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# Method to Identify and Quantify Multiple-Event Roughness

January 2023

Final Report



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16. Abstract

FAA Advisory Circular (AC) 150/5380-9 "provides guidelines and procedures for measuring and evaluating runway roughness as identified by surface profile data of rigid and flexible airport pavements. The guidance in this AC provides technical procedures to quantify surface irregularities and to determine how surface irregularities may affect specific categories of airplanes."

The AC was a first step towards defining and implementing basic pavement roughness criteria for airfield pavements. The criteria presented in this early version was for single-event bump roughness. It was recognized that there was a technical need to address harmonics or multiple-bump event roughness.

The research results contained in the report are in response to that technical need. A method has been developed that locates and quantifies multiple-event roughness using measured profile data only. The method works for taxiways as well as runways. In addition, a "screening" process was developed to quickly categorize pavements as acceptable, excessive, or unacceptable. Excessive or unacceptable pavement sections can then be evaluated for potential corrective action.

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LIST OF ACRONYMS

| | |
|---|---|
| ABS | Absolute value |
| AC | Advisory Circular |
| AFB | Air Force Base |
| APR | APR Consultants, Inc. |
| APRas | Airport Pavement Roughness Assessment Software |
| AR&L–ER | Auto Rod & Level–ER |
| BAA | Broad Area Announcement |
| BB | Blanking band |
| BBI | Boeing Bump Index |
| CG | Center of Gravity |
| CL | Centerline |
| CP | Cockpit |
| EOM | Equations of motion |
| FAA | Federal Aviation Administration |
| GA | General Aviation |
| GW | Gross weight |
| Kts | Knots Velocity |
| MAC | Mean aerodynamic chord (inches) |
| MMAC | Mike Monroney Aeronautical Center |
| MSL | Mean sea level |
| MLG | Main landing gear |
| MTOGW | Maximum takeoff gross weight |
| NLG | Nose landing gear |
| Nz | Load factor |
| PCC | Portland concrete cement |
| PCI | Pavement condition index |
| PI | Profile index |
| PI-100 | Profile index for a 100-foot simulated profilograph |
| PI-25 | Profile index for a standard 25-foot profilograph |
| PSI | Pounds per square inch |
| PSD | Power Spectral Density |
| PST | Pilot simulator test |
| RSE | Rolling straightedge |

# EXECUTIVE SUMMARY

In the Federal Aviation Administration (FAA) Advisory Circular (AC) 150/5380-9, *Guidelines and Procedures for Measuring Airfield Pavement Roughness*, the FAA provides guidance for determining when a runway has become too rough. The method in this AC is intended for single-event roughness and does not address multiple-event roughness. The FAA is performing research into developing a method to identify and quantify multiple-event roughness.

This report summarizes a method using measured profile data for runways and taxiways to locate and quantify multiple-event roughness.

Definitions for three specific types of roughness that impact aircraft operations are:

- **Type 1—Shock:** The result of encountering a sharp change in elevation such as a step bump, raised slab, spall, or very short wavelength bump or dip.

- **Type 2—Short Wavelength:** A clear cutoff length that defines short versus long wavelength roughness does not exist; however, short wavelength roughness is defined as roughness that minimally impacts the aircraft as a whole. Each strut tends to react to the localized roughness independently, e.g., the response at the main landing gear (MLG) has a minimal effect on the response at the nose landing gear (NLG) for Type 2 roughness and vice versa.

- **Type 3—Long Wavelength:** Bumps and dips that excite the aircraft's rigid body modes of vibration (pitch and plunge). This type of roughness couples the MLG and NLG responses. The MLG response will impact the NLG response and vice versa.

Types 1 and 2 roughness are the primary concern for taxiways since speeds are low and controllable, whereas all three types of roughness can affect aircraft response on commercial runways where speed is high.

The method developed uses multiple analysis tools to locate and quantify the three types of roughness (i.e., Profile index [PI]-100, PI-25, 12-foot straightedge [RSE], Boeing Bump Index [BBI]). For taxiways, two evaluation tools are needed since speeds are low (i.e., PI-25 and 12-foot RSE). The tools are defined as:

- **PI-100:** 100-foot *simulated* profilograph with a 1-inch blanking band locates and quantifies Type 3 (longer wavelength) roughness.

- **PI-25:** 25-foot profilograph with a 0.4-inch blanking band locates and quantifies Type 2 roughness.

- **12-foot Straightedge (RSE):** Pavement profile deviations from a 12-foot RSE using a threshold of 0.4 inches locates and quantifies Type 1 roughness. Single bumps and dips like a raised slab are washed out when looking at an index such as PI-100, PI-25, or BBI over a larger pavement section. A deviation threshold of 0.4 inches is consistent with the *must grind* threshold for new pavement acceptance.

- **Boeing Bump Index (BBI):** Boeing Bump Index is computed to be consistent with the current AC 150/5380-9. This tool is also used to detect single-event bumps and dips with wavelengths greater than 100 feet.

Limits of acceptability were developed for each analysis tool that define what is acceptable, excessive, and unacceptable.

In addition, a three-step screening process was developed specifically for multiple-event roughness evaluation to quickly identify pavement roughness that might require corrective action. The pavement is divided into 500-foot sections.

**Step 1**. Measure pavement profile.

**Step 2**. Conduct a roughness screening to identify pavement sections that are acceptable, excessive, and unacceptable. If any section is found to be excessive or unacceptable, proceed to Step 3.

**Step 3.** Further evaluation for potential corrective action.

If excessive or unacceptable sections of the pavement result from the screening, tools in the FAA program, ProFAA, enable the user to make informed decisions and recommendations regarding corrective action.

The research was conducted using the commercially available program, ProVAL, with the intent to incorporate the method into ProFAA.

## 1. INTRODUCTION

Airport pavements are an essential element in the air transport industry. Their lifecycle performance is impacted by several factors, including pavement smoothness. Maintaining smooth airport pavements has many advantages. Smooth pavements:

- Last longer by reducing dynamic loads
- Reduce aircraft structural fatigue damage
- Reduce operations and servicing costs
- Improve aircraft braking performance
- Minimize ground-induced pilot controllability issues
- Improve ride quality

Currently, Federal Aviation Administration (FAA) (2009) Advisory Circular (AC)150/5380-9, *Guidelines and Procedures for Measuring Airfield Pavement Roughness*, provides guidance for determining when a runway has become too rough. It does not apply to taxiways. The stated purpose:

> This Advisory Circular provides guidelines and procedures for measuring and evaluating runway roughness as identified by surface profile data of rigid and flexible airport pavements. The guidance in this Advisory Circular provides technical procedures to quantify surface irregularities and to determine how surface irregularities may affect specific categories of airplanes.

