	4,890	11.28
18	A380-800 Body	1,234,500	57.08	218.0	300	1,412	11.20
19	A380-800 Wing	1,234,500	38.05	218.0	300	1,570	12.23

Figure 4 - Example 1A Results Table 1 Input Traffic Data

There are several purposes for the Results Table 2 shown in Figure 5. The primary function is to show the PCN of each aircraft as calculated by the CDF method. “Critical Aircraft Total Equivalent Coverages” shows the required coverages for failure as if it were the critical aircraft. These values are calculated by assuming that the aircraft in question is critical and folding in equivalent coverages of all the other aircraft according to AC 150/5335-5B CDF methodology described earlier. A complete explanation of this process is given in Appendix 1 of -5B.

“Thickness for Total Equivalent Coverages” shows the required thickness based on the previous column equivalent coverages and the aircraft gross weight. These thicknesses are calculated using AC 150/5320-6D edge stress rules. A relatively uniform range of calculated thicknesses, with values being a little less than the evaluation thickness of 17 inches, shows that this pavement is well designed for this traffic.

The “Maximum Allowable Gross Weight” for each aircraft shows the allowable gross weight based on the total equivalent coverages for that aircraft at the design thickness of 17 inches. This value is also calculated using -6D rules.



Results Table 2. PCN Values

No.	Aircraft Name	Critical Aircraft Total Equiv. Covs.	Thickness for Total Equiv. Covs.	Maximum Allowable Gross Weight	PCN on B(295)	CDF	ACN Thick at Max. Allowable Gross Weight
1	B747-400ER	193,219	16.22	981,487	77.3	0.0265	15.24
2	B747-8	102,889	16.19	1,051,668	83.8	0.0041	15.81
3	B787-8	137,995	16.20	543,365	79.7	0.0634	15.45
4	B717-200 HGW	>5,000,000	16.35	131,129	39.8	0.0008	11.21
5	B727-200 Basic	334,431	16.24	202,173	58.6	0.0010	13.40
6	B737-300/400/500	1,197,207	16.28	163,900	49.3	0.0257	12.37
7	B737-700/800	249,830	16.23	191,439	57.7	0.1443	13.31
8	B757-200	>5,000,000	16.42	269,860	39.6	0.0003	11.17
9	B767-300 ER	1,381,665	16.29	444,187	63.7	0.0076	13.93
10	B777-300 ER	422,155	16.25	838,196	97.1	0.0098	16.92
11	MD11ER	227,101	16.22	683,714	77.5	0.0071	15.25
12	MD83	316,515	16.24	175,480	56.8	0.0032	13.21
13	A319-100 opt	2,300,365	16.31	163,557	44.8	0.0066	11.84
14	A320 Twin opt	374,142	16.24	188,080	54.4	0.0675	12.95
15	A321-100 std	203,750	16.22	197,888	59.1	0.0384	13.45
16	A300-B4 STD	1,449,570	16.29	391,686	63.2	0.0020	13.88
17	A340-200 opt	3,613,310	16.32	561,002	54.1	0.0006	12.92
18	A380-800 Body	1,804,677	16.30	1,333,041	76.2	0.0003	15.14
19	A380-800 Wing	313,513	16.24	1,336,239	73.4	0.0021	14.88
					Total CDF =	0.4111	

Figure 5 - Example 1A Results Table 2 PCN Values

The next set of columns shows ACN's for each aircraft based on the values in the Maximum Allowable Gross Weight column, and they are relabeled PCN. Select the highest PCN from the PCN column of Figure 5, which is 97 RBWT for the 777-300ER in this example.

The column labeled "ACN Thick…." shows the required thickness for the standard subgrade category modulus (Rigid Code B, k=295 pci) at the maximum allowed gross weight for each individual aircraft. Although somewhat redundant, the greatest thickness corresponds with the highest PCN in the traffic mix.

With the Total CDF is being less than 1.000, indication is provided that the pavement can not only accommodate the evaluation traffic, but that it could handle more traffic until the total CDF limit of 1.000 is reached.

Although lower CDF values mean that these aircraft have lower impact on the pavement, the highest CDF does not necessarily determine the highest PCN. The lower CDF just indicates the relative importance of the aircraft to the PCN calculation.

Finally, there are two aircraft that show >5,000,000 "Critical Aircraft Total Equivalent Coverages" in the second column, meaning that these aircraft have very large equivalent coverage levels and correspondingly very low CDF contributions.

Results Table 4 from the Detailed Output, as seen in Figure 6, contains the comma separated data necessary to graphically show the PCN. Its main purpose is to enable graphical illustrations of the output data. Simply highlight the entire table, including the headings, and copy it to cell B5 in the Data Parse worksheet of the support spreadsheet (partially shown in Figure 7). The project title in cell B4, which will appear on the graphs, may also be changed at this time.

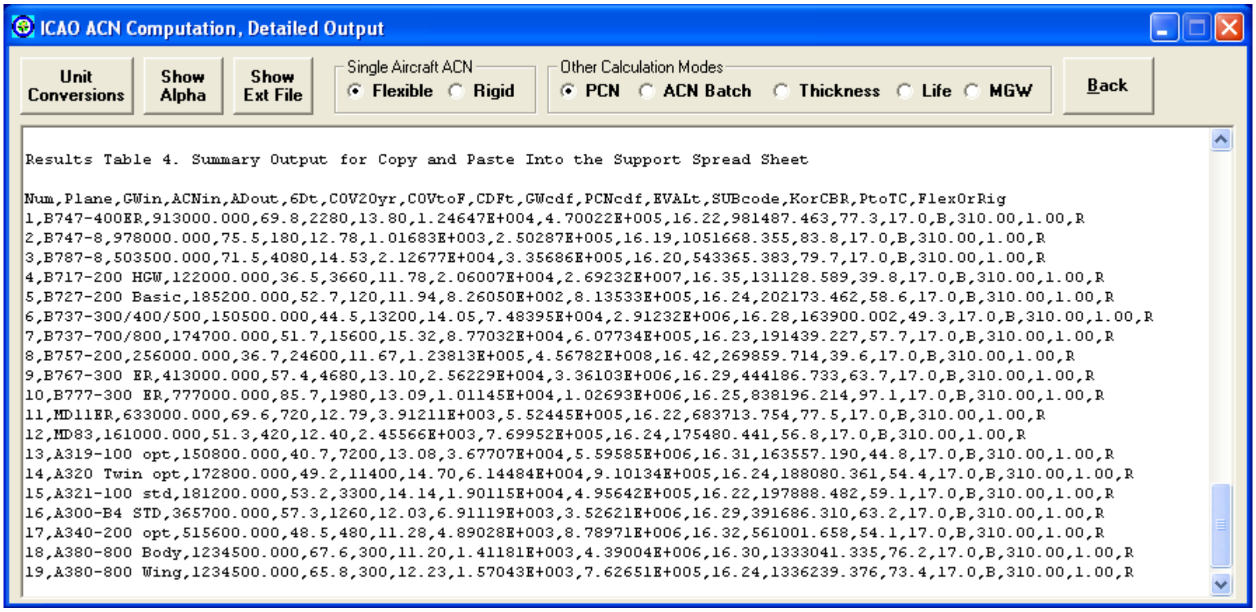


Figure 6 - Example 1A Results Table 4 Summary Output Data

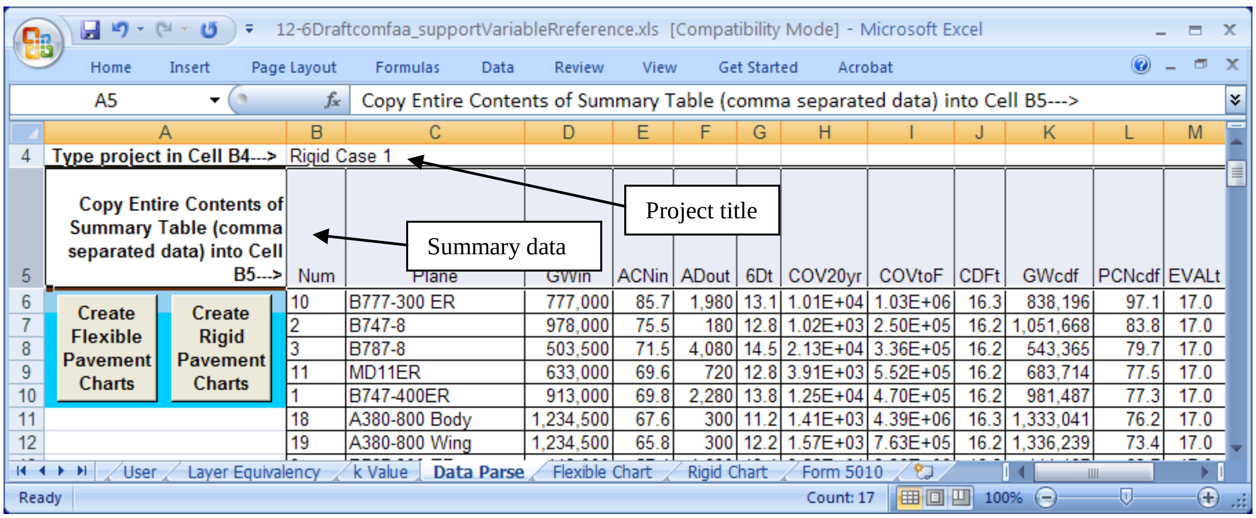


Figure 7 - Example 1A Data Parse Entry into Support Spreadsheet

Clicking the "Create Rigid Pavement Charts" box will generate one table and two graphs in the "Rigid Charts" worksheet. The table is identical to Figure 7, except that only the six most demanding aircraft in the traffic mix are repeated, and it is repeated graphically in the two charts.

Referring back to Figure 7, both the 6Dt (column G) and CDFt (column J) thickness requirements are seen in comparison to the evaluation thickness (column M). Comparison of the last two shows the expectation of pavement strength for the traffic mix. CDF thicknesses that are less than evaluation thicknesses indicate that the PCN will be sufficient for the aircraft. Conversely, CDF thicknesses that are greater than evaluation thicknesses are a sign that the pavement that will not be suitable for the traffic, at least for the period of time desired.

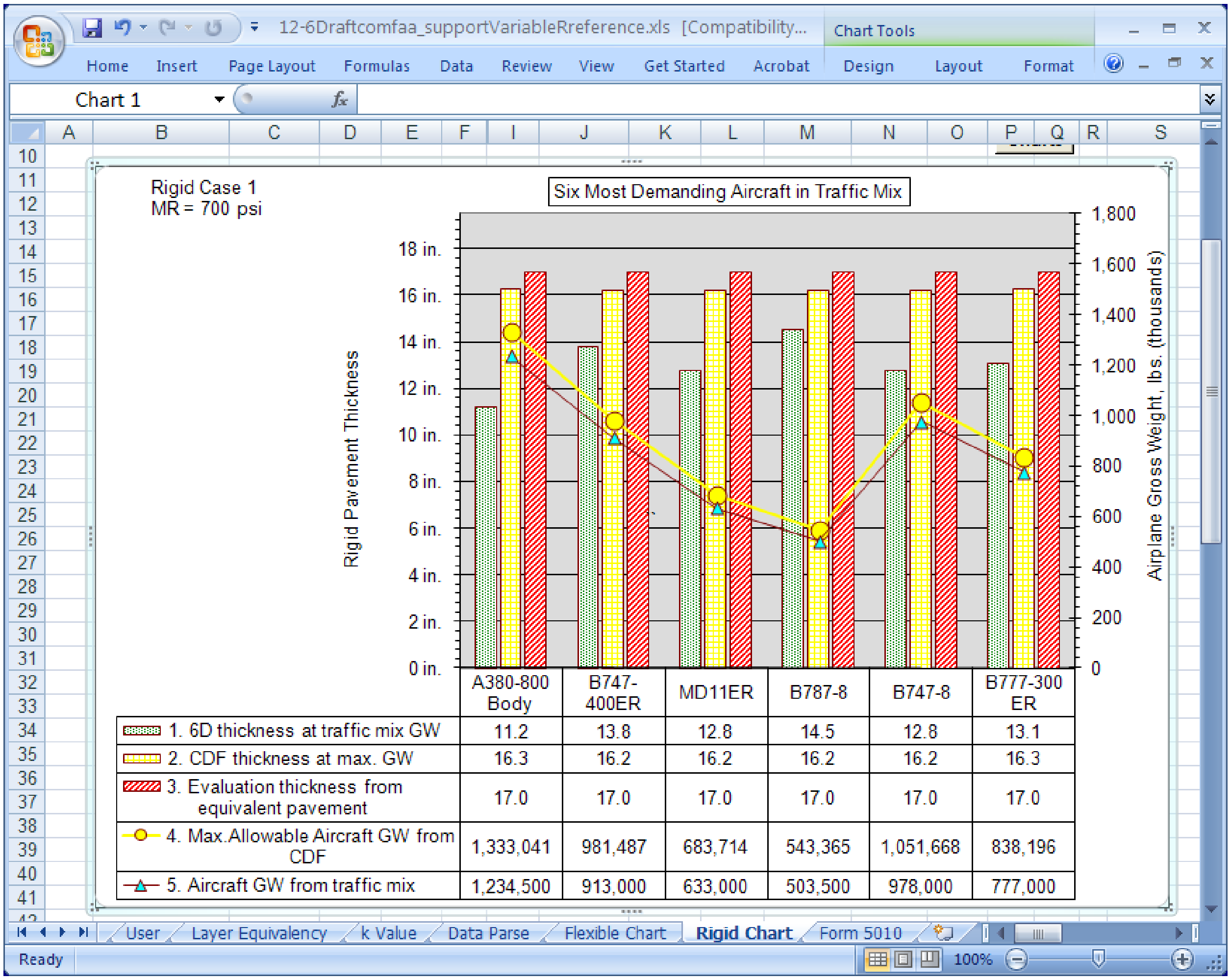


Figure 8 - Example 1A Thickness and Maximum Gross Weight

The “Maximum Allowable Aircraft Gross Weight from CDF” (line 4) is a precursor of the PCN calculation in that the PCN of each aircraft is simply the ACN at this weight. In this example these weights are greater than the input weights (line 5), indicating that each will have a PCN that exceeds its ACN.

The “Maximum Allowable Aircraft Gross Weight from CDF” in Figure 9 shows the graphic comparison of ACN and PCN for the six most demanding aircraft of the traffic mix. In addition, an important indication of the PCN validity for the pavement is seen by the annual departures line 3. If the highest PCN has very low departures, then the next lower PCN may be a better number. This is left to the engineer to decide.

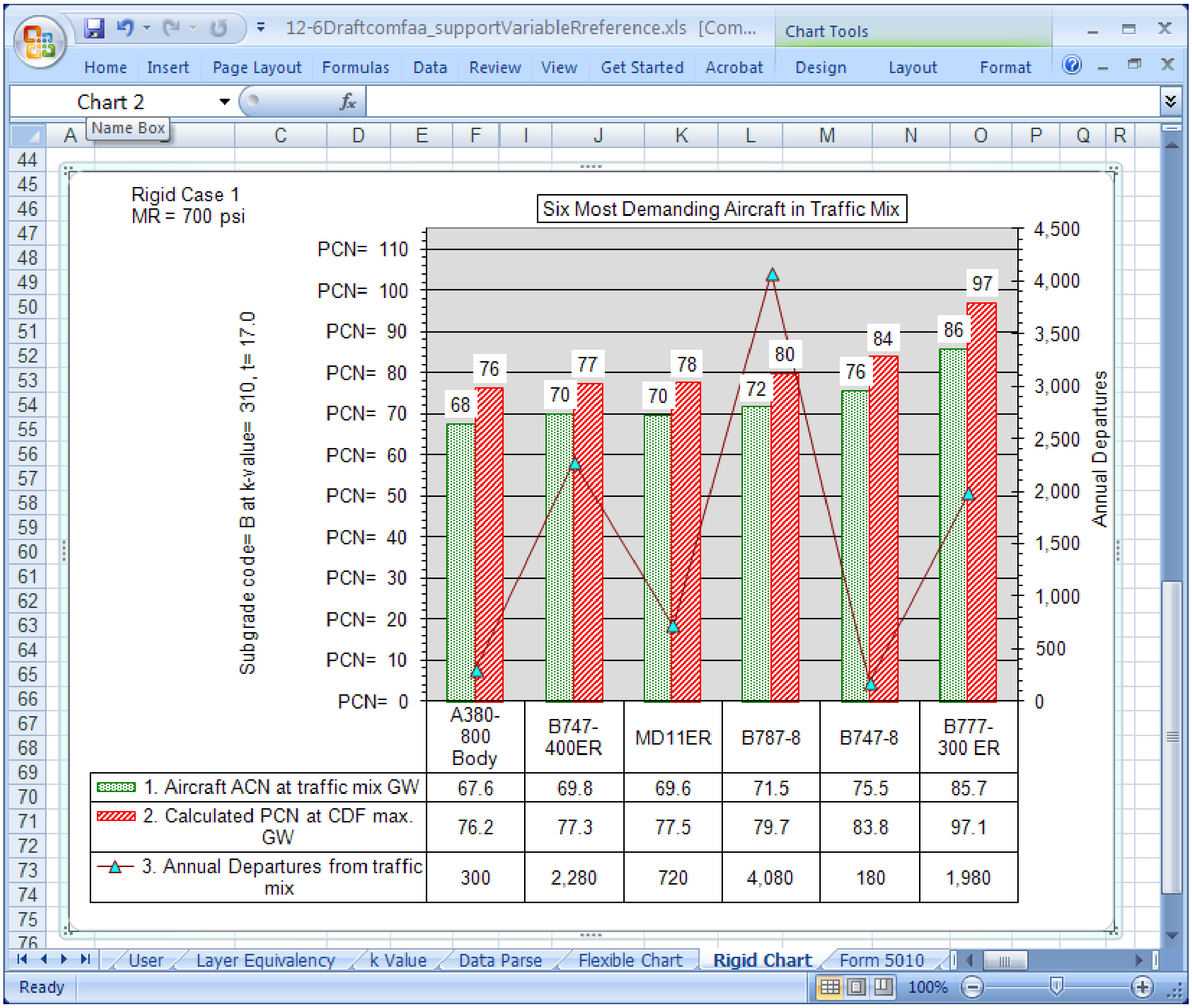


Figure 9 – Example 1A ACN and PCN Comparison

Table 3 presents a comparison of allowable gross weights according to the FAA method and the PCN method (calculated using PCN 97.1 RB). Note that a number of models could not be rated with the FAA method, but are readily available by using the PCN results.

