A Manufacturer's Point of View of ACN / PCN

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ABSTRACT

Reflecting on the historical record of full-scale airfield pavement testing (dating from the 1940's to the 1970's), and updating the record with test-to-failure data from the FAA National Airport Pavement Test Program, the pavement life cycle relationship to aircraft loading as indexed by landing gear type (dual, dual tandem, triple dual tandem, etc.) has been revisited. The resulting collection of pavement failure data was analyzed for applicability to the existing S-77-1 methodology (using what is commonly referred to as the CBR equation). The investigation establishes that the CBR equation retains its utility for predicting pavement thickness requirements and pavement life for airfield pavements. It is concluded that the unique solution of the CBR equation at the 10,000 coverage level, for four subgrade support conditions (as defined by ICAO ACN guidelines) continues to be well suited to the use for which it was intended.

KEY WORDS: Pavement Loading, ACN, PCN, Alpha Factors

(Open with the title slide on screen – Slide 1)

Ladies and Gentlemen, delegates and distinguished guests; it is my pleasure to be here in South Africa to talk to you about a topic that has been of serious concern to the major airframe manufacturer's for over a decade. It is very fitting to have this discussion here, at a major international destination, because it is at just such locales as this, that this issue comes to full fruition. Just over twenty years ago, the International Civil Aviation Organization (ICAO) with the aid of an internationally appointed group of airfield pavement experts from around the globe, introduced the ACN / PCN System. (Slide 2) The system was intended to be a simple means by which to express the pavement loading of commercial aircraft and at the same time express the ability of a pavement to sustain aircraft loading. If the system works, an airport at a place like Durban or Johannesburg or even Peitermaritzberg can make an accurate determination of the ability of their runways and taxiways to support the load of an aircraft that might be coming from New York or Frankfurt or Kariba Dam. Simply knowing the ACN of the aircraft and comparing it to the PCN of your pavement, tells the airport whether they can support the operation, or whether they should have a concern.

The system was developed by Mr. Connie O'Massey (Ref: O'Massey 1978) of the McDonnell-Douglas Corporation using the standard California Bearing Ratio (CBR) Method of analysis for flexible pavement and the Portland Cement Association (PCA) Westergard center case design method for rigid pavement (Slide 3). For a set of four defined standard soils, an index of the pavement loading of the aircraft is calculated. An airport then can rate their pavement into the one of the four standard soil conditions that most closely aligns with their locale, and by rating their pavement via this system, an allowed weight can be declared. In 1981, ICAO adopted the system for use at all international airports worldwide, making the reporting of pavement strength in the system mandatory by 1983 (Ref: ICAO 1999).

The flexible pavement ACN (CBR equation) is shown here (Slide 4) (Ref: Periera 1977). The key elements in the equation are the iterative nature of the calculation (thickness leads to an equivalent single wheel load, which leads to a new thickness calculation, and then the new thickness is used to find a new EWSL, and so on), and the alpha factor which addresses pavement life by way of the number of wheels in a landing gear group.

PCN's are assigned by the airport or airport authority as a declaration of the pavement load limit - expressed in terms of the ACN of the critical aircraft at it's critical weight on the most critical (or most representative) pavement cross-section on the airport in question.
By using standard conditions with recognized common design methods, all users have a full understanding of the numeric values of the ACN and their derivation. Both the flexible and rigid ACN calculation methods are publicly released in FORTRAN source code by the International Civil Aviation Organization (Ref: ICAO 1983), allowing full disclosure of the methodology involved. No sleight-of-hand or deceiving characterization of the pavement loading intensity of any aircraft is possible with the methodology.

However, in 1989 Boeing committed to a six-wheel landing gear for the 777 aircraft (Slide 5) and our early calculations of the ACN's for this aircraft indicated that perhaps the six-wheel gear wasn't dealt with very well in the case of flexible pavement. We then embarked on a journey that was far more arduous than even we could have predicted (Slide 6). Here's a timeline that shows you what I mean.

We showed our calculations to the FAA and to the US Corps of Engineers and they agreed to reconsider their original derivation of failure data for aircraft having six or more wheel landing gear, and by 1994 a study was released (Ref: Barker 1994) that indicated that a change was appropriate to the CBR Method for the six wheel landing gear case.

Following that, ICAO convened an ACN Study Group to formalize the findings of the Corps study and to agree on the implementation of the finding. Unfortunately a consensus decision could not be reached, so the study group was given leave to further study the issue and to develop a resolution. In February 1995 ICAO allowed the ACN calculation for the six-wheel gear to be characterized in an interim fashion, with full disclosure of the interim nature of the numeric values so-calculated. Note that ACN is not pavement design, but is a comparative means to compare the relative pavement loading of aircraft.

Boeing undertook a 4-year (1994 through 1997) full scale test of an instrumented flexible pavement test section with the help of the Progresstech Company of Moscow, testing for load response, load interaction within a pavement section, and loading to complete failure of the test section, and we published the results (Ref: Cornwell, Chaudhary, DeBord, Gervais and Krastins 1994) and made the test data available to ICAO and to industry (Slide 7).

The analysis of the four years of test data resulted in a strain-based method to resolve ACN for six wheel gear aircraft (which also could have been applied to landing gear configurations with more complex landing gear configurations). Slide 8 – Here's a plot of the strain-based method that we devised as a result of our testing. Even though these results were promising, the pavement design community did not accept the findings. At question, was both the utility and accuracy of multi-layer elastic analysis tools, and the material characterization of the individual layers that made up the pavement cross-section.