Figure 1 shows a plot of the Boeing Bump Index (BBI) defining what is acceptable, excessive, and unacceptable. BBI focuses on bump amplitude versus wavelength and accounts for single event roughness only. AC 150/5380-9 recognizes that BBI does not consider multiple events as stated in the foreword:

> This Advisory Circular represents a first step towards defining and implementing basic pavement roughness criteria for airfield pavements. The criteria presented in this version of the Advisory Circular is intended to address isolated bump events and does not address cyclic or harmonic events which can have a substantial impact on airplane components and operations. Future research in this area will attempt to define limits for gravitational forces experienced by airplane components (landing gear, wings, etc.) and occupants. (FAA, 2009)

This research project addresses that need. The primary goal of this research is to develop a method that identifies and quantifies airport pavement roughness for single and multiple bumps and dips using measured profile data only.

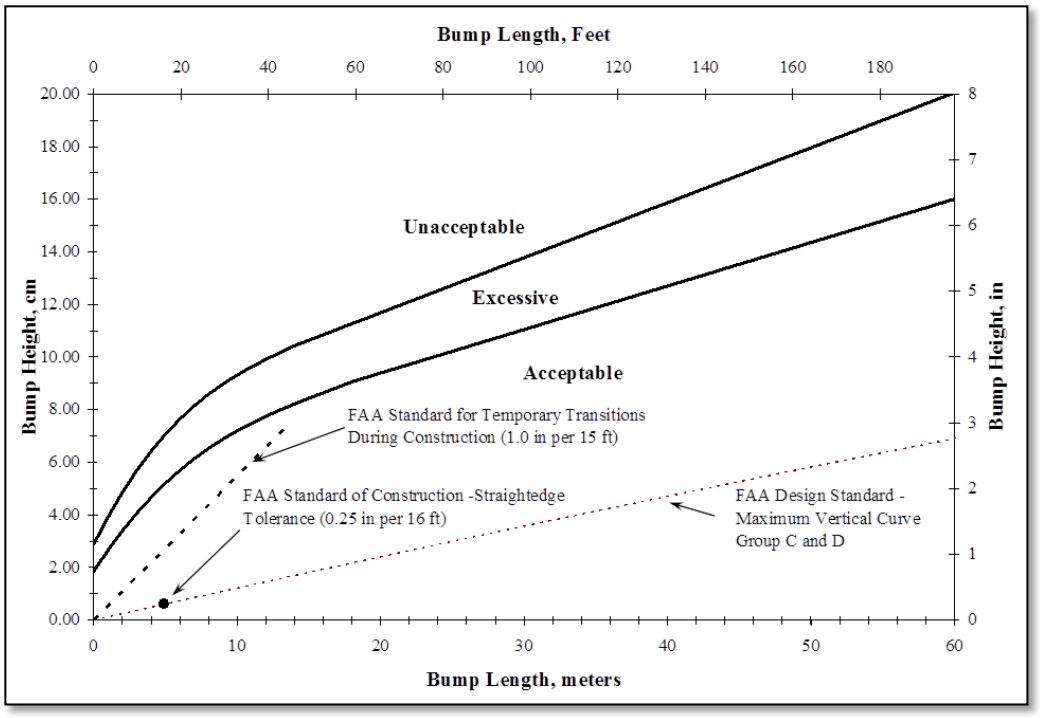


Figure 1. Boeing Bump Index Defining a Single-Event Bump as Acceptable, Excessive, and Unacceptable

## 2. DEFINING AIRPORT PAVEMENT ROUGHNESS

Roughness is often identified as being caused by long wavelength or short wavelength bump(s) or dip(s). The way roughness affects the aircraft's response defines short or long wavelength roughness. A primary factor to an aircraft's response to roughness is the speed at which the aircraft encounters the roughness. The aircraft will respond very differently to a bump at 20 knots versus 100 knots.

Three categories further define roughness. Types 1 and 2 are more likely to be the primary concern for taxiways since speeds are low and controllable. Types 1 and 2 are also more likely to be the primary concern for general aviation (GA) airports because of the short distance between nose and main landing gear on most GA aircraft. Whereas all three types can affect aircraft response on commercial runways where speed is high during takeoff and landing operations. Finally, all three types of roughness can have a single event or multiple events.

### 2.1 TYPE 1—SHOCK

Type 1 roughness is the result of encountering a sharp change in elevation such as a step bump, a raised slab, spall, or very short wavelength bump or dip. Shock loading is typically too fast for the struts and tires (suspension system) to fully react to the roughness. Tire size and tire pressure will affect the aircraft's response. A large tire, such as a main landing gear (MLG) tire on a Boeing 737, could bridge spalls that a smaller tire, like that of a smaller aircraft's nose landing gear (NLG),

might not. Tire pressure coupled with tire diameter will affect the tire's ability to engulf a sharp bump like a raised slab.

## 2.2 TYPE 2—SHORT WAVELENGTH

Short wavelength roughness has little effect on the aircraft's whole-body response because it minimally affects the aircraft's rigid body modes of vibration (pitch and plunge). In other words, the response at the MLG has a minimal effect on the response at the NLG and vice versa. Each strut tends to react to the localized roughness independently when encountering Type 2 roughness.

## 2.3 TYPE 3—LONG WAVELENGTH

Long wavelength roughness can significantly affect the aircraft's whole-body response because it excites the aircraft's rigid body modes of vibration (pitch and plunge). This type of roughness couples the MLG and NLG responses. The response at the MLG, which carries the majority of the aircraft's weight, will affect the response at the NLG. The response at the NLG will have less influence on the MLG because of the reduced loading. Type 3 roughness is caused by bumps and dips like runway intersections with crowns, vertical curves, or other changes in grade.

# 3. APPROACH

## 3.1 EVALUATE AIRPORT PAVEMENTS FOR ROUGHNESS USING PROFILE DATA ONLY

The profilograph is a 25-foot device used for smoothness acceptance specified in AC 150/5370-10H (FAA, 2018). It was originally developed for road and highway smoothness acceptance testing but has been adopted for use on airport pavements as well. It uses a simple yet clever approach that accounts for single- and multiple-event roughness that includes bumps and dips. The algorithm includes a blanking band (BB) that eliminates benign roughness. It accounts for varying amplitudes of the bumps and dips with a one-tenth-inch incremental weighting approach. The algorithm breaks the pavement into sections and computes a profile index (PI) value that is reported for each section.

The primary limitation for the profilograph's use on airport pavements is detection over the 25-foot span of the device. Commercial aircraft can have a wheelbase up to 100 feet in length, so a 25-foot profilograph cannot capture all the roughness types to which the aircraft will respond, particularly Type 3 roughness. Figure 2 illustrates a Boeing 777-200 and a 25-foot profilograph on the same scale.