Table 3 - Example 1A Allowable Gross Weights

Aircraft	MTW	D200	DT400	DDT800	PCN 97 RB
	(1000 lb)	(1000 lb)	(1000 lb)	(1000 lb)	(1000 lb)
B777-300ER	777	--	--	--	839
B747-8	978	--	--	800	1,165
B787-8	504	--	400	--	625
B727-200	186	200	--	--	312
MD-11	633	--	--	--	802
B747-400ER	913	--	--	800	1.155
A380 Body	1,234	--	--	--	1,563

Example 1B - Reducing the Modulus of Rupture

Pavement Characteristics

Runway properties relevant to the analysis are shown in Table 4 for runway 15/33, but the Modulus of Rupture is reduced from 700 to 650 psi. The purpose of this example is to show the sensitivity of PCN to one of the pavement parameters.

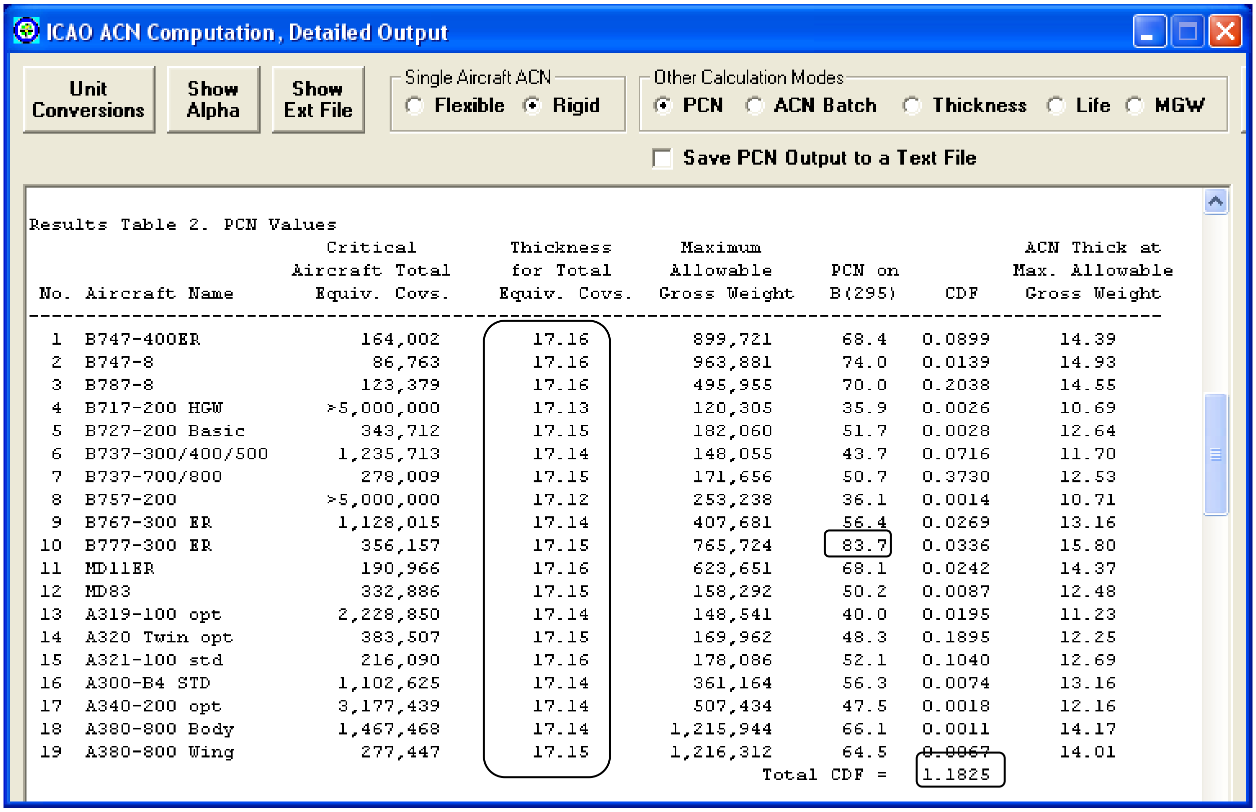
Table 4 - Example 1B Pavement Properties

Construction date:	2011		
PCC depth	17	in.	P-501
Base	6	in.	P-306
PCC Modulus Elasticity	4,000,000	psi	
Modulus of Rupture	650	psi	
Subgrade k	193	pci	
Effective k	310	pci	Code B
Design life	20	years	
FAA 5010 rating	D200	DT400	DDT800

With the same traffic as in Example 1A, Figure 10 shows that the PCN is reduced from 97 RB to 84 RB, while the critical aircraft ACN remains at 86 RB. There are two other indications that the pavement is overloaded. The first is that the thickness for total equivalent coverages exceeds the design thickness of 17.0 inches. The second is that the total CDF is greater than 1.00.

Examination of the graphic results of Figure 11 shows the relation between ACN and PCN for the six most demanding aircraft. If the M_R was at 665 psi rather than 650, the runway could be rated at PCN 87 RBWT, which would be greater than the highest ACN (not shown here).

PCN is obviously very sensitive to M_R, and it is seen that accurate measurement of pavement parameters is very important.



Results Table 2. PCN Values

No.	Aircraft Name	Critical Aircraft Total Equiv. Covs.	Thickness for Total Equiv. Covs.	Maximum Allowable Gross Weight	PCN on B(295)	CDF	ACN Thick at Max. Allowable Gross Weight
1	B747-400ER	164,002	17.16	899,721	68.4	0.0899	14.39
2	B747-8	86,763	17.16	963,881	74.0	0.0139	14.93
3	B787-8	123,379	17.16	495,955	70.0	0.2038	14.55
4	B717-200 HGW	>5,000,000	17.13	120,305	35.9	0.0026	10.69
5	B727-200 Basic	343,712	17.15	182,060	51.7	0.0028	12.64
6	B737-300/400/500	1,235,713	17.14	148,055	43.7	0.0716	11.70
7	B737-700/800	278,009	17.15	171,656	50.7	0.3730	12.53
8	B757-200	>5,000,000	17.12	253,238	36.1	0.0014	10.71
9	B767-300 ER	1,128,015	17.14	407,681	56.4	0.0269	13.16
10	B777-300 ER	356,157	17.15	765,724	83.7	0.0336	15.80
11	MD11ER	190,966	17.16	623,651	68.1	0.0242	14.37
12	MD83	332,886	17.15	158,292	50.2	0.0087	12.48
13	A319-100 opt	2,228,850	17.14	148,541	40.0	0.0195	11.23
14	A320 Twin opt	383,507	17.15	169,962	48.3	0.1895	12.25
15	A321-100 std	216,090	17.16	178,086	52.1	0.1040	12.69
16	A300-B4 STD	1,102,625	17.14	361,164	56.3	0.0074	13.16
17	A340-200 opt	3,177,439	17.14	507,434	47.5	0.0018	12.16
18	A380-800 Body	1,467,468	17.14	1,215,944	66.1	0.0011	14.17
19	A380-800 Wing	277,447	17.15	1,216,312	64.5	0.0067	14.01
					Total CDF =	1.1825	

Figure 10 - Example 1B Results Table 2 PCN Values

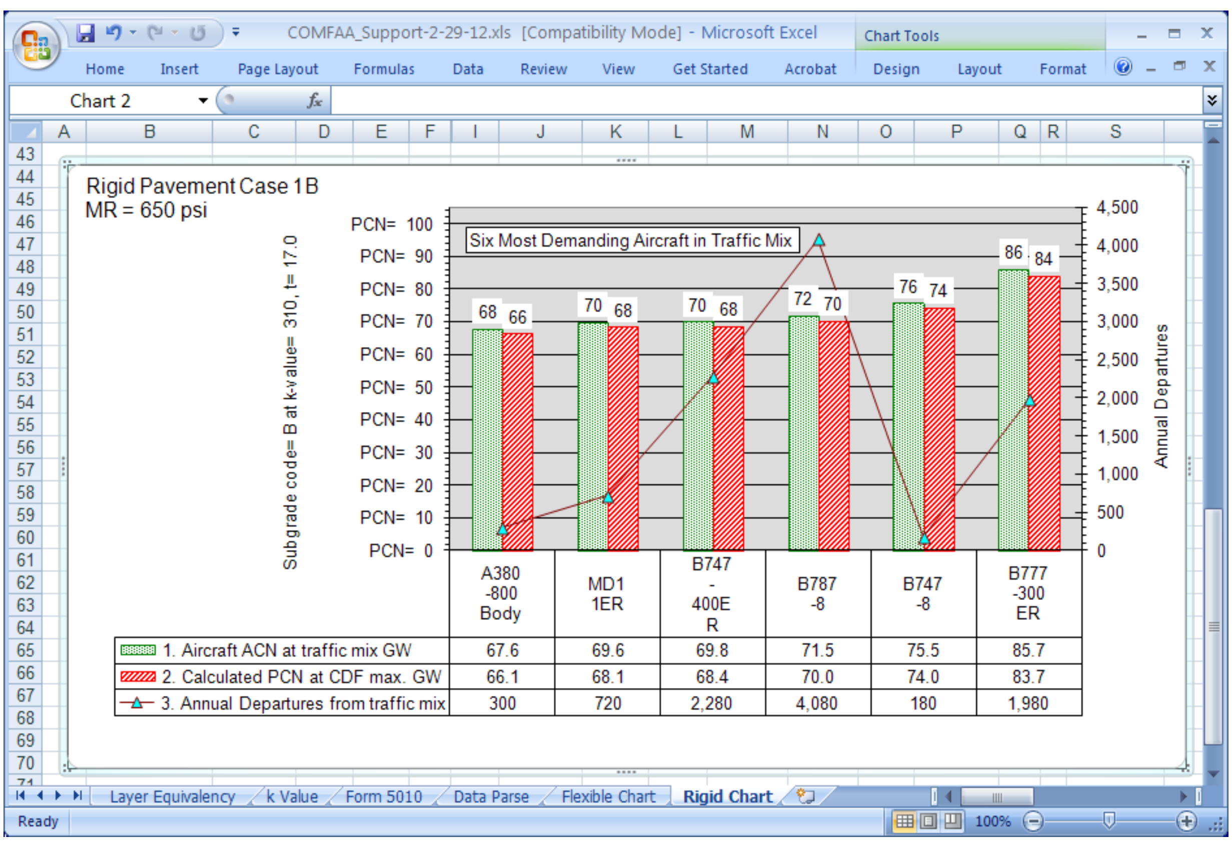


Figure 11 - Example 1B ACN and PCN Comparison

Example 1C - Reducing the Thickness

Pavement Characteristics

In this case the Modulus of Rupture is retained at 700 psi, but the thickness is reduced to 16 inches. Refer to Table 4 for the characteristics.

It is readily apparent from Figure 12 that the reduction in thickness of one inch has about the same effect as the reduction in the Modulus of Rupture from 700 to 650 psi in the previous example. Not only is the pavement overloaded as indicated by the inadequate PCN, but the total CDF being greater than one supports this conclusion.

These examples show the importance of verifying that the pavement parameters are correct. Similar variations may be seen for rigid pavement when other properties such as effective subgrade modulus are considered; however, errors in the traffic count are not nearly as pronounced. Although it might be acceptable to the airport authority to allow these operations, it will lead to reduced life or require increased maintenance.

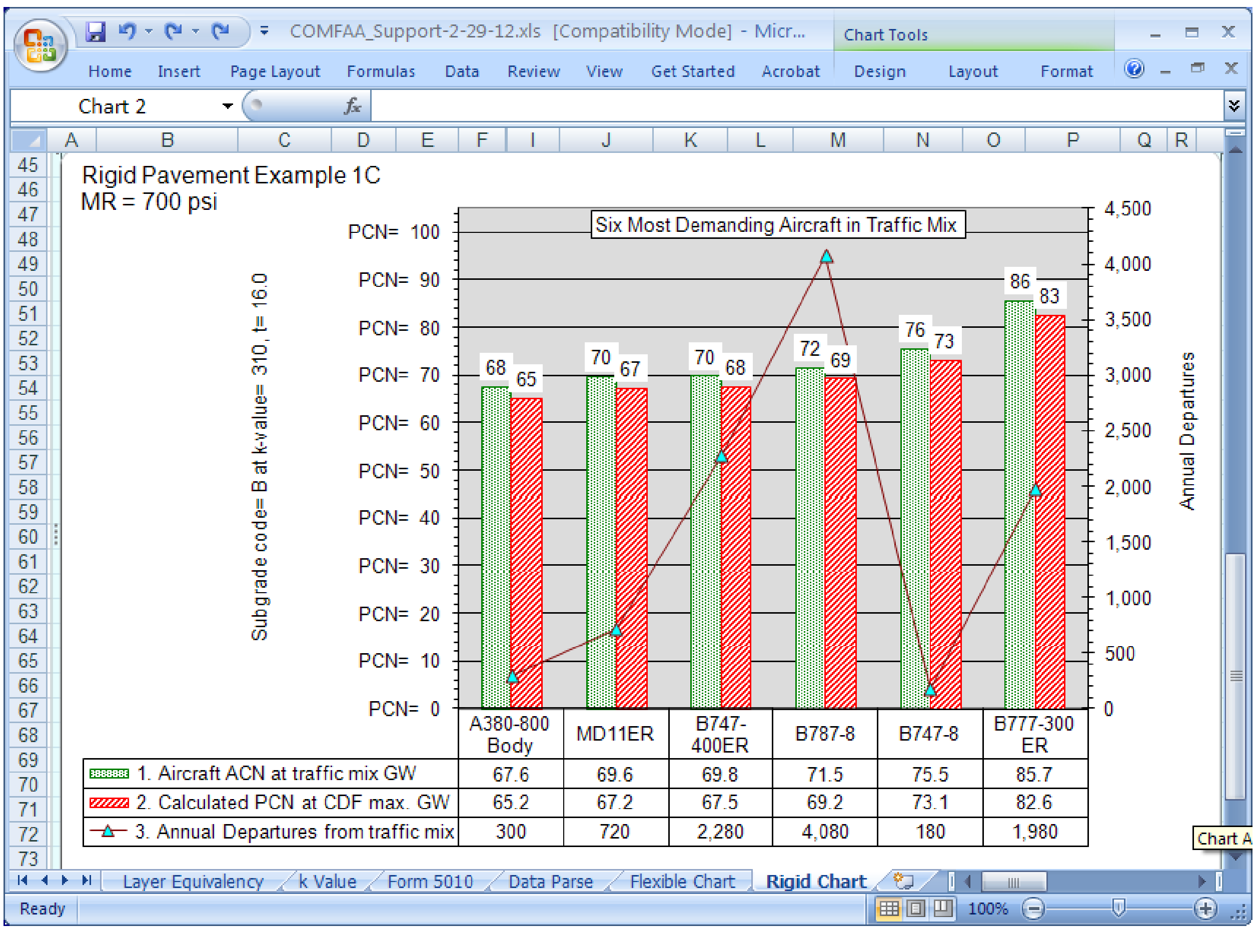


Figure 12 - Example 1C Results Table 2 PCN Values

Boeing

Example 2 - Flexible Pavement

Annual Traffic

The average annual traffic is contained in Table 1 for this runway.

Example 2A - Flexible Pavement Runway 11/29

Pavement Characteristics

Runway properties relevant to the analysis are shown in Table 5 for runway 11/29. This table contains FAA 5010 ratings, and the goal is to replace them with PCN's. This runway is classified as flexible, so there are a number of procedures required that are different from rigid pavement runways. While analysis of rigid pavement allowed modification of the subgrade modulus, in flexible pavement the evaluation thickness is altered.

Table 5 - Example 2A Pavement Properties

Overlay date:	1999		
Construction date:	1983		
Surface thickness	6	in.	P-401
Base	10	in.	P-209
Subbase	15	in.	P-154
Evaluation thickness	33	in.	
CBR	9		Code B
Remaining life	8	years	
FAA 5010 rating	D180	DT300	DDT650

Evaluation Thickness

The thickness of the flexible pavement section under consideration must be referenced to a standard flexible pavement section for evaluation purposes. If the pavement has excess or improved materials, the total pavement thickness may be adjusted according to the methods expressed in AC 150/5320-6D. Whereas in rigid pavement the subgrade modulus was adjusted, flexible pavement analysis requires that the reference thickness conform to rules developed from FAA and Corps of Engineers field testing.

The standard section is the total thickness requirement as calculated by the support spreadsheet, assuming minimum layer thickness for the asphalt surface, minimum base layer thickness of material and a variable thickness subbase layer. Two reference pavement sections are used according to the criteria of Table 6.

Table 6 - FAA Flexible Pavement Reference Layer Thickness

Structural Layer	Less than Four Wheels on Main Gear	Four or More Wheels on any Main Gear
Asphaltic Concrete (P-401)	3	5
High Quality Granular Base (P-209)	6	8

When no aircraft in the traffic mix have four or more wheels on a main gear, the minimum asphalt surface course thickness requirement is 3 inches and the minimum high quality crushed aggregate base course thickness requirement is 6 inches. When one or more aircraft in the traffic mix have four or more wheels on a main gear, the minimum asphalt surface course thickness requirement is 5 inches and the minimum high quality crushed aggregate base course thickness requirement is 8 inches. Reference thicknesses can be changed in cells B30 and B31 of the support spreadsheet (discussed later).

When there is not sufficient material to obtain the surface course thickness of 3 or 5 inches and/or the standard crushed aggregate base course thickness of 6 or 8 inches, the subbase thickness is reduced by using a slightly more conservative inverse of the layer equivalency factor for surface course material. In this situation, refer to the instructions in AC 150/5335-5B, Table A2-1.

Recommended equivalency factors for adjusting the thickness are shown in Table 7. Ranges of equivalency factors are shown rather than single values since variations in the quality of materials, construction techniques, and control can influence the equivalency factor.