ICAO reconvened the Study Group in 1997 but no consensus was reached. ICAO ruled that the use of the interim technique was to continue until a more widely recognized and agreed method could be devised.

The US FAA at this same time undertook a full-scale test on six representative flexible pavement test sections (and three rigid pavement sections as well) comprising three of the standard subgrade support conditions that are indexed in the ACN method (Ref: Hayhoe, McQueen and Guo 1993). By 1998 the fully instrumented test sections were built (McQueen 2000), and trafficking with representative six and four-wheel load configurations was started (here's a photo of the load vehicle - Slide 9). By early 2002 all of the original flexible pavement sections had been tested to failure, but some sections did not fail at the subgrade level, which is the critical design condition addressed by the CBR method, and is the condition to which ACN's are indexed.

Since some of the key sections of the FAA test pavements did not fail as planned, FAA devised a series of near term flexible pavement sections that were also tested to failure (the last section of which just failed under load last month).

The FAA results are shown here (Slide 10) (Ref: Gervais, Hayhoe and Garg 2003) and were very heartening, as the data shows that the alpha factors are very close to the 1994 derivations, and indicate that six wheel gear aircraft can be assigned alpha factors that reflect the wide distribution of load that the landing gear affords.

It should also be mentioned that in 1998 Airbus Industrie (as it was then called) together with French Civil Aviation Authority (STBA) and the French pavement design bureau (LCPC) also undertook a full scale flexible pavement test along a section of taxiway at the Toulouse airport to resolve gear to gear interaction and life cycle reaction to load. The pavements were tested to 5000 passes, and were then overlaid (Slide 11). The tests however did not focus on a solution to the flexible pavement ACN dilemma, but were directed toward a solution of confirming a good landing gear separation and load distribution for the A380 aircraft. I understand that Airbus, together with their partners are engaged in the creation of a new multi-layer elastic system flexible pavement design method, but they have not suggested any proposed changes to the ACN system as a result of their tests.

Here is a table (Slide 12) that describes the various interpretations of the FAA test data (Ref: Gervais, Hayhoe and Garg 2003). Clearly, the results indicate that a six-wheel gear loads a pavement in a fashion that is consistent with the trend of the two wheel to four wheel gear relationship, and the location of the failure data are very near to the points we suggested in 1989 when we began a public inquiry into this matter. For example, (Slide 13) shows one fashion in which the FAA has plotted their failure data (Ref: Gervais, Hayhoe and Garg 2003), clearly indicating that the six-wheel gear alpha factors are not nearer to the four wheel curve, but are well below it. We at Boeing have performed our own curve fit of the failure data, attempting to maintain consistency between the interpretations of the US Corps of Engineers in their original plots (Ref: Ahlvin, Ulery, Hutchinson and Rice 1971) and including the FAA failure data (Slide 14) and here again it is evident that the six-wheel gear delivers on it's promise of distributing load over a wide area in a fashion that is similar to the twelve-wheel data that was originally plotted by the US Corps of Engineers.

As a result of these analyses, Boeing believes that the current CBR technique can easily be utilized to deal with six wheel landing gear, and that a resolution to the ACN dilemma within the existing methodology is both a realistic and practical goal. The simplicity of the original technique, along with full disclosure of the source codes used, are (or should be), a requirement of any ACN methodology.

I should also point out that some have suggested that a multi-layer elastic system-based flexible pavement ACN solution technique should be devised. In order for that to be practical, a complete description of the engineering properties of the materials that make up the pavement cross-section must be agreed upon and must be well documented (Slide 15). Even though this has been discussed previously at the ICAO level, it must be acknowledged that there are many multi-layer elastic system codes in use today, but only two have been publicly released, LEAF (Ref: Hayhoe 2002) which is publicly available on the FAA website, and JULEA; however, other codes have been suggested. In any case though, it is our view that for application to flexible pavement ACN's, full disclosure of all inputs and the detail code, must be allowed and made a priority – anything else would be unacceptable to the users of the system.

CONCLUSIONS

I will conclude my remarks with my main point. Boeing is of the opinion that the solution to the flexible pavement ACN dilemma is best resolved within the framework of the original CBR method. It is believed that the reduction of the data from the FAA tests and the analysis of the pavement failure data will be completed shortly, and that the data can be analyzed within the framework of the traditional flexible pavement model. With these results, we believe that a final and permanent resolution to this issue can be concluded.

Finally, I conclude with the observation that aircraft development (Slide 16) cannot and should not be held hostage by an unresolved issue of something as simple as the pavement loading attributes of an aircraft. An ACN solution for six, eight, ten or even more wheel landing gear should be entirely possible within the framework of the CBR method. While some may argue that elastic layer solutions are critical to a full understanding of the limitations of pavement design, ACN is intended to be simply a method by which to compare individual aircraft via well-recognized tools. As it was envisioned by it's founders in 1980, and was again concluded by the 1994 Corps of Engineers Report, an ACN calculation of virtually any landing gear configuration can be accommodated by the standard CBR methodology. PCN's may be the case that most justifies dealing with the intricacies of detail pavement design via multi-layer elastic systems and the like, but ACN is supposed to simply be a standard means by which we compare aircraft on representative pavements. The CBR method, as updated by the Corps in 1994, and rejoined by the data from the FAA National Airfield Pavement Test Program fully meets that need.

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