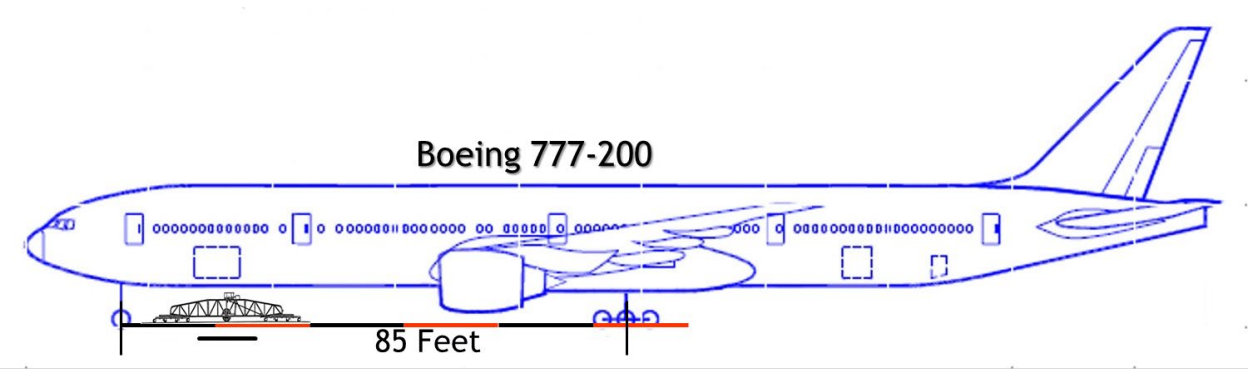


Figure 2. Boeing 777-200 Compared to a 25-Foot Profilograph

The approach used in this multiple-bump-event research simulates a longer profilograph using measured profile data and the same basic algorithm used in the standard method to compute the PI.

The research investigates the length of the simulated profilograph and defines the BB, section length, etc., to use with the longer simulated profilograph. In addition, the research establishes limits of acceptability defining what is acceptable, excessive, and unacceptable in terms of these indices.

Much of the research uses the commercially available program ProVAL to accommodate the longer profilograph length. The intent is to develop the method and tools needed to detect multiple-event roughness in ProVAL, and then incorporate the methods and tools into ProFAA.

Many military and commercial runway and taxiway profiles are available to support this research. Their roughness levels ranged from smooth, new pavements to very rough, in-service pavements. These profiles and previously-conducted roughness analyses provided additional correlation when establishing the limits that define what is acceptable, excessive, and unacceptable.

In addition to the measured profiles, the FAA's Mike Monroney Aeronautical Center (MMAC) Pilot Simulator Test (PST) provided another source of profile data. The PST profiles also ranged from smooth to very rough and were rated with pilot subjective ratings (Hudspeth, Stapleton, Ballew, & Sparkman, 2014) to help define what are acceptable, excessive, and unacceptable levels of roughness.

The aircraft simulation program Airport Pavement Roughness Assessment Software (APRas) was also used to compute aircraft dynamic response. Simulating aircraft response to a measured runway profile provided the capability needed to compare computed runway roughness levels to the Boeing *g* criteria described in the Boeing Document D6-81746 (Boeing, 1995), where *g* is vertical accelerations at the aircraft's center of gravity.

APRas and ProVAL are the key tools used in the development of the concept. Forty military and commercial runways and more than 21 military and commercial taxiway profiles are evaluated. Twelve PST runway profiles and 16 taxiway profiles are evaluated. This large sample of profiles

is sufficient to evaluate the concept and empirically establish limits of acceptability. The limits are also correlated to the pilot subjective ratings conducted in the PST.

In summary:

- APRas is used to compute Center of Gravity (CG) and Cockpit (CP) vertical acceleration for each profile. The simulated speed on runways is 90 knots. Taxiway simulated speed is 20 knots. The computed vertical accelerations are compared to the Boeing *g* criteria to determine if they fall into Boeing's definition of acceptable, excessive, or unacceptable.

- ProVAL is used to compute the simulated longer profilograph (PI-100) and the standard profile index (PI-25), and a 12-foot straightedge.

- ProFAA is used to compute the BBI for each runway profile analyzed.

Combining and assessing the results of these tools provided a method that will evaluate the profile for single- and multiple-event roughness using profile data only. This includes all three types of pavement roughness described in the introduction. By analyzing numerous runways and taxiways it was possible to establish limits of acceptability for each analysis tool. These limits are categorized as acceptable, excessive, or unacceptable using profile data only, but are based on Boeing *g* criteria. The values defining acceptable, excessive, and unacceptable for each tool are a best fit for all profiles examined. The next step in this research is to develop a screening procedure that will determine if corrective action could be required.

## 3.2 AIRPORT PAVEMENT ROUGHNESS SCREENING PROCEDURE

The intent of this research is to develop a method of locating and quantifying multiple-event roughness using ProVAL, and then to incorporate the method into ProFAA. It is anticipated that some pavements or pavement sections, when analyzed, could require corrective action when objectionable roughness is located. This led to the development of a procedure to screen the profile and determine if corrective action is required. Other tools such as aircraft simulation will be required in ProFAA to determine what (if any) corrective action to implement. The screening process would become a new tool to be developed in an updated version of ProFAA.

The three-step screening process enhances ProFAA's pavement roughness evaluation capability.

### 3.2.1 Read-in Measured Runway Profile Data

There are many off-the-shelf profile measuring devices capable of accurately measuring airfield pavements. Measured profile data from multiple device types are used, including inertial profilers, external reference profilers, and inclinometers. Typically, multiple lines of survey are used to show consistency.

### 3.2.2 Conduct a Roughness Screening in ProFAA Using the Results of This Research

The screening method in ProFAA will automatically compute PI-100, PI-25, 12-foot straightedge (RSE), and BBI. If all sections of the pavement are acceptable, the analysis is complete until the

next pavement evaluation cycle. If any section is excessive, or unacceptable, the user proceeds to Step 3 for further analysis.

### 3.2.3 Corrective Action

If excessive or unacceptable sections of the pavement are found in the screening, other tools in ProFAA will be used to make informed decisions and recommendations regarding if/when corrective action is needed. For example, potential options to consider include:

- Evaluate potential corrective actions
    - Conduct operation with a displaced threshold
    - Panel replacement in objectionable section(s)
    - Asphalt overlay
    - Diamond grinding
    - Limit operations to departure only
    - Limit operations to specific aircraft types
- Immediate closure of that section(s)
- Assess the effectiveness of the corrective action using aircraft simulation on a simulated corrected pavement in ProFAA

The primary advantage of this three-step approach for smoothness evaluation is efficiency. The assessment is complete if the screening shows all sections to be acceptable. This is likely to be the case for many in-service pavements. In addition, if a particular runway or taxiway section(s) is found objectionable, corrective action can focus on that area.