Table 7 - FAA Flexible Pavement Equivalency Factors

Structural Item	Description	Range Convert to P-209	Recommended Convert to P-209	Range Convert to P-154	Recommended Convert to P-154
P-501	Portland Cement Concrete (PCC)	--	--	--	--
P-401	Plant Mix Bituminous Pavements (HMA)	1.2 to 1.6	1.6	1.7 to 2.3	2.3
P-403	Plant Mix Bituminous Pavements (HMA)	1.2 to 1.6	1.6	1.7 to 2.3	2.3
P-306	Econocrete Subbase Course (ESC)	1.2 to 1.6	1.2	1.6 to 2.3	1.6
P-304	Cement Treated Base Course (CTB)	1.2 to 1.6	1.2	1.6 to 2.3	1.6
P-212	Shell Base Course	--	--	--	--
P-213	Sand-Clay Base Course	--	--	--	--
P-220	Caliche Base Course	--	--	--	--
P-209	Crushed Aggregate Base Course	1.0	1.0	1.2 to 1.6	1.4
P-208	Aggregate Base Course	1.0	1.0	1.0 to 1.5	1.2
P-211	Lime Rock Base Course	1.0	1.0	1.0 to 1.5	1.2
P-301	Soil-Cement Base Course	n/a	--	1.0 to 1.5	1.2
P-154	Subbase Course	n/a	--	1.0	1.0
P-501	Portland Cement Concrete (PCC)	Range Convert to P-401 2.2 to 2.5, Recommended 2.5			

In the selection of equivalency factors, consideration should be given to the traffic using the pavement, total pavement thickness, and the thickness of the individual layer. For example, a thin layer in a pavement structure subjected to heavy loads spread over large areas will result in an equivalency factor near the low end of the range. Conversely, light loads on thick layers will call for equivalency factors near the upper end of the ranges. Notwithstanding, the recommended values are sufficient for most applications. Note that Items P-212, P-213, and P-220 have no equivalency factors listed, as they do not appear in the FAA equivalency spreadsheet.

The support spreadsheet of Figure 13 details the process of calculating the evaluation thickness. The P-401 layer in cell G6 of the excess is converted to P-209. Likewise, the excess amount of P-209 in cell G9 is converted to P-154.

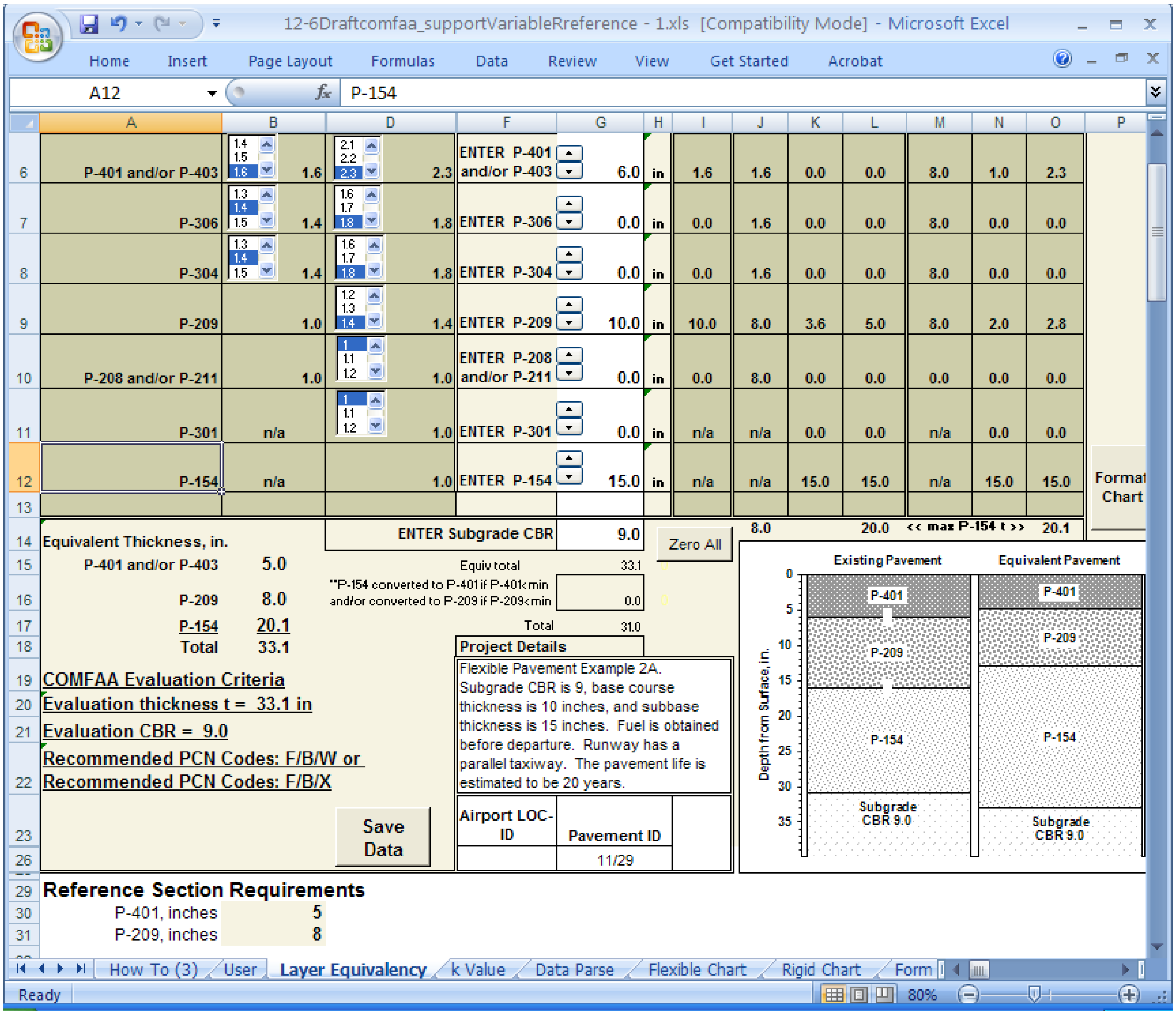


Figure 13 - Example 2A Pavement Layer Equivalency

Here is how the evaluation thickness is calculated with a standard layer thickness for four or more wheels:

P-401	6.0” – 5.0”	= 1.0” excess material
	1.0” x 1.6	= 1.6” to be added to P-209
P-209	10.0” – 8.0”	= 2.0” excess material
	2.0” x 1.4	= 2.8” to be added to P-154
	1.6” x 1.4	= 2.2” to be added to P-154
P-154		= 15.0”
Evaluation Thickness		= 5.0”+ 8.0” + 2.8” + 2.2” + 15.0” = 33.0”

Note that the thickness calculated in the support spreadsheet is slightly greater than as calculated manually. This is due to the total calculation being based on “subgrade up” rather than the more conventional “surface down” conversion as in cells L14 and O14. The FAA does not reference this method in the pavement design advisory circulars, but since it is in the FAA-supplied spreadsheet, it should be followed if it is significantly different. In this case, the 0.1 inch difference will be ignored for the PCN calculation.

PCN Calculation of Runway 11/29

After entering the traffic of Table 1 and the pavement characteristics of Table 5 into COMFAA (as shown in Figure 14), click the Details button when the calculation steps have finished.

Initially the pavement and traffic characteristics are displayed as output, such as in Figure 15, along with the recommended subgrade category.

Next, the input traffic data is shown as Figure 16 (Table 1 in the Details). Note the value of the 6D thicknesses, which are those calculated individually for each model according to the methods in AC 150/5320-6D. These numbers have no relation to the PCN calculation and are only shown for comparison to the evaluation thickness. However, it is expected that each of these values will be less than the evaluation thickness for a properly designed pavement.

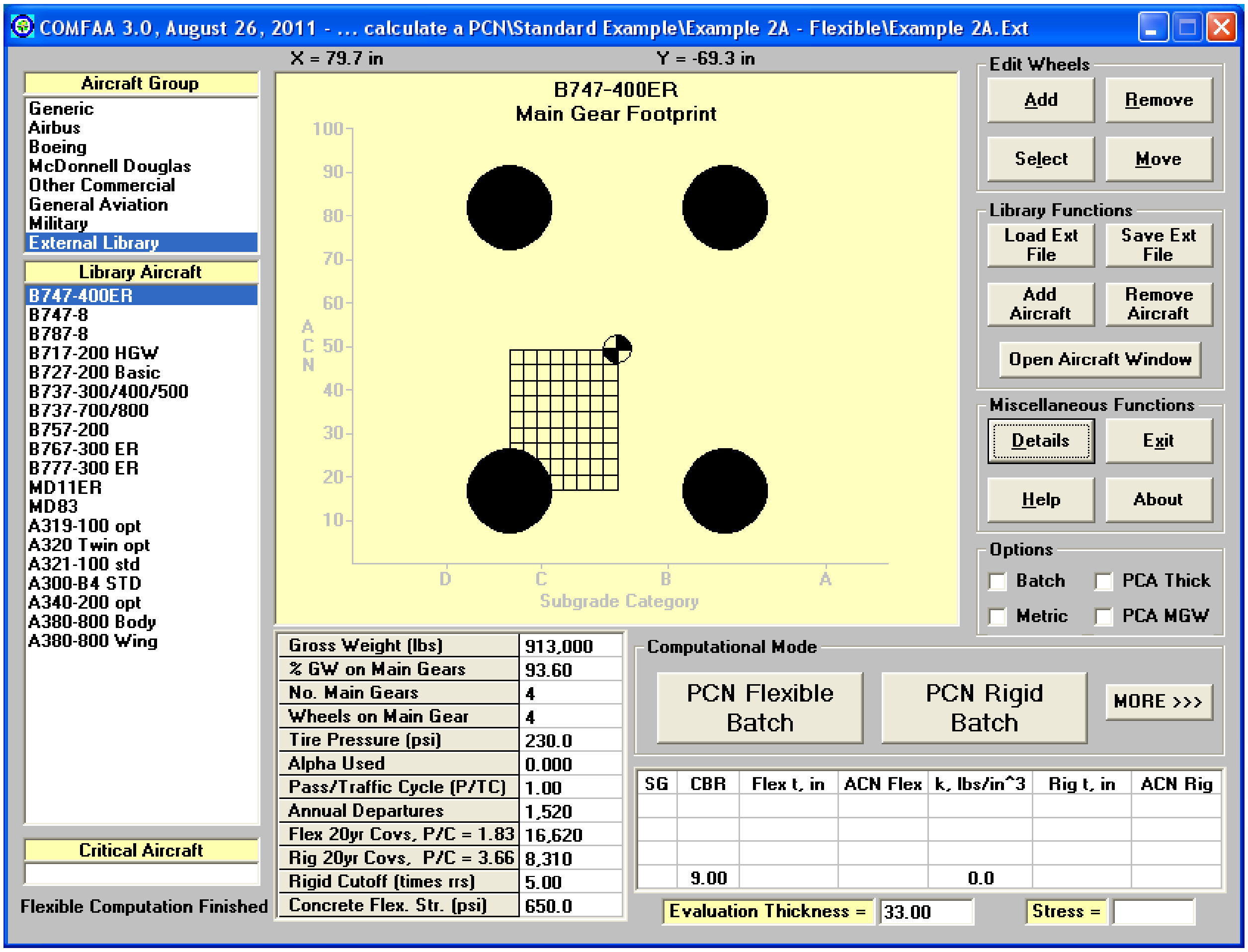


Figure 14 - Example 2A COMFAA Input Screen

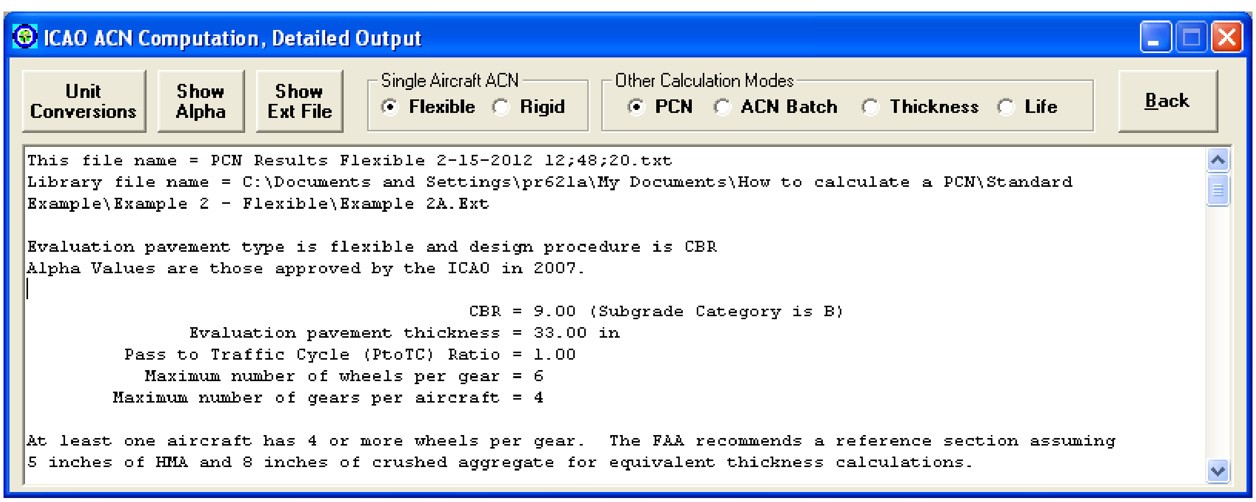
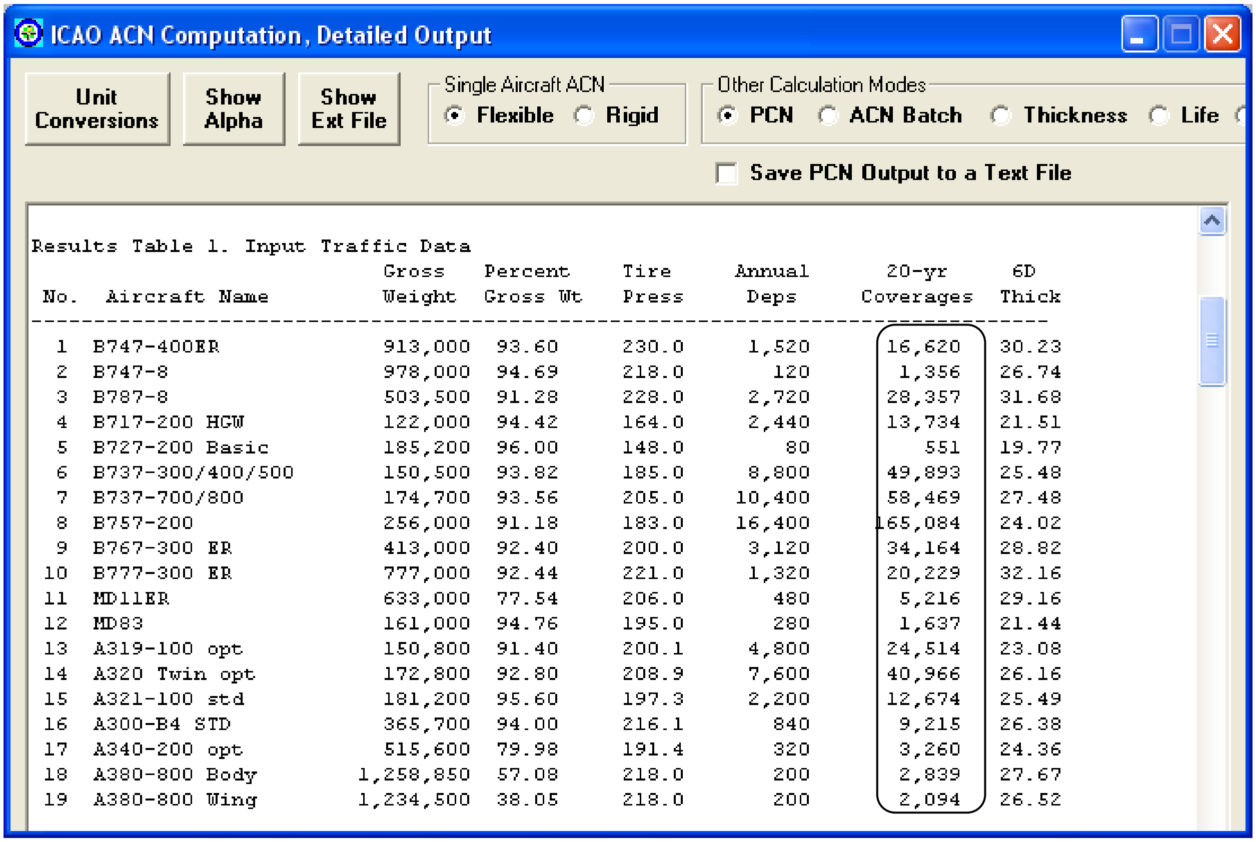


Figure 15 - Example 2A Initial Flexible Pavement Output Details



Results Table 1. Input Traffic Data

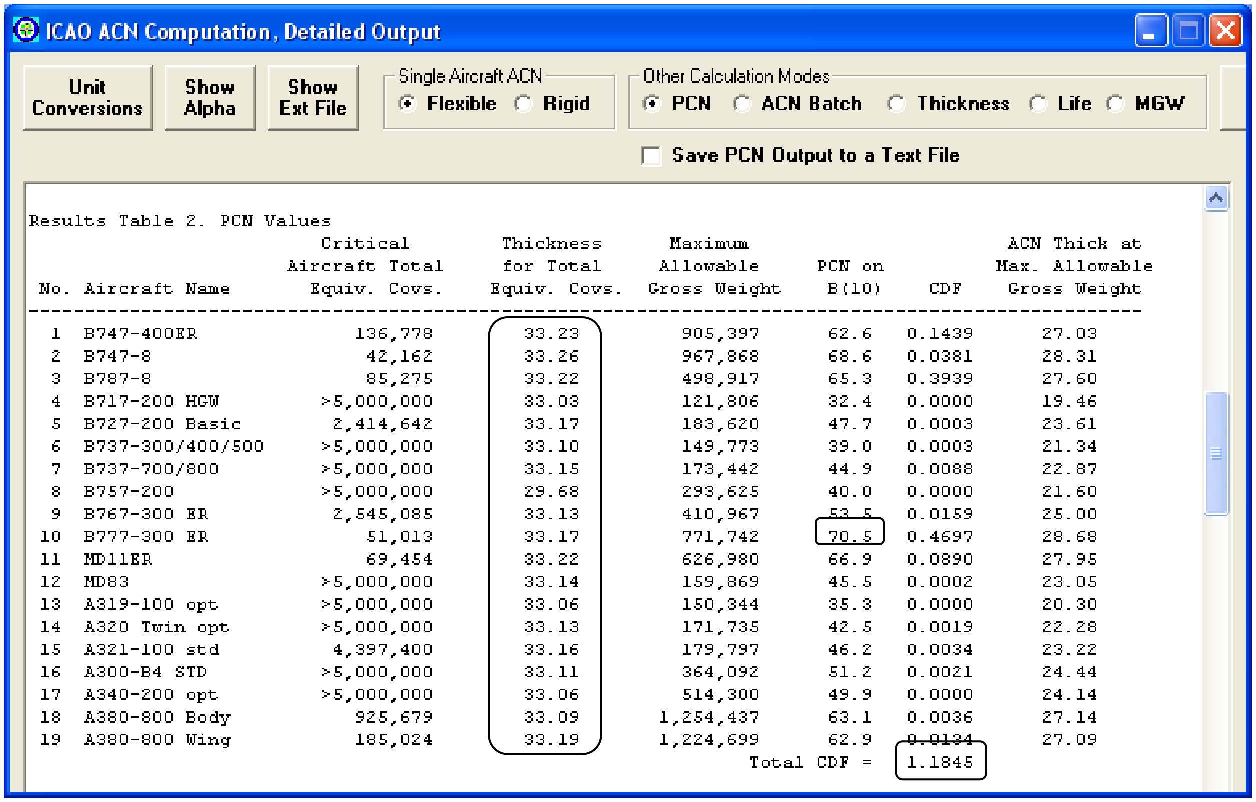
No.	Aircraft Name	Gross Weight	Percent Gross Wt	Tire Press	Annual Deps	20-yr Coverages	6D Thick
1	B747-400ER	913,000	93.60	230.0	1,520	16,620	30.23
2	B747-8	978,000	94.69	218.0	120	1,356	26.74
3	B787-8	503,500	91.28	228.0	2,720	28,357	31.68
4	B717-200 HGW	122,000	94.42	164.0	2,440	13,734	21.51
5	B727-200 Basic	185,200	96.00	148.0	80	551	19.77
6	B737-300/400/500	150,500	93.82	185.0	8,800	49,893	25.48
7	B737-700/800	174,700	93.56	205.0	10,400	58,469	27.48
8	B757-200	256,000	91.18	183.0	16,400	165,084	24.02
9	B767-300 ER	413,000	92.40	200.0	3,120	34,164	28.82
10	B777-300 ER	777,000	92.44	221.0	1,320	20,229	32.16
11	MD11ER	633,000	77.54	206.0	480	5,216	29.16
12	MD83	161,000	94.76	195.0	280	1,637	21.44
13	A319-100 opt	150,800	91.40	200.1	4,800	24,514	23.08
14	A320 Twin opt	172,800	92.80	208.9	7,600	40,966	26.16
15	A321-100 std	181,200	95.60	197.3	2,200	12,674	25.49
16	A300-B4 STD	365,700	94.00	216.1	840	9,215	26.38
17	A340-200 opt	515,600	79.98	191.4	320	3,260	24.36
18	A380-800 Body	1,258,850	57.08	218.0	200	2,839	27.67
19	A380-800 Wing	1,234,500	38.05	218.0	200	2,094	26.52

Figure 16 - Example 2A Results Table 1 Input Traffic Data

The 777-300ER has the highest PCN of 70.5 FB, which is shown in the table of Figure 17. Further examination of this table reveals that the pavement is overloaded by several criteria. The first indication is in the fourth column labeled “Thickness for Total Equivalent Coverages” in which virtually all aircraft require more than the equivalent thickness of 33.0 inches. However, with thicknesses being near the evaluation thickness of 33.0 inches, this pavement could also be considered marginally capable for the traffic.

The second indication is in the last column that shows a total CDF greater than 1.0000 at 1.1845. Although the program has calculated a range of PCN values, with the total CDF above 1.00, further engineering work needs to be done. Solutions are discussed at the end of this example.

Table 3 of the COMFAA detailed output contains the comma separated data necessary to graphically show the PCN. Its main purpose is to provide data for graphical illustrations of the output. As was done for previous examples, highlight the entire table, including the title line, and paste into cell B5 in the Data Parse worksheet of the support spreadsheet. These tables not shown here since the process is the same as that already delineated.



Results Table 2. PCN Values

No.	Aircraft Name	Critical Aircraft Total Equiv. Covs.	Thickness for Total Equiv. Covs.	Maximum Allowable Gross Weight	PCN on B(10)	CDF	ACN Thick at Max. Allowable Gross Weight
1	B747-400ER	136,778	33.23	905,397	62.6	0.1439	27.03
2	B747-8	42,162	33.26	967,868	68.6	0.0381	28.31
3	B787-8	85,275	33.22	498,917	65.3	0.3939	27.60
4	B717-200 HGW	>5,000,000	33.03	121,806	32.4	0.0000	19.46
5	B727-200 Basic	2,414,642	33.17	183,620	47.7	0.0003	23.61
6	B737-300/400/500	>5,000,000	33.10	149,773	39.0	0.0003	21.34
7	B737-700/800	>5,000,000	33.15	173,442	44.9	0.0088	22.87
8	B757-200	>5,000,000	29.68	293,625	40.0	0.0000	21.60
9	B767-300 ER	2,545,085	33.13	410,967	53.5	0.0159	25.00
10	B777-300 ER	51,013	33.17	771,742	70.5	0.4697	28.68
11	MD11ER	69,454	33.22	626,980	66.9	0.0890	27.95
12	MD83	>5,000,000	33.14	159,869	45.5	0.0002	23.05
13	A319-100 opt	>5,000,000	33.06	150,344	35.3	0.0000	20.30
14	A320 Twin opt	>5,000,000	33.13	171,735	42.5	0.0019	22.28
15	A321-100 std	4,397,400	33.16	179,797	46.2	0.0034	23.22
16	A300-B4 STD	>5,000,000	33.11	364,092	51.2	0.0021	24.44
17	A340-200 opt	>5,000,000	33.06	514,300	49.9	0.0000	24.14
18	A380-800 Body	925,679	33.09	1,254,437	63.1	0.0036	27.14
19	A380-800 Wing	185,024	33.19	1,224,699	62.9	0.0134	27.09
					Total CDF =	1.1845	

Figure 17 - Example 2A Results Table 2 PCN Values

Both the -6D and CDF thickness requirements are seen in comparison to the evaluation thickness in Figure 18. Comparison of these values shows the expectation of pavement thickness for the traffic mix. A CDF that is greater than the evaluation thickness indicates that the pavement will not be sufficient, at least for the period of time desired. Conversely, CDF values that are less than the evaluation thickness are a sign that the pavement that will be suitable for the traffic.

The “Maximum Allowable Aircraft Gross Weight from CDF” in Figure 18 is the same as the fifth column in Figure 17, and it is a precursor of the PCN calculation in that the PCN is simply the ACN at that weight. It is determined by assuming that that aircraft is critical and calculating the effect of the others in the traffic mix by use of the CDF procedure. In this example the allowable weights are slightly less than the “Aircraft GW from Traffic Mix” (from Figure 20), indicating that each will have an ACN that exceeds its respective PCN.

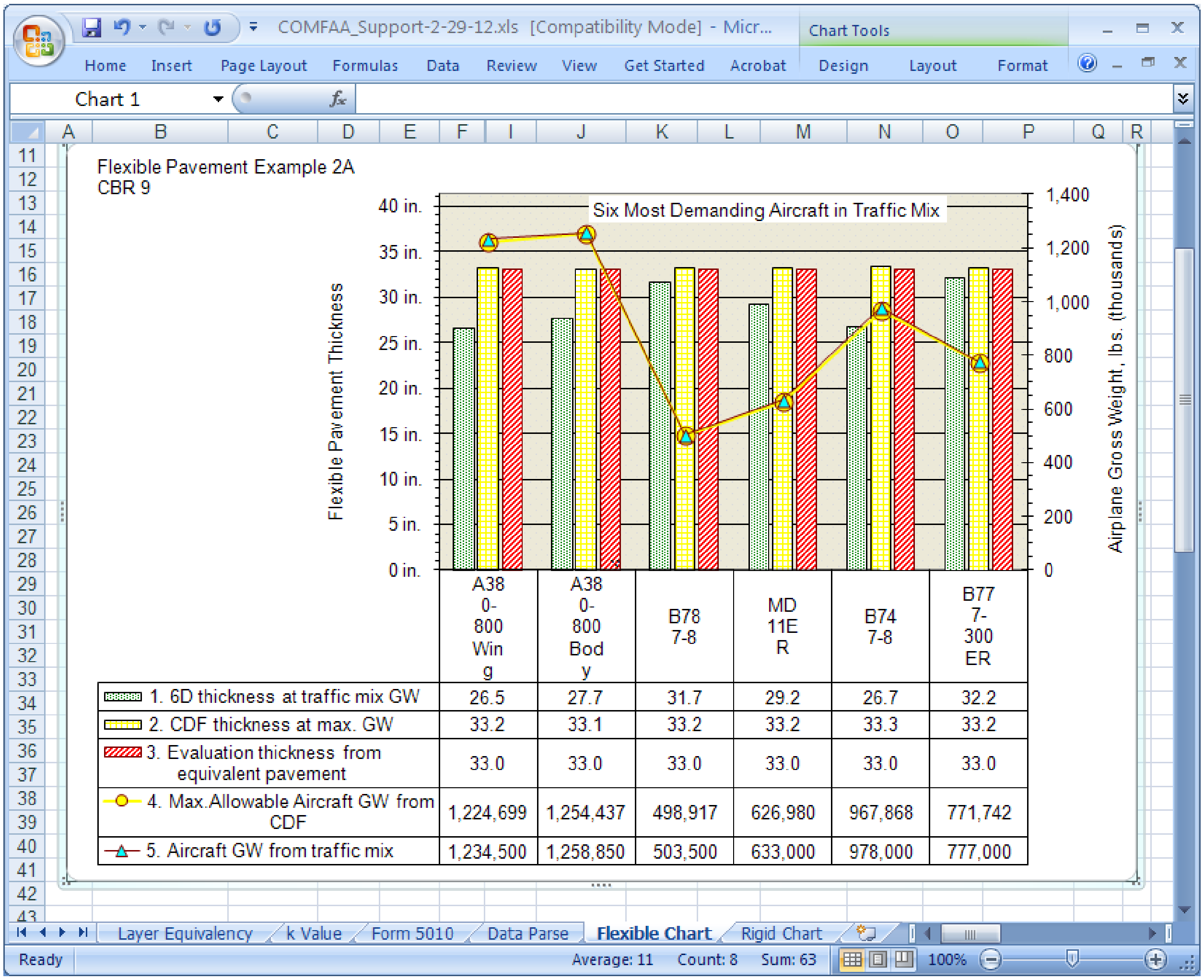


Figure 18 - Example 2A Thickness and Maximum Weight Requirements

Graphic comparisons of ACN and PCN are seen in Figure 19 for the six most demanding aircraft of the traffic mix. Although the indicated PCN of 71 FBWT is slightly less than the ACN, it may be close enough for the airport authority to be acceptable.

It is very important to realize that the PCN calculation is based on a combination of factors, including pavement thickness, equivalency factors, CBR, and traffic projections. Each will affect the final number in various degrees, so the PCN should be looked at as an estimation of the pavement strength and not as a precisely derived value. This allows judgment of the airport engineer to be the final determination as to the acceptability of the pavement for the traffic.

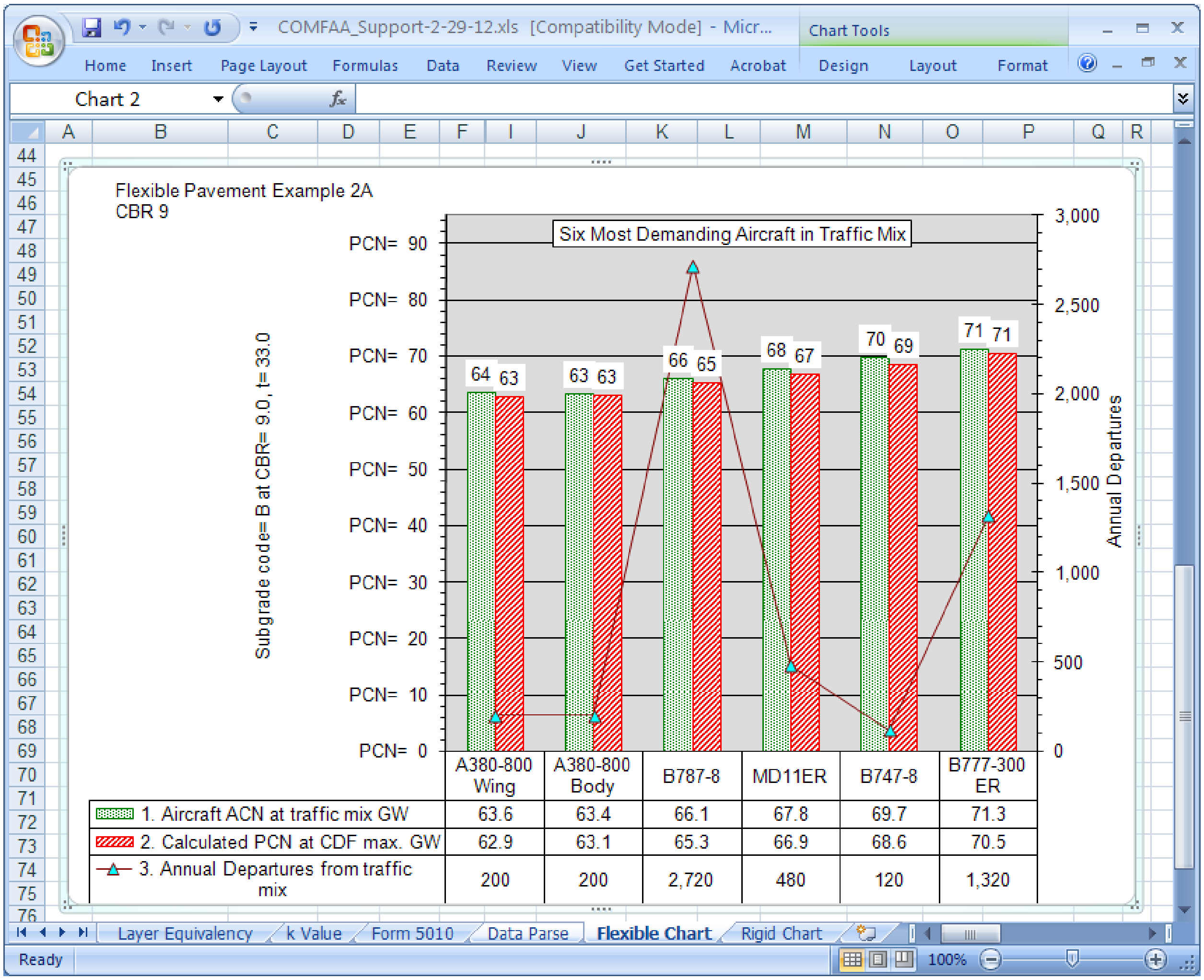


Figure 19 - Example 2A ACN and PCN Comparison

Table 8 presents a comparison of allowable gross weights according to the FAA method and the PCN method. As was the case in Rigid Pavement Example 1A, a number of models could not be rated with the FAA method, but the strength rating is readily available by using the PCN results.

Table 8 - Example 2A Allowable Gross Weights

Aircraft	MTW	D180	DT300	DDT650	PCN 71 FB
	(1000 lb)	(1000 lb)	(1000 lb)	(1000 lb)	(1000 lb)
B777-300ER	777	--	--	--	772
B747-8	978	--	--	650	992
B787-8	504	--	300	--	530
B727-200	186	180	--	--	249
MD-11	633	--	--	--	655
B747-400ER	913	--	--	650	991
A380	1,234	--	--	--	1,353

Example 2B - Adding an Overlay

If it is determined that the pavement strength is not sufficient, then an overlay is may be in order. Pavement characteristics are not shown here, but simply increase the P-401 thickness of Table 5 with a 2 inch overlay to an 8 inch total surface thickness. The total pavement thickness, shown in Figure 20, increases over 4 inches from 33.1 to 37.7 due to the effect of the conversion factors.

Figure 21 shows that the PCN greatly exceeds the ACN required for the increased thickness; however, use of these results requires careful consideration. Notice the large number of aircraft with equivalent coverages that are >5,000,000 and have corresponding CDF values at 0.0000. This means that the contribution of these aircraft to the reduction in pavement life is very minimal at this thickness. The total CDF is less than 0.01, giving strong indication that the pavement is over designed for the traffic mix, and this is also a sign that this pavement rating of PCN 104 is too high. With the very small total CDF, the pavement is not stressed enough to yield a valid rating.