ProFAA would be used to evaluate the effectiveness of a potential corrective action plan. ProFAA currently has constant speed aircraft simulation capability for several older aircraft types. Planned ProFAA upgrades include adding takeoff and landing simulation capability and the addition of more aircraft types to provide a more accurate representation of today's commercial fleet.

Finally, periodic pavement evaluations that include smoothness, Pavement Condition Index (PCI), structural integrity, and friction will help achieve the FAA *40 Year Pavement* goal. (Brill, 2014)

## 4. RESULTS

### 4.1 TASK 1—DEVELOP A METHOD TO IDENTIFY ROUGHNESS USING MEASURED PROFILE DATA ONLY

The research conducted in this BAA project is centered on the development of a method to identify multiple-event roughness using profile data only.

Simulated aircraft dynamic response is an accurate way to predict the response to a given runway profile. However, there are many different conditions to simulate, such as aircraft type, the speed of encounter, the gross weight, and CG location, just to mention a few. It would be an arduous task

to consider all these conditions. This created the need to find a method to locate and quantify acceptable, excessive, and unacceptable roughness using profile data only.

The profilograph has been used by the industry for smoothness evaluation for many years as a new pavement smoothness acceptance tool. However, it is limited by its physical length and cannot account for longer wavelengths that impact aircraft response. New profile measurement technology and advances in software are now available that can eliminate the 25-foot restriction. The algorithm used with the current profilograph has proven to be an effective tool for locating and quantifying roughness, but again, for a 25-foot length.

The method developed in this research uses a simulated profilograph length of 100 feet as opposed to a conventional 25-foot profilograph. The term **PI-100** is the index name given to the simulated 100-foot profilograph. PI-100 was developed to detect runway roughness that impacts whole body aircraft response (Type 3 roughness). The PI-100 index was developed to assess in-service airport pavements for roughness that contain multiple- and single-event bumps and dips.

Aircraft simulated response was needed to develop the method of using measured profile data only to locate and quantify single- and multiple-event roughness. The current BBI method was developed in a similar way, but for single events only.

The criteria used to define levels of roughness was developed by the Boeing Company (Boeing, 1995). It defines roughness level in *g*'s. The term Nz, commonly referred to as load factor, represents the vertical acceleration at the aircraft's CG. Load factor is a common method used in the aircraft's initial design as well as in the computation of remaining life. It is also used to define when loads are unacceptable.

Table 1 lists the Boeing criteria (Nz-peak *g*'s) used to define a runway as Acceptable (green), Excessive (yellow), or Unacceptable (red) (Boeing, 1995).

Table 1. Boeing *g* Criteria

| | |
|---|---|
| Red > 0.80 | Unacceptable |
| Yellow 0.54 to 0.80 | Excessive |
| Green <0.54 | Acceptable |

Using APRas, the Boeing 737-800 responses were computed for a variety of measured runway and taxiway profiles. The predicted responses were then compared to the limits specified in the Boeing criteria (Table 1). Using ProVAL, PI-100, PI-25, and 12-foot RSE were computed for each of these measured profiles. ProFAA was used to compute BBI for each profile. By comparing the APRas-computed aircraft response to the Boeing criteria as a *g* limit, thresholds for PI-100, PI-25, and the 12-foot RSE limits were established and used to define what is acceptable, excessive, and unacceptable. BBI limits were previously defined in AC 150/5380-9. These analysis tools (PI-100, PI-25, 12-foot RSE, and BBI) and their corresponding thresholds enable multiple-event roughness to be located and quantified using profile data only.

The thresholds are a best fit that describe the roughness levels of all profiles used in this research. They range from smooth to very rough.

APR Consultants, Inc. (APR) has collected profile data for many runways and taxiways over the past 29 years. They ranged in roughness level from very rough causing many pilot complaints to very smooth new pavements. These profiles were essential in the development of the multiple bump event detection method. They provided an opportunity to correlate measured profile data with aircraft response. Since each runway used in this research had been previously assessed for roughness level, there was a basis to compare profile to aircraft response. In addition, having a wide variety of profiles to assess improved the statistical reliability. More than 40 military and commercial runway profiles were used in this research to define the limits of acceptability for runways. In addition, 12 PST runways were used to help validate the limits. Twenty-one military and commercial taxiways were used to establish the taxiway limits of acceptability. Seventeen PST taxiways were used to help validate the taxiway limits.

The step-by-step process used to develop the roughness assessment method is as follows:

- Use aircraft simulation technology to predict aircraft response on many runways with known roughness levels.
- Compare the predicted aircraft response to the Boeing criteria in Table 1.
- Compute PI-100, PI-25, and 12-foot RSE for each runway in ProVAL. Compute the BBI in ProFAA.
- Compile the results in a Microsoft® Excel® spreadsheet.
- Determine the optimum values for PI-100, PI-25, and 12-foot RSE that best fit the many profiles used to derive the procedure (BBI already has established limits).
- Set limits that define acceptable, excessive, and unacceptable levels of roughness based on the empirical best fit.

Tables 2 and 3 show the limits of acceptability that were established for runways and taxiways. Note that the limits of PI-25 acceptability shown for taxiways are the same as for runways. However, the *g* limits for taxiways were based on ride comfort. The 0.4-*g* level is also the ride comfort criteria commonly used for runways. This report contains color-coded charts throughout; green is acceptable, yellow is excessive, and red is unacceptable.

Table 2. Limits of Acceptability for Runways

| PI-100<br>(1-in. BB) | PI-25-ft<br>(0.4-in. BB) | 12-ft RSE | BBI |
|---|---|---|---|
| Red > 35 | Red > 35 | Red > (ABS 0.80) | Red > 1.2 Unacceptable |
| Yellow 20–35 | Yellow 20–35 | Yellow (ABS 0.4 to 0.80) | Yellow 1.0 to 1.2 Excessive |
| Green < 20 | Green < 20 | Green < (ABS 0.4) | Green < 1.0 Acceptable |

ABS = Absolute value

Runways require four separate evaluation tools: PI-100, PI-25, 12-foot RSE, and BBI.

- **PI-100:** This tool is required to locate and quantify Type 3 roughness. It is computed using a 100-foot-long simulated profilograph with a 1-inch BB.

- **PI-25:** This tool is required to locate and quantify Type 2 roughness. It is computed for a standard 25-foot profilograph, but with a 0.4-inch BB.

- **RSE:** Deviation from a 12-foot RSE using a deviation threshold of 0.4 inches is computed primarily to detect Type 1 roughness. Single bumps and dips, like a raised slab, can be washed out when looking at an index such as PI-100, PI-25, or BBI roughness over a 500-foot section. A deviation threshold of 0.4 inches was chosen because this value is consistent with the "must grind" threshold for new pavement acceptance. A 12-foot length was selected because it is consistent with FAA AC 150/5370 (P-401 and P-501).