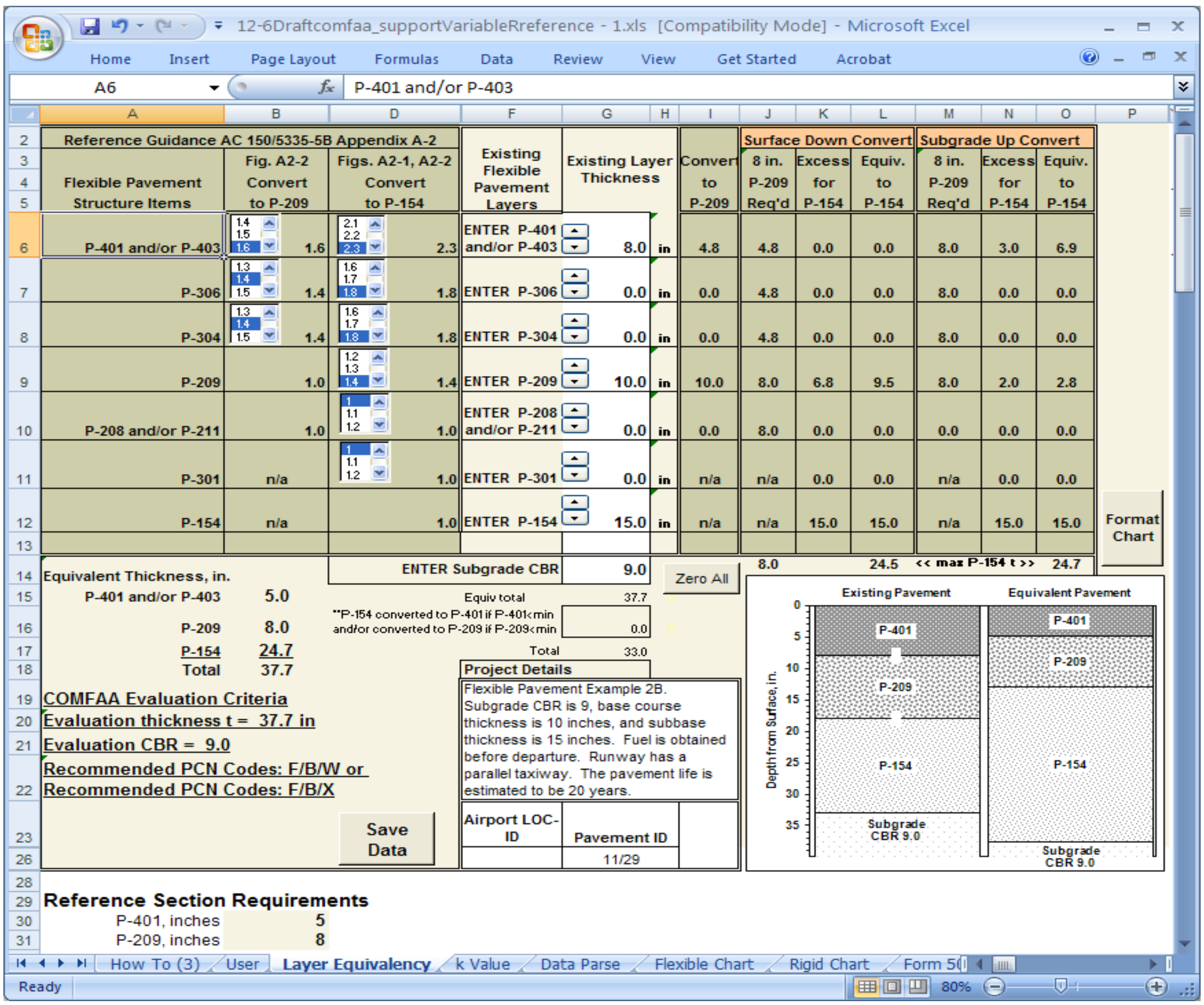


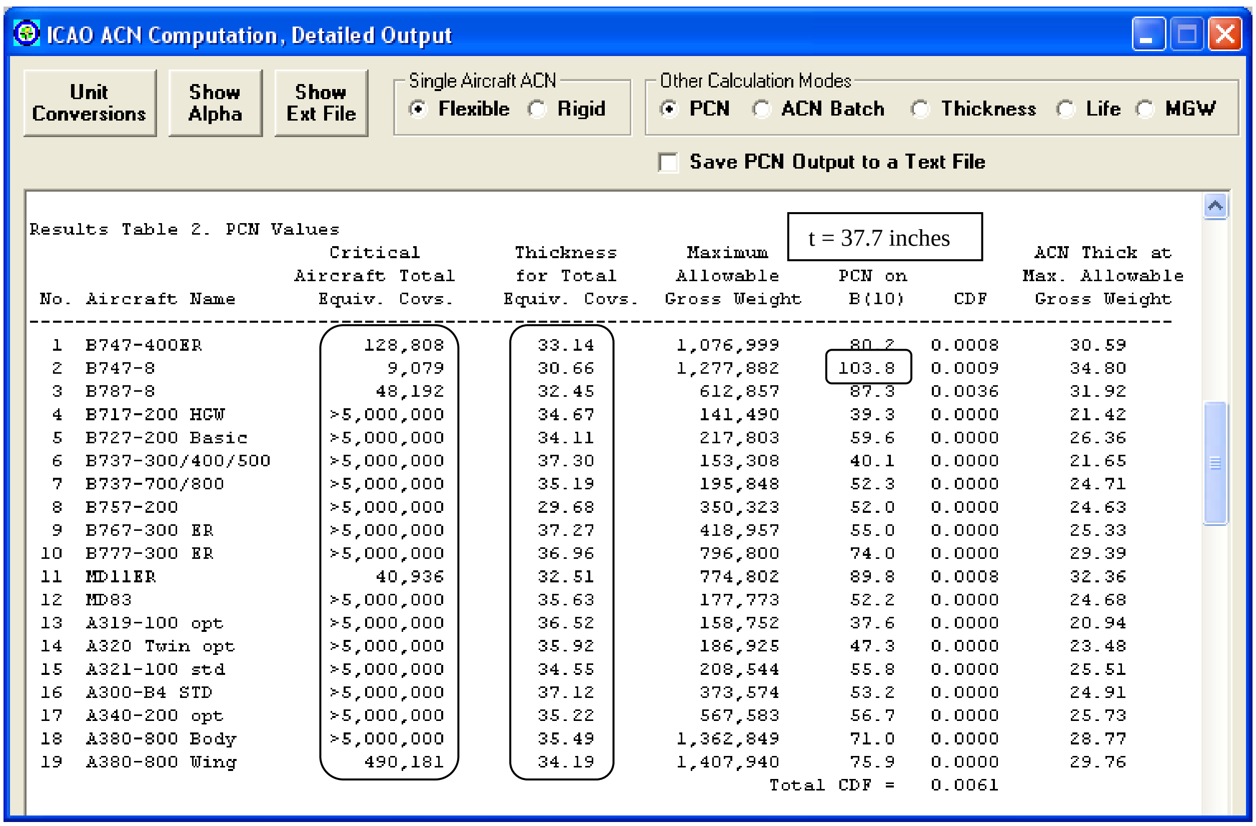
Figure 20 - Example 2B Evaluation Thickness Change

Another indication of overdesign is that the thicknesses for equivalent coverages are widely dispersed, as opposed to that in Figure 17 where the there is little scatter. When this level of dispersion occurs, and with the minimal CDF level it is best to make adjustments such as reducing the analysis thickness. Accordingly, for a design thickness of 34.0 inches like in Figure 22, the equivalent coverage thickness is much more uniform, especially for aircraft that are not at >5,000,000 equivalent coverages. The CDF in this case reflects that the pavement is approaching the desired value of 1.0.

Finally, the PCN in this case is at 74 FB, which is adequate for the traffic, as seen graphically in Figure 23.

It is not suggested that the additional thickness of less than 2 inches can be placed, but that the airport authority now has the ability to set a PCN within a range from 74 to that approaching 104. This covers future situations in which the traffic volume might increase, and the airport authority will still have confidence in the pavement strength, regardless of the volume increase in a critical aircraft.

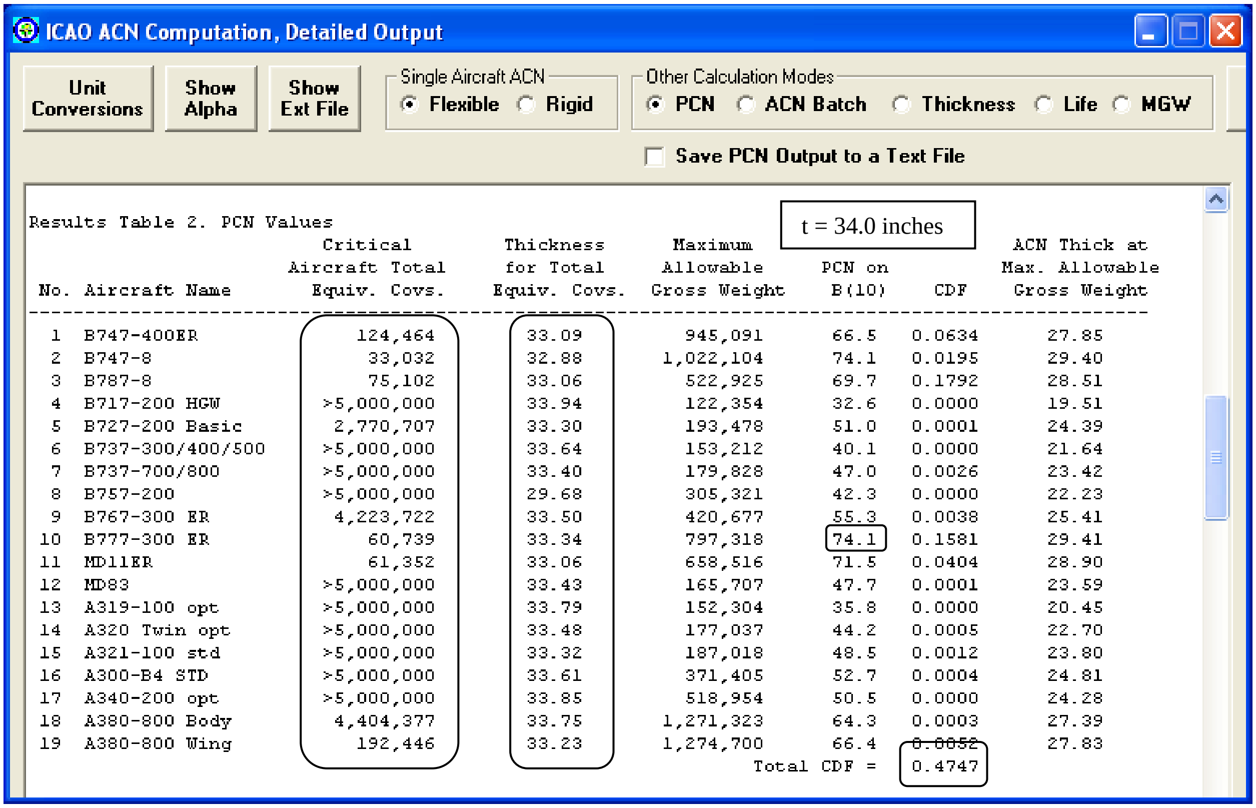
By placing the overlay, the pavement is considered to have a new 20-year life; however, it is always wise to review calculations sooner in that current prevailing conditions might change.



Results Table 2. PCN Values

No.	Aircraft Name	Critical Aircraft Total Equiv. Covs.	Thickness for Total Equiv. Covs.	Maximum Allowable Gross Weight	PCN on B(10)	CDF	ACN Thick at Max. Allowable Gross Weight
1	B747-400ER	128,808	33.14	1,076,999	80.2	0.0008	30.59
2	B747-8	9,079	30.66	1,277,882	103.8	0.0009	34.80
3	B787-8	48,192	32.45	612,857	87.3	0.0036	31.92
4	B717-200 HGW	>5,000,000	34.67	141,490	39.3	0.0000	21.42
5	B727-200 Basic	>5,000,000	34.11	217,803	59.6	0.0000	26.36
6	B737-300/400/500	>5,000,000	37.30	153,308	40.1	0.0000	21.65
7	B737-700/800	>5,000,000	35.19	195,848	52.3	0.0000	24.71
8	B757-200	>5,000,000	29.68	350,323	52.0	0.0000	24.63
9	B767-300 ER	>5,000,000	37.27	418,957	55.0	0.0000	25.33
10	B777-300 ER	>5,000,000	36.96	796,800	74.0	0.0000	29.39
11	MD11ER	40,936	32.51	774,802	89.8	0.0008	32.36
12	MD83	>5,000,000	35.63	177,773	52.2	0.0000	24.68
13	A319-100 opt	>5,000,000	36.52	158,752	37.6	0.0000	20.94
14	A320 Twin opt	>5,000,000	35.92	186,925	47.3	0.0000	23.48
15	A321-100 std	>5,000,000	34.55	208,544	55.8	0.0000	25.51
16	A300-B4 STD	>5,000,000	37.12	373,574	53.2	0.0000	24.91
17	A340-200 opt	>5,000,000	35.22	567,583	56.7	0.0000	25.73
18	A380-800 Body	>5,000,000	35.49	1,362,849	71.0	0.0000	28.77
19	A380-800 Wing	490,181	34.19	1,407,940	75.9	0.0000	29.76
					Total CDF =	0.0061	

Figure 21 - Example 2B Results Table 2 PCN Values



Results Table 2. PCN Values

No.	Aircraft Name	Critical Aircraft Total Equiv. Covs.	Thickness for Total Equiv. Covs.	Maximum Allowable Gross Weight	PCN on B(10)	CDF	ACN Thick at Max. Allowable Gross Weight
1	B747-400ER	124,464	33.09	945,091	66.5	0.0634	27.85
2	B747-8	33,032	32.88	1,022,104	74.1	0.0195	29.40
3	B787-8	75,102	33.06	522,925	69.7	0.1792	28.51
4	B717-200 HGW	>5,000,000	33.94	122,354	32.6	0.0000	19.51
5	B727-200 Basic	2,770,707	33.30	193,478	51.0	0.0001	24.39
6	B737-300/400/500	>5,000,000	33.64	153,212	40.1	0.0000	21.64
7	B737-700/800	>5,000,000	33.40	179,828	47.0	0.0026	23.42
8	B757-200	>5,000,000	29.68	305,321	42.3	0.0000	22.23
9	B767-300 ER	4,223,722	33.50	420,677	55.3	0.0038	25.41
10	B777-300 ER	60,739	33.34	797,318	74.1	0.1581	29.41
11	MD11ER	61,352	33.06	658,516	71.5	0.0404	28.90
12	MD83	>5,000,000	33.43	165,707	47.7	0.0001	23.59
13	A319-100 opt	>5,000,000	33.79	152,304	35.8	0.0000	20.45
14	A320 Twin opt	>5,000,000	33.48	177,037	44.2	0.0005	22.70
15	A321-100 std	>5,000,000	33.32	187,018	48.5	0.0012	23.80
16	A300-B4 STD	>5,000,000	33.61	371,405	52.7	0.0004	24.81
17	A340-200 opt	>5,000,000	33.85	518,954	50.5	0.0000	24.28
18	A380-800 Body	4,404,377	33.75	1,271,323	64.3	0.0003	27.39
19	A380-800 Wing	192,446	33.23	1,274,700	66.4	0.0052	27.83
					Total CDF =	0.4747	