- **BBI:** BBI is computed to be consistent with the current FAA AC 150/5380-9. This tool is also used to detect single-event bumps and dips with wavelengths greater than 100 feet.

Table 3. Limits of Acceptability for Taxiways

| PI-25 (0.4-in. BB) | 12-ft RSE |
|---|---|
| Red > 0.35 | Red > (ABS 0.80) |
| Yellow 20 to 0.35 | Yellow (ABS 0.4 to 0.80) |
| Green < 20 | Red > (ABS 0.80) |

ABS = Absolute value

Taxiways require only two evaluation tools since aircraft speeds are low; PI-100 and BBI are not required since Type 3 roughness is not a concern at these speeds.

- **PI-25:** This tool is required to locate and quantify Type 2 roughness. It is computed for a standard 25-foot profilograph but with a 0.4-inch BB.

- **RSE:** Deviation from a 12-foot RSE using a deviation threshold of 0.4-inches is computed primarily to detect Type 1 roughness.

**Section Length:** A section length of 500 feet is used because most multiple-event runways that APR has analyzed are typically two to three events. Plus, the fact that if there are more than three events, they will still be detected but in the next pavement section.

The results of six profiles (R1, R4, R6, R7, R40, and T1) are shown below. These six pavements demonstrate how each assessment tool can effectively identify the roughness of the pavement. These examples also demonstrate that roughness can be accurately located and quantified using profile data only. They also show the need for multiple analysis tools to detect the three types of roughness. In addition, they demonstrate that smooth pavements test smooth, which is an important feature of the method developed. The results of all other runway and taxiway analyses can be found in the appendices.

The simulated aircraft responses for the six selected profiles were for a Boeing 737-800 at 172,500 pounds traveling at a constant speed of 90 knots.

- **R1** is a large commercial airport runway in the United States. It contained multiple Type 3 events that generated pilot complaints, particularly in the first section of the runway.
- **R4** is a GA airport runway that was generating pilot complaints and was suspected of causing premature NLG maintenance on a business jet based at R4.
- **R6** is a Portland concrete cement (PCC) runway with dynamic soil conditions. This runway generated pilot complaints that eventually led to panel replacements in the affected area. Two distinct bumps caused the Type 3 roughness.
- **R7** is a large commercial runway with a recent asphalt reconstruction overlay.
- **R40** is a very old PCC runway that was smooth except for one area that generated pilot complaints in a DC-8-30 cargo aircraft. This single bump resonated with that particular aircraft/bump combination.
- **T1** is a parallel taxiway at a U.S. Naval Air Station for F-18 fighters. There were no known complaints of roughness.

4.1.1 Analysis of Runway R1

Figure 3 shows a plot of the repeated bumps and dips in the first 2,000 feet of Runway R1.

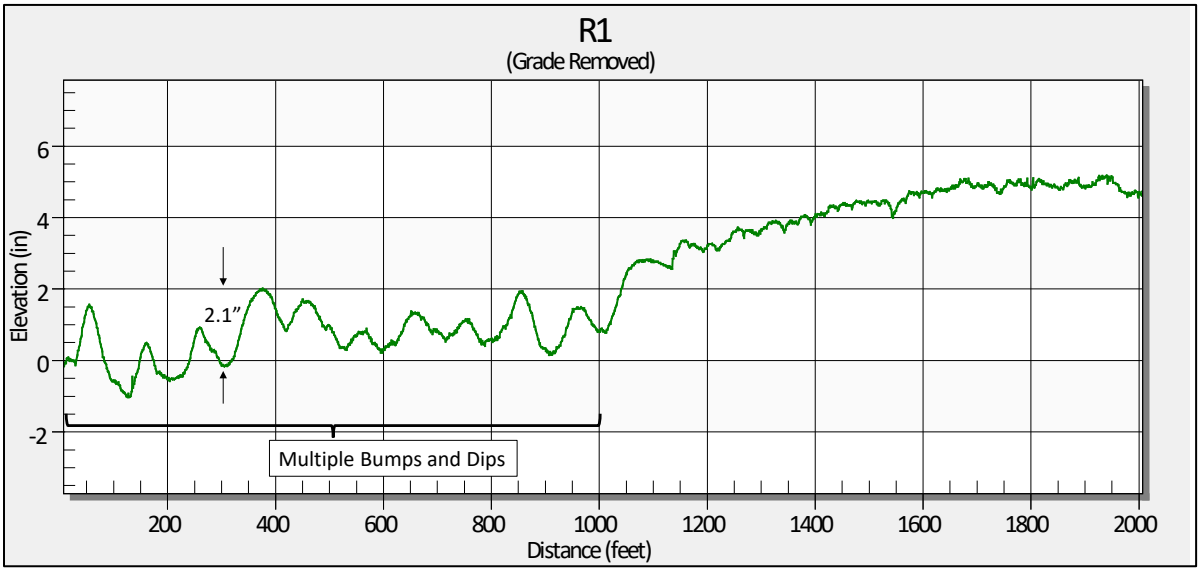


Figure 3. Plot of the First 2,000 Feet of Runway R1

Table 4 shows the results for the runway designated R1. The analysis of Runway R1 detected, located, and quantified the multiple-event roughness. PI-100 was the most effective analysis tool for Runway R1.

- The CG and CP vertical accelerations (*g*'s) were found to be excessive.
- PI-100 results identified the areas that produced the excessive aircraft response. The PI-100 analysis tool clearly identified multiple Type 3 bumps and dips.
- PI-25 results identified several areas of Type 2 roughness.
- The 12-foot RSE results identified one location that exceeded 0.4-inch deviation (Type 1 roughness).
- BBI found the entire runway to be acceptable. This is because the BBI considers single bumps only. Multiple bumps and dips caused the excessive aircraft response. This example shows the need for updating FAA Advisory Circular 150/5380-9 to assess for multiple bumps and dips in succession.