Figure 22 - Example 2B Results, Table 2 Adjusted PCN Values

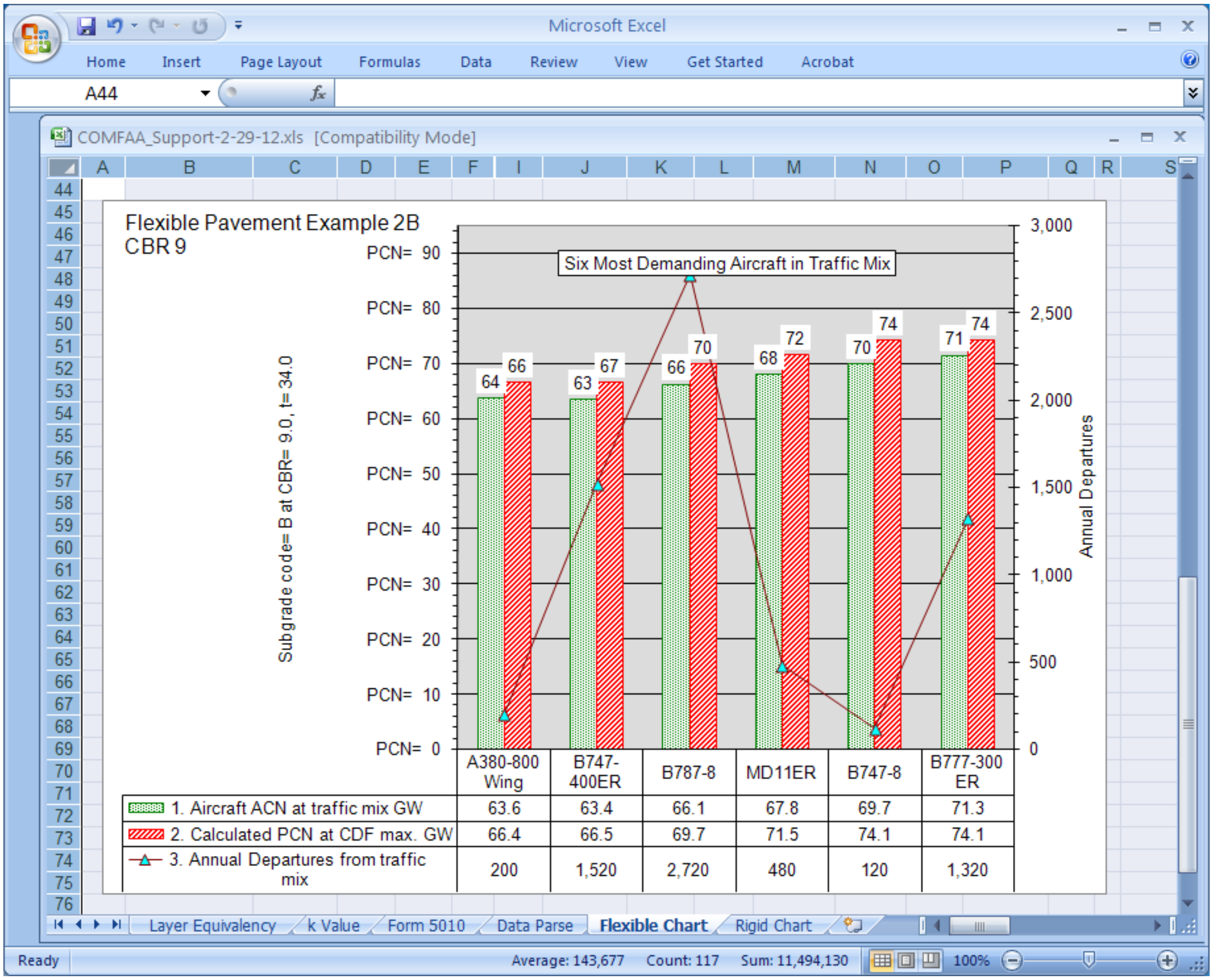


Figure 23 - Example 2B ACN and PCN Comparison

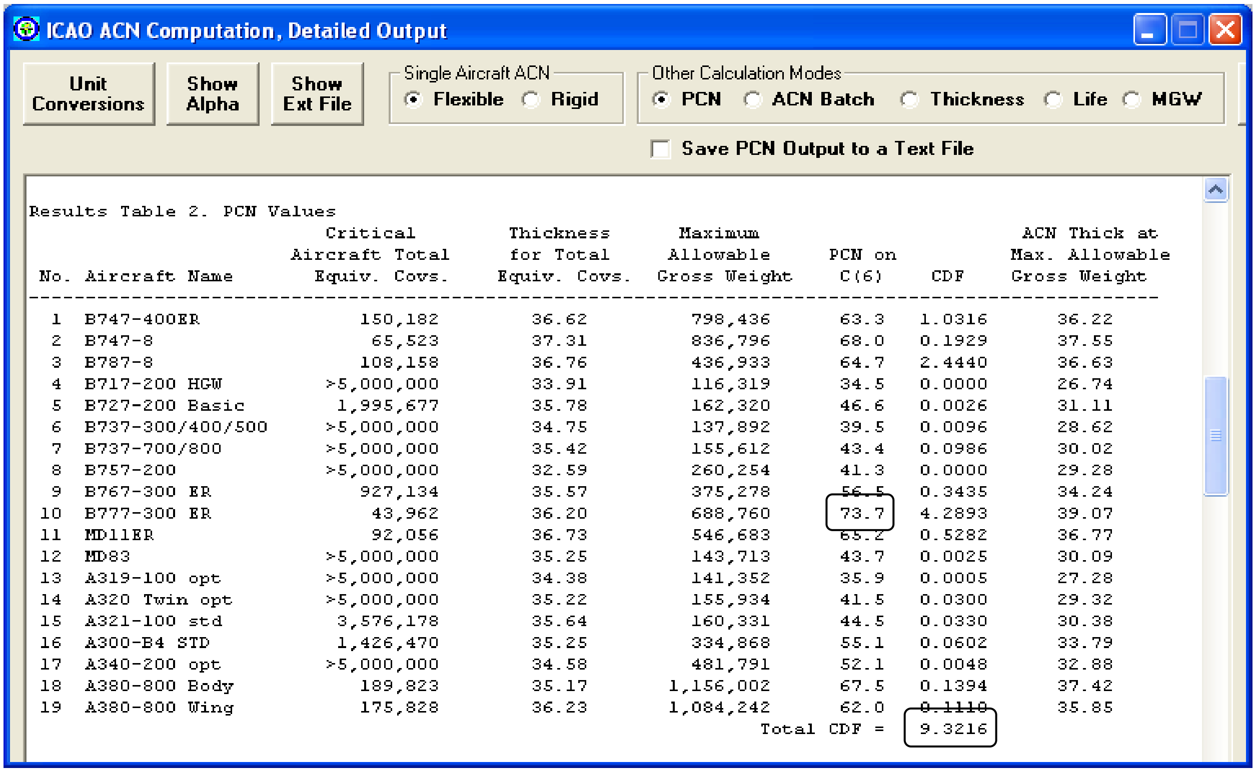
Example 2C - Reducing the CBR

Pavement Characteristics

Runway properties relevant to the analysis are shown in Table 5 for runway 11/29, but the CBR has been reduced from 9 to 8. While there is no change in the evaluation thickness of 33 inches, the subgrade code is now C.

With the same traffic as in Example 2A, Figure 26 shows that the PCN is reduced to 73 FC, while the critical aircraft ACN is at 89 FC. There are two other indications that the pavement is overloaded. The first is that the thickness for total equivalent coverages exceeds the design thickness of 33.0 inches. The second is that the total CDF is much greater than 1.00.

Graphical representation of the PCN versus ACN is shown in Figure 25. From this, it is obvious that the correct CBR determination is one of the critical parameters for this analysis.



Results Table 2. PCN Values

No.	Aircraft Name	Critical Aircraft Total Equiv. Covs.	Thickness for Total Equiv. Covs.	Maximum Allowable Gross Weight	PCN on C(6)	CDF	ACN Thick at Max. Allowable Gross Weight
1	B747-400ER	150,182	36.62	798,436	63.3	1.0316	36.22
2	B747-8	65,523	37.31	836,796	68.0	0.1929	37.55
3	B787-8	108,158	36.76	436,933	64.7	2.4440	36.63
4	B717-200 HGW	>5,000,000	33.91	116,319	34.5	0.0000	26.74
5	B727-200 Basic	1,995,677	35.78	162,320	46.6	0.0026	31.11
6	B737-300/400/500	>5,000,000	34.75	137,892	39.5	0.0096	28.62
7	B737-700/800	>5,000,000	35.42	155,612	43.4	0.0986	30.02
8	B757-200	>5,000,000	32.59	260,254	41.3	0.0000	29.28
9	B767-300 ER	927,134	35.57	375,278	56.5	0.3435	34.24
10	B777-300 ER	43,962	36.20	688,760	73.7	4.2893	39.07
11	MD11ER	92,056	36.73	546,683	65.2	0.5282	36.77
12	MD83	>5,000,000	35.25	143,713	43.7	0.0025	30.09
13	A319-100 opt	>5,000,000	34.38	141,352	35.9	0.0005	27.28
14	A320 Twin opt	>5,000,000	35.22	155,934	41.5	0.0300	29.32
15	A321-100 std	3,576,178	35.64	160,331	44.5	0.0330	30.38
16	A300-B4 STD	1,426,470	35.25	334,868	55.1	0.0602	33.79
17	A340-200 opt	>5,000,000	34.58	481,791	52.1	0.0048	32.88
18	A380-800 Body	189,823	35.17	1,156,002	67.5	0.1394	37.42
19	A380-800 Wing	175,828	36.23	1,084,242	62.0	0.1110	35.85
					Total CDF =	9.3216	

Figure 24 - Example 2C Results Table 2 PCN

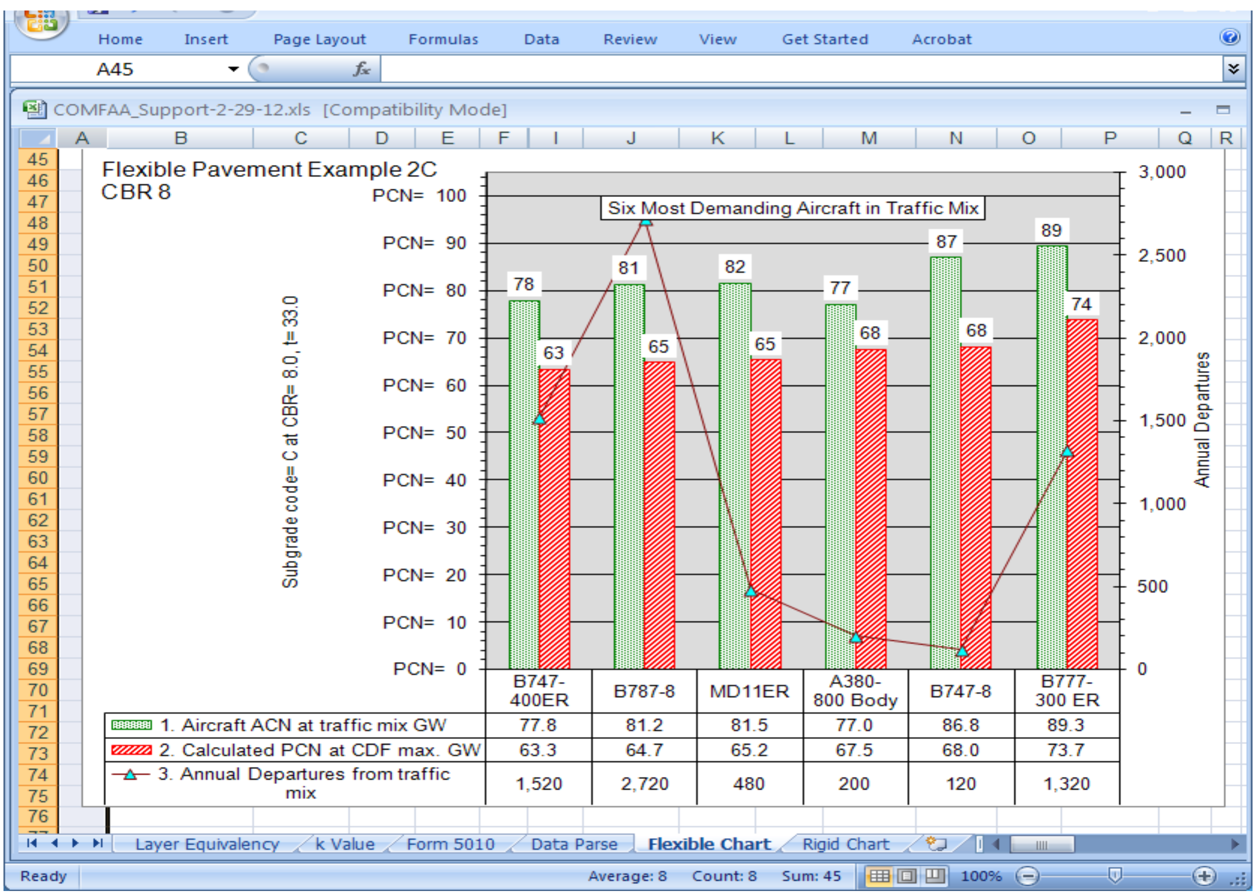


Figure 25 - Example 2C ACN and PCN Comparison

Example 3 - Composite Pavement

Annual Traffic

This airport has one runway – 17/35, and it is composed of several built up layers of mixed properties. The section analyzed is in the middle of the runway, so that any pavement strength issues must be addressed. The airport authority has reported the average annual traffic as seen in Table 9.

Table 9 - Example 3 Traffic

Aircraft	Gear Type	Gross Weight (lb)	Average Annual Departures
A319-100	D	150,000	9,500
A320 Bogie	2D	167,300	7,200
A330-200	2D	469,000	3,700
B727-200C	D	172,000	600
B737-300/500	D	140,000	11,300
B737-700	D	153,500	32,120
B737-800	D	173,000	40,150
B747-400B	2D/2D2	873,000	660
B757-200	2D	250,000	1,095
B767-200	2D	335,000	460
B767-300	2D	271,000	28,105
B767-300 ER	2D	409,000	660
B767-400 ER	2D	451,000	1,490
B777-200	3D	537,000	720
B777-200 ER	3D	634,500	770
DC10-10	2D	443,000	1,200
DC9-51	D	121,000	820
MD83	D	150,500	2,555
MD90	D	157,000	19,400
MD11ER	2D/D1	621,000	700

Example 3A - Composite Pavement Runway 17/35

Pavement Characteristics

Runway properties relevant to the analysis are shown in Table 10 for runway 17/35. This runway is classified as flexible because of the surface composition, but it is composed of layers that differentiate it from the typical rigid or flexible runway. The primary difference is that the PCC layer lies directly on the subgrade, beneath the rest of the layers, making calculation of the equivalent thicknesses somewhat unique.

Application of the equivalency factors for composite pavement sections is not covered in AC 150/5335-5B, so it was required that consultation with the FAA be utilized. Their recommendation was to add all like layers before the equivalency conversions, and then treat the pavement as is normally done for either flexible or rigid. In this case add all like pavements together to determine equivalencies.

Table 7 recommends conversion of P-501 to P-401 by a factor of 2.5. This results in a P-401 equivalent thickness of:

P-501	6.0” x 2.5	=	15.0” P-401
P-401	4.0” + 2.0” + 15.0”	=	21.0” P-401

Figure 26 shows the evaluation thickness is 53.5 inches for this pavement structure, with the PCC layer contributing 15 inches, as calculated above. The total evaluation thickness is based on the “Subgrade up Convert”, rendering it slightly thicker than if the more conventional “Surface Down Convert” was utilized. The conversions are determined like this:

P-401	21.0” - 5.0”	=	16.0” excess material
	16.0” x 1.6	=	25.6” convert to P-209
	(25.6” - 8.0”)/1.6	=	11.0” excess for P-154
	11.0” x 2.3	=	25.3” to be added to P-154
P-304	4.0” x 1.6	=	6.4” to be added to P-154
P-209	6.0” x 1.4	=	8.4” to be added to P-154
P-154	25.3”+6.4”+8.4”	=	40.1”
Subgrade Down Convert		=	5.0”+ 8.0” + 40.1” = 53.1”
Subgrade Up Convert (details not shown)		=	5.0”+ 8.0” + 40.5” = 53.5”

Table 10 - Example 3A Pavement Properties

Runway:	17/35		
Overlay date:	1999		
Construction date:	Varies		
Surface HMA	4	in.	P-401
Base CTB	4	in.	P-304
Base HMA	2	in.	P-401
Subbase	6	in.	P-209
Subbase PCC	6	in.	P-501
Evaluation thickness	53.5	in.	Figure 28
CBR	4		Code D
Remaining life	7	years	

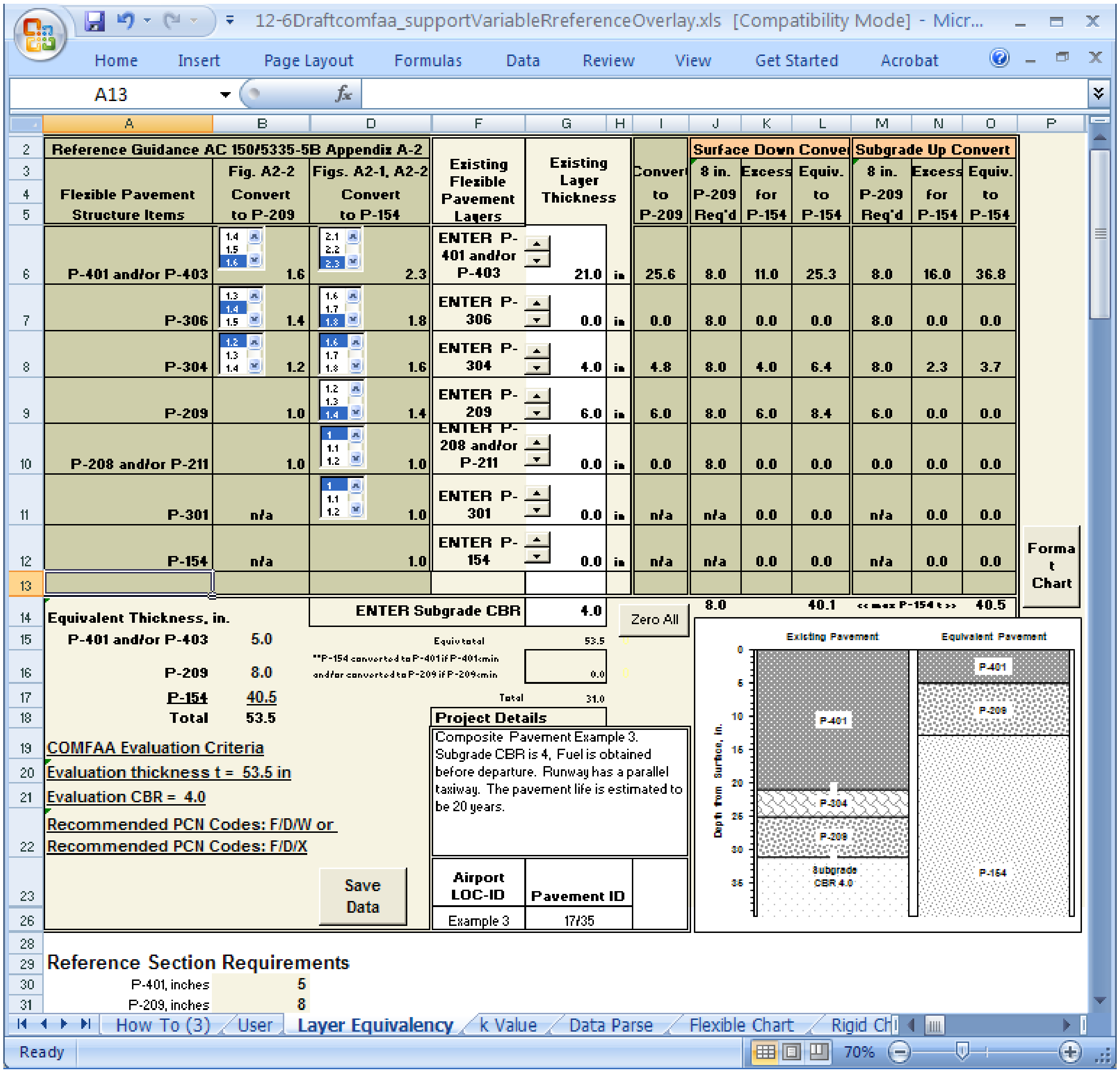
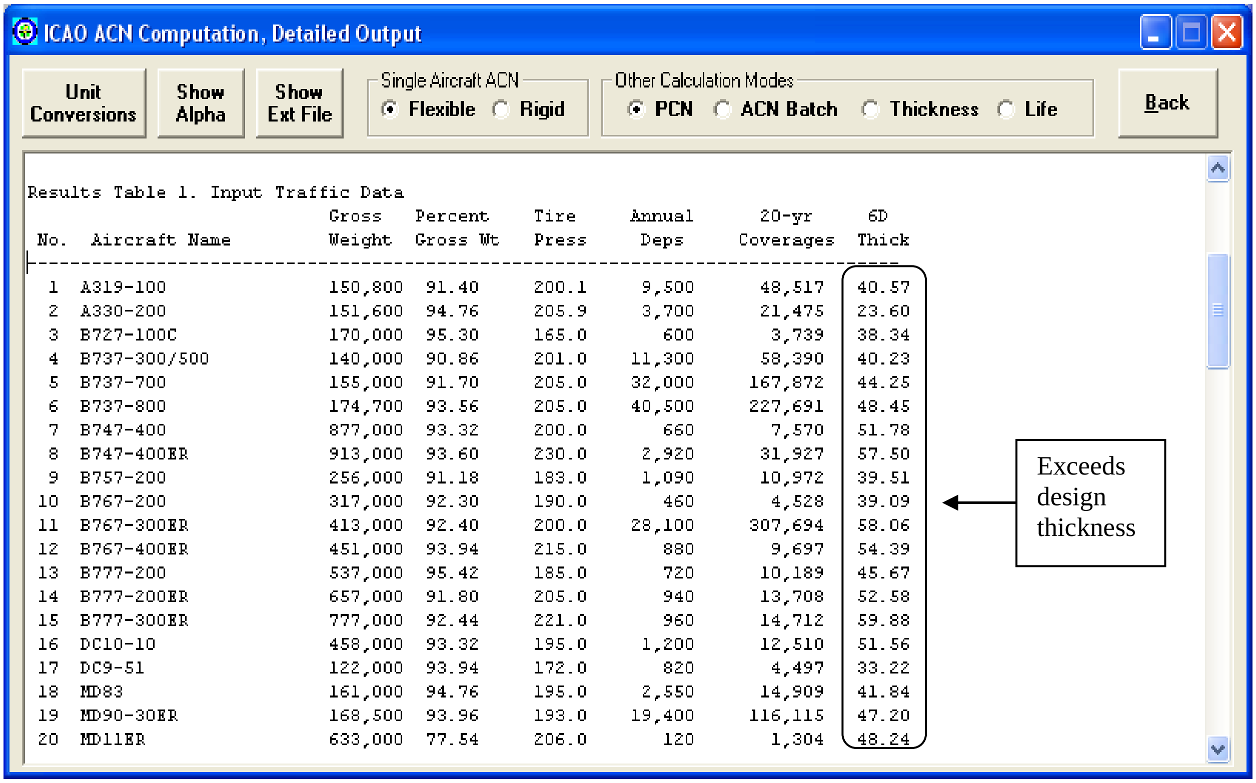


Figure 26 - Example 3A Composite Pavement Layer Equivalency

With the runway properties of Table 10 and the traffic of Table 9, COMFAA results are shown in Figure 27. The equivalent thickness in this case is not adequate for the traffic, with several of the six most demanding aircraft requiring -6D thicknesses that exceed 53.5 inches. Likewise, all aircraft shown have CDF thicknesses that are well above the equivalent number. The need for improved pavement capability is also evident from the PCN chart of Figure 28 in that the ACN's greatly exceed the PCN's for the six most demanding aircraft.



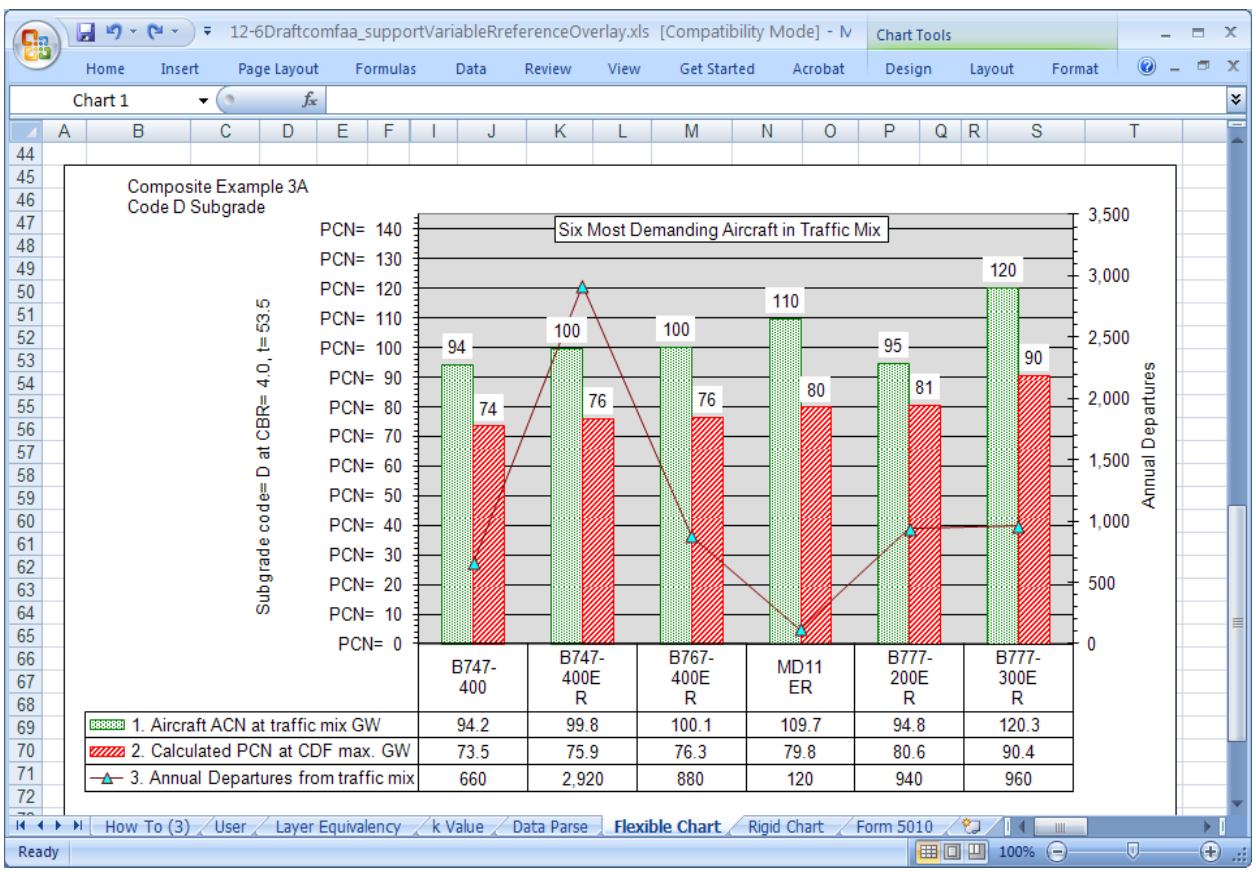
ICAO ACN Computation, Detailed Output

Unit Conversions | Show Alpha | Show Ext File | Single Aircraft ACN: Flexible, Rigid | Other Calculation Modes: PCN, ACN Batch, Thickness, Life | Back

Results Table 1. Input Traffic Data

No.	Aircraft Name	Gross Weight	Percent Gross Wt	Tire Press	Annual Deps	20-yr Coverages	6D Thick
1	A319-100	150,800	91.40	200.1	9,500	48,517	40.57
2	A330-200	151,600	94.76	205.9	3,700	21,475	23.60
3	B727-100C	170,000	95.30	165.0	600	3,739	38.34
4	B737-300/500	140,000	90.86	201.0	11,300	58,390	40.23
5	B737-700	155,000	91.70	205.0	32,000	167,872	44.25
6	B737-800	174,700	93.56	205.0	40,500	227,691	48.45
7	B747-400	877,000	93.32	200.0	660	7,570	51.78
8	B747-400ER	913,000	93.60	230.0	2,920	31,927	57.50
9	B757-200	256,000	91.18	183.0	1,090	10,972	39.51
10	B767-200	317,000	92.30	190.0	460	4,528	39.09
11	B767-300ER	413,000	92.40	200.0	28,100	307,694	58.06
12	B767-400ER	451,000	93.94	215.0	880	9,697	54.39
13	B777-200	537,000	95.42	185.0	720	10,189	45.67
14	B777-200ER	657,000	91.80	205.0	940	13,708	52.58
15	B777-300ER	777,000	92.44	221.0	960	14,712	59.88
16	DC10-10	458,000	93.32	195.0	1,200	12,510	51.56
17	DC9-51	122,000	93.94	172.0	820	4,497	33.22
18	MD83	161,000	94.76	195.0	2,550	14,909	41.84
19	MD90-30ER	168,500	93.96	193.0	19,400	116,115	47.20
20	MD11ER	633,000	77.54	206.0	120	1,304	48.24

Figure 27 - Example 3A Graphical Composite Pavement Thickness Requirements



	B747-400	B747-400ER	B767-400ER	MD11ER	B777-200ER	B777-300ER
1. Aircraft ACN at traffic mix GW	94.2	99.8	100.1	109.7	94.8	120.3
2. Calculated PCN at CDF max. GW	73.5	75.9	76.3	79.8	80.6	90.4
3. Annual Departures from traffic mix	660	2,920	880	120	940	960

Figure 28 - Example 3A ACN and PCN Comparison

Example 3B - Overlay of Composite Runway 17/35

It is apparent that the PCN is not sufficient for the pavement, considering the variables discussed above, and an overlay may be appropriate. Pavement characteristics are not shown here, but simply increase the P-401 thickness as shown in Figure 26 by 4 inches to 25 inches. The total pavement thickness increases from 53.5 to 62.7 inches due to the effect of the conversion factors. The resulting PCN of 127 FDWT is adequate for the traffic, as seen in Figure 29.

This covers future situations in which the traffic volume might increase, and the airport authority will still have confidence in the pavement strength, regardless of the volume increase in a critical aircraft.

By placing the overlay, the pavement is considered to have a new 20-year life; however, it is always wise to review these calculations after a period of time in that conditions might change

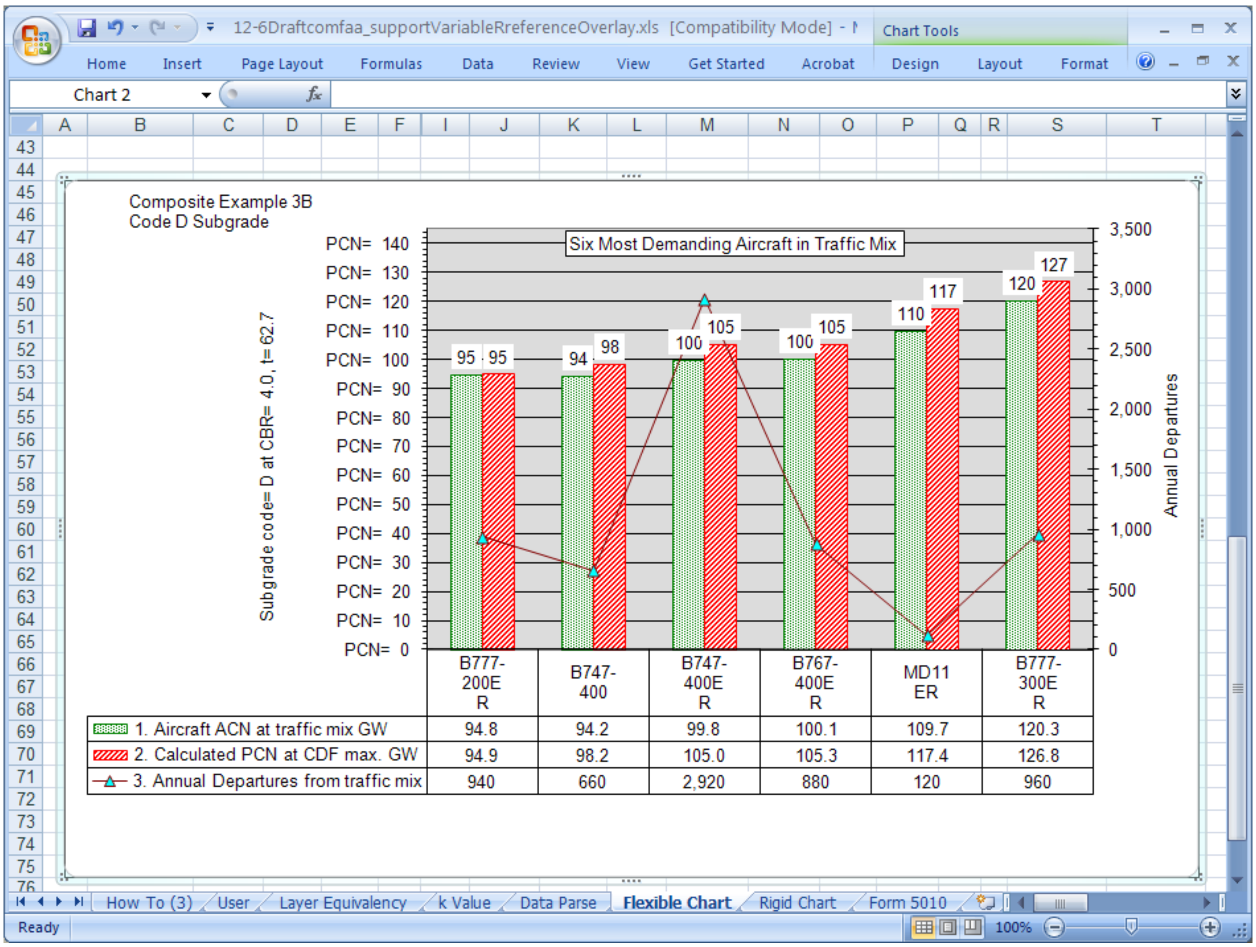


Figure 29 - Example 3B Composite Pavement ACN and PCN Comparison

Example 4 - Excessively Over-designed Pavement

The following runway has excessive thickness for the traffic, and it has to be treated in a different manner. Table 11 shows the runway characteristics, and the evaluation thickness is calculated in Figure 30. Traffic is shown in Table 12.

Table 11 - Example 4 Pavement Properties

Runway 02/20 (Flexible)	8	in.	
Surface HMA	8	in.	P-401
Base	10	in.	P-209
Subbase	17	in.	P-154
Evaluation thickness	40	in.	Figure 33
CBR	16		Code A

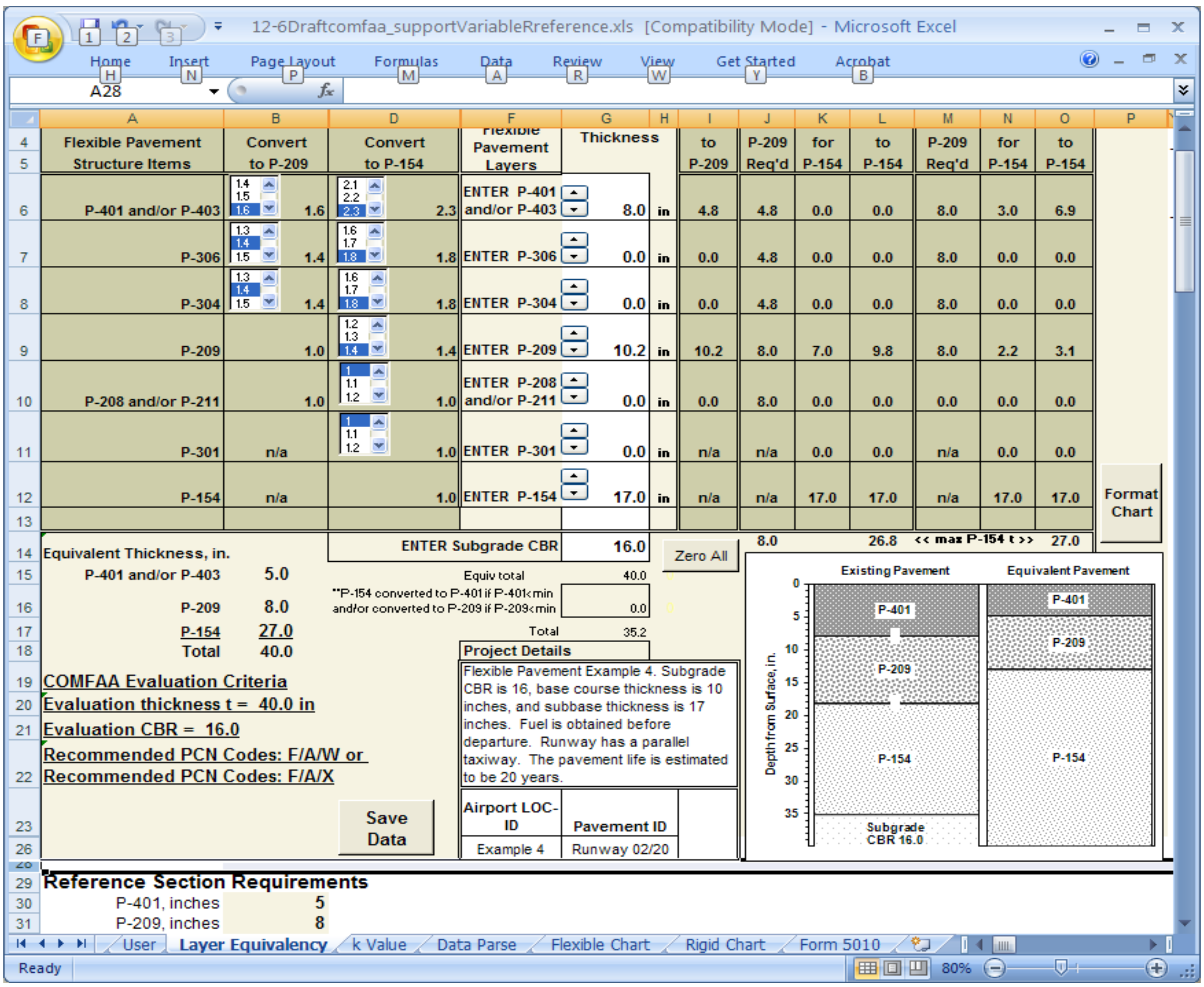


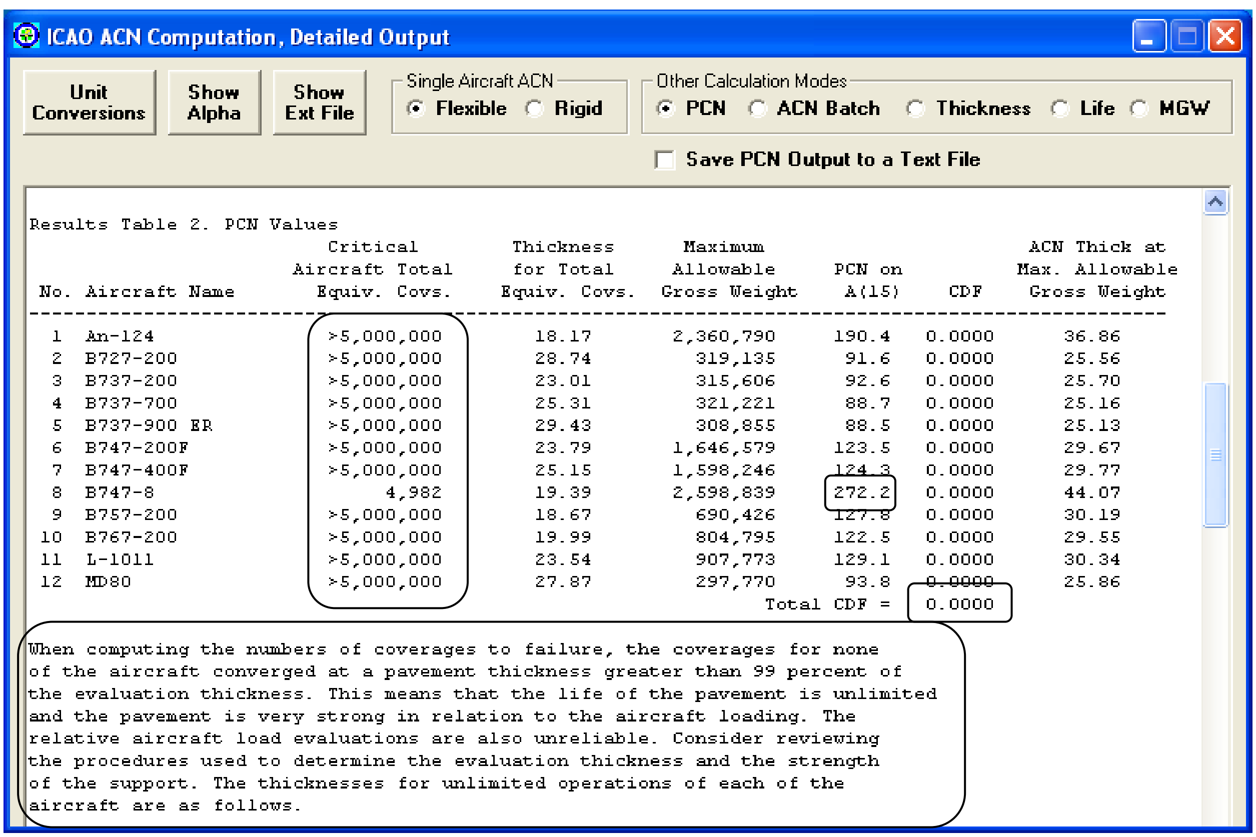
Figure 30 - Example 4 Pavement Layer Equivalency Calculation

Table 12 - Example 4 Traffic

Aircraft	Gear Type	Gross Weight (lb)	Average Annual Departures
AN-124	5D	877,430	3
B727-200	D	185,200	205
B737-200	D	128,600	3,580
B737-700	D	155,000	1,632
B737-900ER	D	188,200	874
B747-200F	2D/2D2	836,000	581
B747-400F	2D/2D2	877,000	444
B747-8F	2D/2D2	978,000	444
B757-200	2D	256,000	874
B767-200	2D	317,000	874
L-1011	2D	432,000	32
MD-80	D	161,000	1,492

PCN Calculation of Runway 02/20

After entering the traffic and the pavement characteristics into COMFAA, the PCN results are determined as shown in Figure 31. The evaluation thickness is far more than adequate for the traffic, with all of the aircraft thickness requirements calculated at much less than 40 inches. Additionally, every aircraft except the 747-8 has greater than 5,000,000 operations allowed, meaning that the pavement has unlimited life under these conditions.