Table 4. Analysis Results for Runway R1

| Section (ft) | CG | CP | PI-100 | PI -25 | 12-ft RSE | BBI |
|---|---|---|---|---|---|---|
| 0-500 | 0.7 | 0.92 | 113.01 | 19.13 | < ABS (4) | Acceptable |
| 501-1000 | 0.6 | 0.81 | 52.01 | 2.11 | < ABS (4) | Acceptable |
| 1001-1500 | <0.54 | <0.54 | 5.11 | 2.11 | < ABS (4) | Acceptable |
| 1500-2000 | <0.54 | <0.54 | 12.11 | 2.64 | < ABS (4) | Acceptable |
| 2001-2500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| 2501-3000 | <0.54 | <0.54 | 0.83 | 1.06 | < ABS (4) | Acceptable |
| 3001-3500 | <0.54 | <0.54 | 5.07 | 0.00 | < ABS (4) | Acceptable |
| 3501-4000 | <0.54 | <0.54 | 0.87 | 0.00 | < ABS (4) | Acceptable |
| 4001-4500 | <0.54 | <0.54 | 0.41 | 0.00 | < ABS (4) | Acceptable |
| 4501-5000 | <0.54 | <0.54 | 0.27 | 0.00 | < ABS (4) | Acceptable |
| 5001-5500 | <0.54 | 0.62 | 1.25 | 0.53 | < ABS (4) | Acceptable |
| 5501-6000 | <0.54 | <0.54 | 3.21 | 0.00 | < ABS (4) | Acceptable |
| 6001-6500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| 6501-7000 | <0.54 | <0.54 | 0.75 | 0.00 | < ABS (4) | Acceptable |
| 7001-7500 | <0.54 | <0.54 | 0.00 | 6.34 | < ABS (4) | Acceptable |
| 7501-8000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| 8001-8500 | <0.54 | <0.54 | 20.42 | 0.00 | < ABS (4) | Acceptable |
| 8501-9000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| 9001-9500 | <0.54 | <0.54 | 3.29 | 6.86 | < ABS (4) | Acceptable |
| 9501-10000 | <0.54 | <0.54 | 6.26 | 550.44 | 0.052 | Acceptable |
| 10001-10500 | 0.59 | 0.85 | 59.51 | 38.02 | < ABS (4) | Acceptable |
| 10501-11000 | <0.54 | <0.54 | 17.17 | 33.26 | < ABS (4) | Acceptable |

ABS = Absolute value

4.1.2 Analysis of Runway R4

Figure 4 shows a plot of the first 2,500 feet of the GA Runway R4 with repeated Type 2 roughness caused by repeated unevenness of the 20-foot PCC panels. Table 5 contains the results of all analyses for Runway R4.

- The CG and CP vertical accelerations were found to be excessive.
- PI-100 results identified no areas that produced Type 3 roughness.
- PI-25 results identified multiple areas of Type 2 roughness.
- The 12-foot RSE results identified multiple areas that exceeded 0.4-inch deviation (Type 1 roughness).
- BBI found the entire runway to be acceptable.

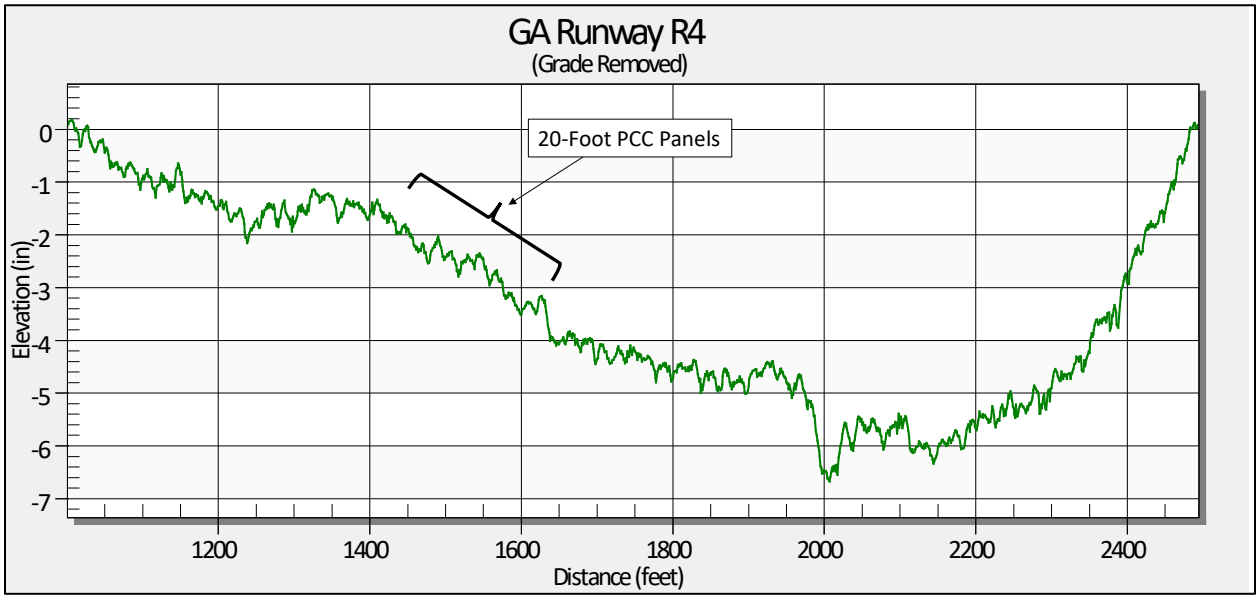


Figure 4. Plot of the First 2,500 Feet of Runway R4

Table 5. Analysis Results for Runway R4

| Section (ft) | CG | CP | PI-100 | PI -25 | 12-ft RSE | BBI |
|---|---|---|---|---|---|---|
| 0-500 | <0.54 | <0.54 | 6.96 | 20.22 | < ABS (4) | Acceptable |
| 501-1000 | <0.54 | <0.54 | 4.78 | 5.64 | < ABS (4) | Acceptable |
| 1001-1500 | <0.54 | <0.54 | 5.35 | 24.64 | 0.41 | Acceptable |
| 1500-2000 | <0.54 | 0.67 | 9.34 | 20.87 | < ABS (4) | Acceptable |
| 2001-2500 | <0.54 | <0.54 | 7.65 | 28.05 | 0.47 | Acceptable |
| 2501-3000 | <0.54 | <0.54 | 2.79 | 14.81 | < ABS (4) | Acceptable |
| 3001-3500 | <0.54 | <0.54 | 20.41 | 8.85 | 0.45 | Acceptable |

| Section (ft) | CG | CP | PI-100 | PI -25 | 12-ft RSE | BBI |
|---|---|---|---|---|---|---|
| 3501-4000 | <0.54 | <0.54 | 0.93 | 5.28 | < ABS (4) | Acceptable |
| 4001-4500 | <0.54 | <0.54 | 80.41 | 8.68 | < ABS (4) | Acceptable |
| 4501-5000 | <0.54 | <0.54 | 7 | 16.13 | < ABS (4) | Acceptable |
| 5001-5500 | <0.54 | 0.62 | 0.54 | 9.72 | < ABS (4) | Acceptable |
| 5501-6000 | <0.54 | <0.54 | 3.78 | 140.4 | < ABS (4) | Acceptable |
| 6001-6500 | <0.54 | <0.54 | 0.00 | 6.14 | < ABS (4) | Acceptable |

ABS = Absolute value

### 4.1.3 Analysis of Runway R6

Figure 5 shows an expanded plot of the multiple bumps on Runway R6 that caused pilot complaints. These panels were eventually replaced, and the roughness was removed. The analysis of Runway R6 located and quantified the two Type 3 bumps; PI-100 was the only analysis tool that detected the bumps. BBI found the runway to be acceptable. Runway R6 demonstrates the need to update FAA AC 150/5380-9 to evaluate multiple events. Table 6 contains the results of all analyses for Runway R6.