No.	Aircraft Name	Critical Aircraft Total Equiv. Covs.	Thickness for Total Equiv. Covs.	Maximum Allowable Gross Weight	PCN on A(15)	CDF	ACN Thick at Max. Allowable Gross Weight
1	An-124	>5,000,000	18.17	2,360,790	190.4	0.0000	36.86
2	B727-200	>5,000,000	28.74	319,135	91.6	0.0000	25.56
3	B737-200	>5,000,000	23.01	315,606	92.6	0.0000	25.70
4	B737-700	>5,000,000	25.31	321,221	88.7	0.0000	25.16
5	B737-900 ER	>5,000,000	29.43	308,855	88.5	0.0000	25.13
6	B747-200F	>5,000,000	23.79	1,646,579	123.5	0.0000	29.67
7	B747-400F	>5,000,000	25.15	1,598,246	124.3	0.0000	29.77
8	B747-8	4,982	19.39	2,598,839	272.2	0.0000	44.07
9	B757-200	>5,000,000	18.67	690,426	127.8	0.0000	30.19
10	B767-200	>5,000,000	19.99	804,795	122.5	0.0000	29.55
11	L-1011	>5,000,000	23.54	907,773	129.1	0.0000	30.34
12	MD80	>5,000,000	27.87	297,770	93.8	0.0000	25.86
					Total CDF =	0.0000	

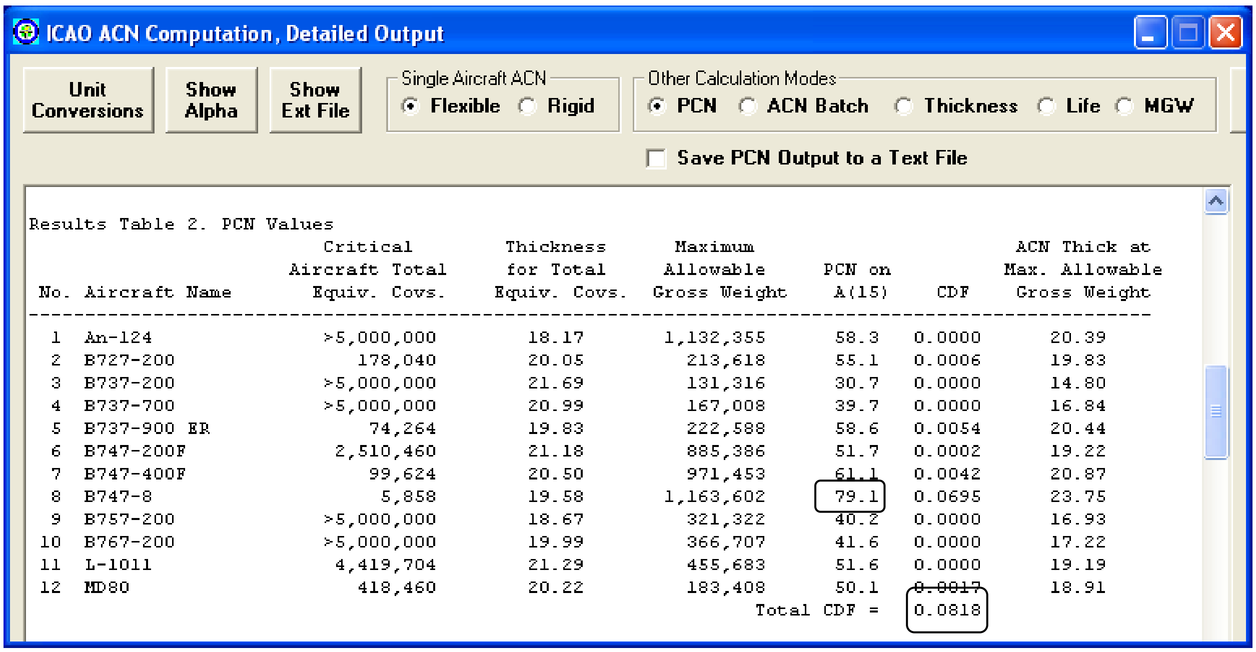
When computing the numbers of coverages to failure, the coverages for none of the aircraft converged at a pavement thickness greater than 99 percent of the evaluation thickness. This means that the life of the pavement is unlimited and the pavement is very strong in relation to the aircraft loading. The relative aircraft load evaluations are also unreliable. Consider reviewing the procedures used to determine the evaluation thickness and the strength of the support. The thicknesses for unlimited operations of each of the aircraft are as follows.

Figure 31 - Example 4 Results Table 2 PCN Showing Unlimited Pavement Life

Note that the total CDF is at 0.00, providing indication that the pavement greatly exceeds that traffic demands. Also, the PCN of the 747-8 is 272 FA, which by inspection is not common sense.

In order to arrive at a valid rating for this runway, it is suggested that the thickness be gradually artificially reduced until the "Thickness for Total Equivalent Coverages." becomes somewhat uniform, such as in Figure 32. In this case, an evaluation thickness of 22 inches results in PCN 79 FAWT shown graphically in Figure 36. Compare this with the highest ACN of 63 FB.

If future traffic that requires a higher PCN is introduced at this airport, then the PCN should be re-evaluated; however, the airport authority will have confidence that there will not be a problem due to the techniques used.



Results Table 2. PCN Values

No.	Aircraft Name	Critical Aircraft Total Equiv. Covs.	Thickness for Total Equiv. Covs.	Maximum Allowable Gross Weight	PCN on A(15)	CDF	ACN Thick at Max. Allowable Gross Weight
1	An-124	>5,000,000	18.17	1,132,355	58.3	0.0000	20.39
2	B727-200	178,040	20.05	213,618	55.1	0.0006	19.83
3	B737-200	>5,000,000	21.69	131,316	30.7	0.0000	14.80
4	B737-700	>5,000,000	20.99	167,008	39.7	0.0000	16.84
5	B737-900 ER	74,264	19.83	222,588	58.6	0.0054	20.44
6	B747-200F	2,510,460	21.18	885,386	51.7	0.0002	19.22
7	B747-400F	99,624	20.50	971,453	61.1	0.0042	20.87
8	B747-8	5,858	19.58	1,163,602	79.1	0.0695	23.75
9	B757-200	>5,000,000	18.67	321,322	40.2	0.0000	16.93
10	B767-200	>5,000,000	19.99	366,707	41.6	0.0000	17.22
11	L-1011	4,419,704	21.29	455,683	51.6	0.0000	19.19
12	MD80	418,460	20.22	183,408	50.1	0.0017	18.91
					Total CDF =	0.0818	

Figure 32 - Example 4 Results Table 2 PCN

An alternate approach to arriving at a valid rating in cases like this would be to increase the PCN by a percentage greater than the highest ACN of the expected traffic. If a factor of 25% were chosen, then the runway would be rated at:

ACN 63 FA x 1.25 = PCN 79 FAWT

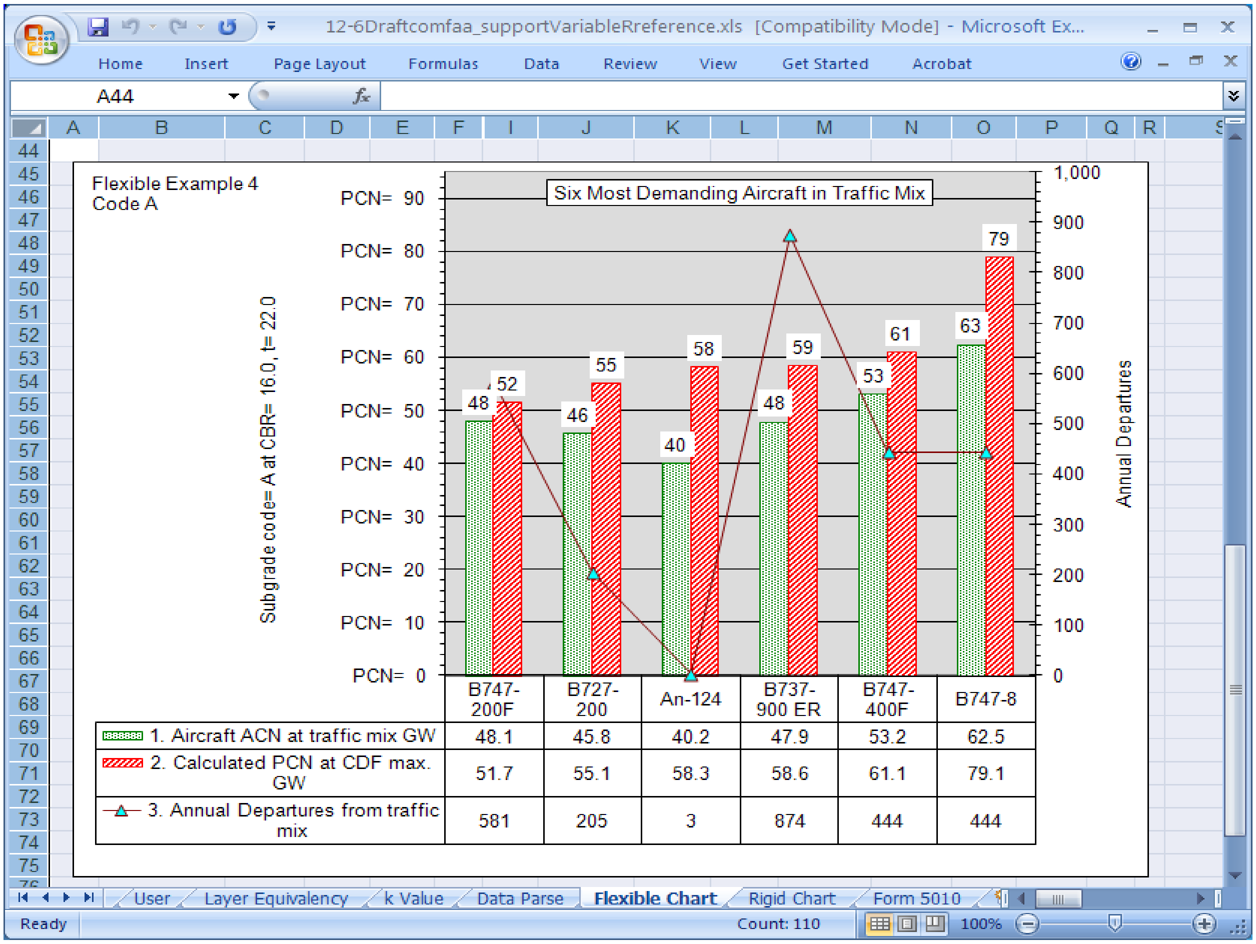


Figure 33 - Example 4 PCN and ACN Comparison

Closing Thoughts

Calculation of ACN is very precise while PCN determination is subject to engineering judgment due to the many variables involved. Thus it is up to the engineer to apply conclusions to the PCN based on knowledge derived from experience and observation.

The FAA PCN procedure assumes that the pavement life is 20 years, both for rigid and flexible pavements. In the examples presented the projected pavement life is usually less than this time period. To overcome this anomaly, the traffic should be counted from the beginning of the assumed pavement life - either at construction or at the last overlay – and the derived PCN is valid from that beginning until the 20 years is realized. For example, if the last overlay was in 1996, then the PCN should be determined with traffic from 1996 to the present, and it would be valid until 2016.

If the PCN is less than the ACN required, then consideration needs to be taken for changes to the pavement or traffic:

- Is the ACN vs. PCN difference enough to be concerned?
- How confident is the traffic projection?
- Will the traffic change in the future, especially for the most six most demanding aircraft?
- Is an overlay scheduled in the near future? If so, the PCN in this case should be acceptable until the refurbishment is accomplished.
- Considering the age and condition of the pavement (Table 5), should an overlay be recommended in the near future? The COMFAA program calculates PCN based on a 20-year pavement life, and the pavement is estimated to have only 8 years of life remaining.
- Were the pavement properties, such as CBR and equivalency factors, accurately derived or just estimated? Small differences in some factors can have significant effect on the final PCN calculation. Here is a tradeoff study of a rigid pavement in which M_R and slab thickness was varied. The effect of 50 psi change in M_R on PCN is about the same as that for one inch of slab thickness:

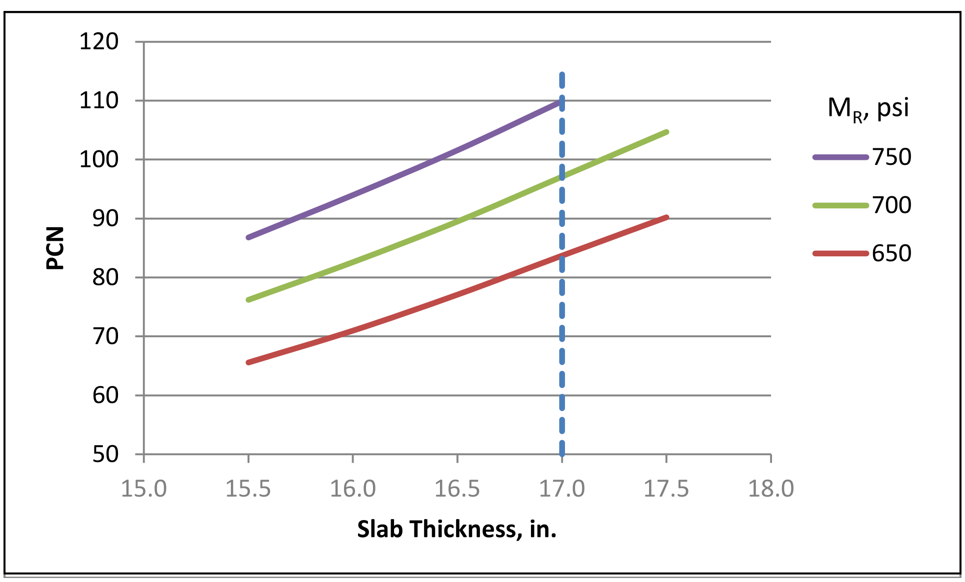


Figure 34 - Effect of M_R and Slab Thickness on PCN

In the life of a pavement, it is possible that either the current or future traffic will load the pavement in such a manner that the assigned pavement rating is exceeded. ICAO presents a simplified method to account for minor pavement overloading in which the overloading may be adjusted by applying a small fixed percentage to the existing PCN. This is subject to a limitation on the number of operations that the overloading airplane will have. However, there is little guidance to the airport authority as to the impact of these adjustments on the pavement in terms of pavement life reduction or increased maintenance requirements.

The following thoughts on overload apply primarily to pavements that have been evaluated by using the *Technical* method. Pavements that have ratings determined by the *Using* aircraft method should follow the ICAO overload guidelines.

Adjustment for pavement overloads starts with the supposition that at least some of the aircraft in the traffic mix have ACN's that exceed the PCN. To resolve these kinds of problems the airport authority will have three options on their pavement strength rating selection:

1. Let the PCN remain, but retain local knowledge that there are some aircraft in the traffic mix that can be allowed to operate with ACN's that exceed the published PCN or at a reduced weight to not exceed the PCN. This option requires that the airport authority constantly be aware of the composure of the entire traffic mix in terms of operating gross weights and loading frequency. If the traffic mix has changes that affect the factors involved in developing a technically based PCN, then the PCN will need to be adjusted to reflect the changes. The airport authority will also have to internally make allowance for or prevent aircraft operations that exceed the PCN. The difficulty in doing so is that the magnitude of the PCN is out of step with the ACN's of some of the traffic. Furthermore, this places the airport at a competitive disadvantage with aircraft operators in that the operators cannot be confident of the ability of their aircraft to operate successfully on that pavement.
2. Provide for an increased PCN by either by adding an overlay or by reconstruction in order to accommodate aircraft with the higher ACN's. This option alleviates the problems discussed for the first option, but it does require additional expense to bring the pavement up to the strength required by the combination of aircraft in the traffic mix. Doing so will, however, allow operations at the required strength and for the desired pavement life.
3. Adjust the PCN upward to that of the airplane with the highest ACN. This option has the benefit of allowing all aircraft in the traffic mix to operate as necessary; however, by increasing the PCN, which implies higher pavement strength, the pavement life will be reduced unless there is a provision for increased maintenance.