- The CG and CP vertical accelerations were found to be excessive.
- PI-100 results identified one area that produced Type 3 roughness.
- PI-25 results identified one area with mild Type 2 roughness in one section.
- The 12-foot RSE results identified no areas that exceeded 0.4-inch deviation (Type 1 roughness).
- BBI found the entire runway to be acceptable.

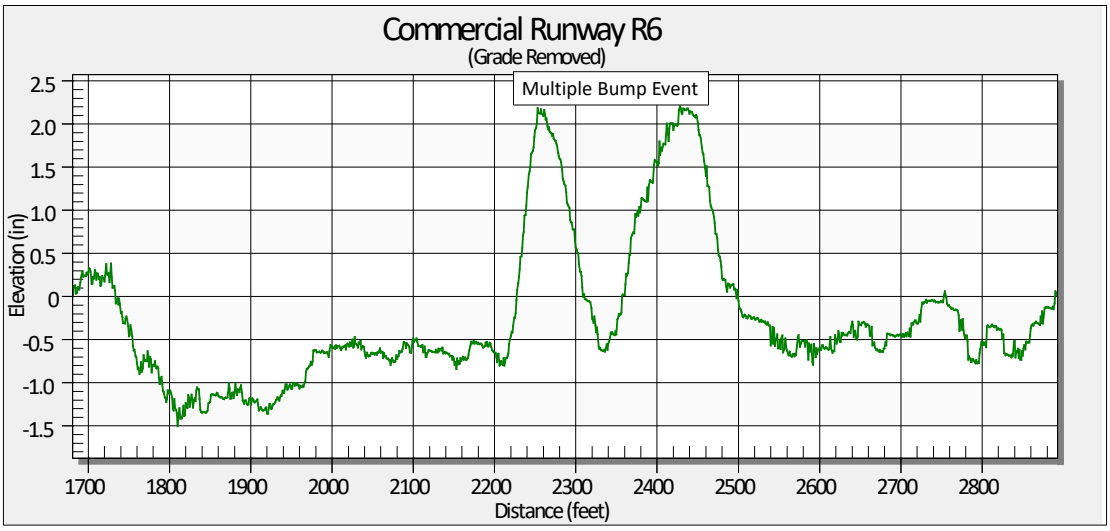


Figure 5. Expanded Plot of Multiple Bumps on Runway R6

Table 6. Analysis Results for Runway R6

| Section (ft) | CG | CP | PI-100 | PI-25 | 12-ft RSE | BBI |
|---|---|---|---|---|---|---|
| 0-500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| 501-1000 | <0.54 | <0.54 | 40.4 | 0.00 | < ABS (4) | Acceptable |
| 1001-1500 | <0.54 | 0.73 | 18.7 | 2.64 | < ABS (4) | Acceptable |
| 1500-2000 | <0.54 | <0.54 | 4.66 | 3.17 | < ABS (4) | Acceptable |
| 2001-2500 | 0.71 | 0.92 | 57.01 | 8.98 | < ABS (4) | Acceptable |
| 2501-3000 | <0.54 | <0.54 | 6.24 | 2.64 | < ABS (4) | Acceptable |
| 3001-3500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| 3501-4000 | <0.54 | <0.54 | 10.37 | 4.22 | < ABS (4) | Acceptable |
| 4001-4500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| 4501-5000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| 5001-5500 | <0.54 | <0.54 | 20.4 | 0.00 | < ABS (4) | Acceptable |
| 5501-6000 | <0.54 | <0.54 | 1.91 | 2.64 | < ABS (4) | Acceptable |
| 6001-6500 | <0.54 | <0.54 | 0.58 | 0.00 | < ABS (4) | Acceptable |
| 6501-7000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| 7001-7500 | <0.54 | <0.54 | 40.42 | 0.53 | < ABS (4) | Acceptable |
| 7501-8000 | <0.54 | <0.54 | 7.16 | 2.11 | < ABS (4) | Acceptable |
| 8001-8500 | <0.54 | <0.54 | 8.39 | 0.53 | < ABS (4) | Acceptable |
| 8501-9000 | <0.54 | <0.54 | 1.18 | 2.11 | < ABS (4) | Acceptable |
| 9001-9500 | <0.54 | <0.54 | 0.00 | 3.7 | < ABS (4) | Acceptable |
| 9501-10000 | <0.54 | <0.54 | 2.83 | 0.00 | < ABS (4) | Acceptable |
| 10001-10500 | <0.54 | <0.54 | 1.77 | 0.00 | < ABS (4) | Acceptable |
| 105001-11000 | <0.54 | <0.54 | 0.00 | 1.58 | < ABS (4) | Acceptable |
| 11001-12000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| 12001-12500 | <0.54 | <0.54 | 13.62 | 5.61 | < ABS (4) | Acceptable |

ABS = Absolute value

### 4.1.4 Analysis of Runway R7

Figure 6 shows a full-length plot of Runway R7 with the end-to-end grade removed for better scaling. This asphalt runway had recently been reconstructed and was considered very smooth. All analysis methods found this runway to be acceptable. Runway R7 is an example where the evaluation is complete after Step 2 in the screening process. There is no need to consider corrective action. Table 7 contains the results of all analyses for Runway R7.

- The CG and CP vertical accelerations were found to be acceptable.
- PI-100 results identified no areas of roughness.
- PI-25 results identified no areas of roughness.
- The 12-foot RSE results identified no areas of roughness.
- BBI found no areas of roughness.

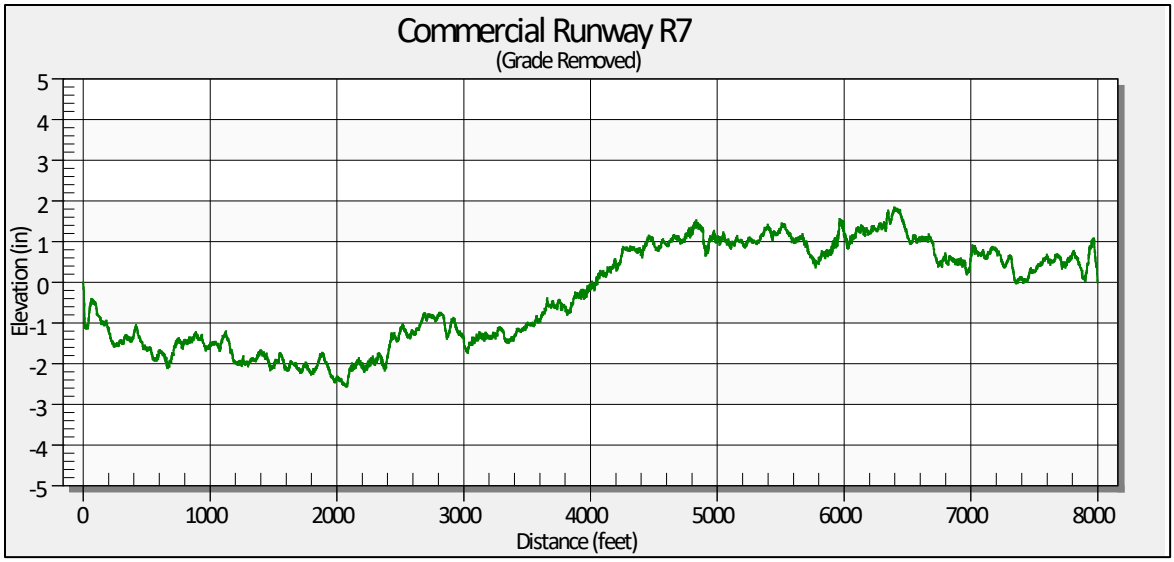


Figure 6. Commercial Runway R7 Recently Reconstructed

Table 7. Analysis Results for Runway R7 (Auto Rod & Level)

| Section (ft) | CG | CP | PI-100 | PI-25 | 12-ft RSE | BBI |
|---|---|---|---|---|---|---|
| 0-500 | <0.54 | <0.54 | 0.00 | 2.73 | < ABS (4) | Acceptable |
| 501-1000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| 1001-1500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| 1500-2000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| 2001-2500 | <0.54 | <0.54 | 0.42 | 0.00 | < ABS (4) | Acceptable |
| 2501-3000 | <0.54 | <0.54 | 0.45 | 0.00 | < ABS (4) | Acceptable |
| 3001-3500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| 3501-4000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| 4001-4500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| 4501-5000 | <0.54 | <0.54 | 0.37 | 0.00 | < ABS (4) | Acceptable |
| 5001-5500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| 5501-6000 | <0.54 | <0.54 | 0.33 | 0.00 | < ABS (4) | Acceptable |
| 6001-6500 | <0.54 | <0.54 | 0.00 | 0.53 | < ABS (4) | Acceptable |
| 6501-7000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| 7001-7500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| 7501-8000 | <0.54 | <0.54 | 5.37 | 0.55 | < ABS (4) | Acceptable |

ABS = Absolute value

### 4.1.5 Analysis of Runway R40

Figure 7 shows a full-length plot of Runway R40 with the end-to-end grade removed for better scaling. This PCC runway consistently produced complaints from DC-8 pilots during takeoff. A single bump located around 2,500 feet caused the DC-8 to resonate with the bump at the speed the bump was encountered. PI-100 was the only assessment tool that located the single bump. The CG

and CP vertical accelerations show excessive *g*'s at that bump location. Table 8 contains the results of all analyses for Runway R40.

- PI-100 results identified one area of Type 3 roughness.
- PI-25 results identified no areas of roughness.
- The 12-foot RSE results identified no areas of roughness.
- BBI found the entire runway length to be acceptable. Runway R40 demonstrates that BBI can be conservative even for single bumps that cause pilot complaints because it does not consider specific aircraft characteristics.

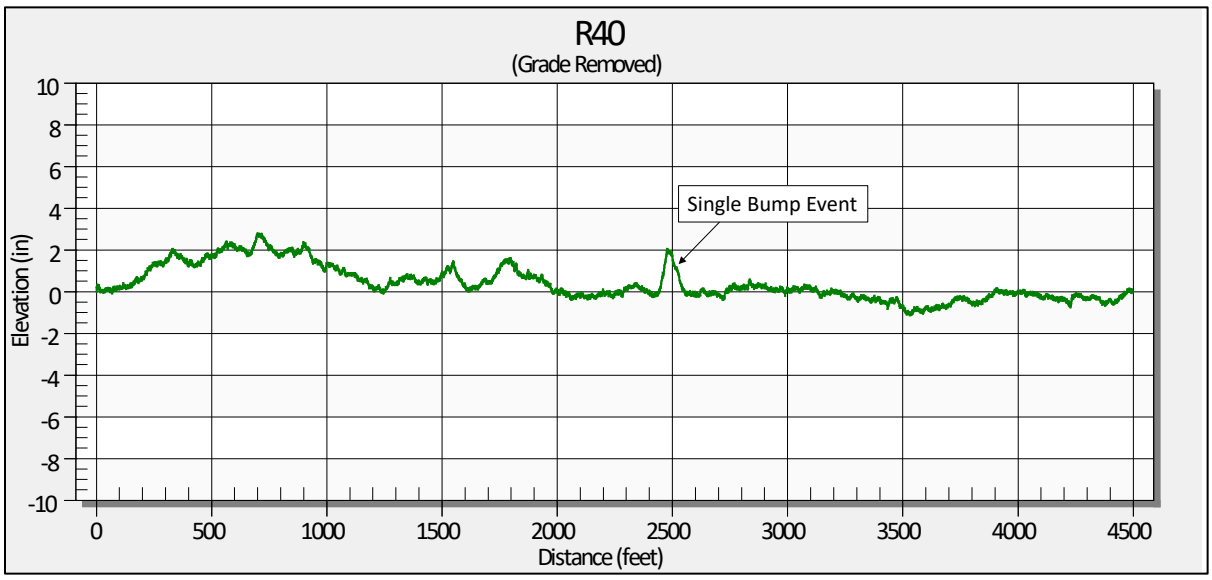


Figure 7. Partial Plot of Runway R40 with Single Bump

Table 8. Analysis Results for Runway R40

| Section (ft) | CG | CP | PI-100 | PI-25 | 12-ft RSE | BBI |
|---|---|---|---|---|---|---|
| 0-500 | <0.54 | <0.54 | 60.42 | 0.00 | < ABS (4) | Acceptable |
| 500-1000 | <0.54 | <0.54 | 1.27 | 0.5 | < ABS (4) | Acceptable |
| 1000-1500 | <0.54 | 0.65 | 50.43 | 3.31 | < ABS (4) | Acceptable |
| 1500-2000 | <0.54 | <0.54 | 0.7 | 4.05 | < ABS (4) | Acceptable |
| 2000-2500 | 0.62 | 0.69 | 23.12 | 0.92 | < ABS (4) | Acceptable |
| 2500-3000 | <0.54 | <0.54 | 0.00 | 4.21 | < ABS (4) | Acceptable |
| 3000-3500 | <0.54 | <0.54 | 0.00 | 1.02 | < ABS (4) | Acceptable |
| 3500-4000 | <0.54 | <0.54 | 0.00 | 1.15 | < ABS (4) | Acceptable |
| 4000-4500 | <0.54 | <0.54 | 0.00 | 1.59 | < ABS (4) | Acceptable |

ABS = Absolute value

4.1.6 Analysis of Taxiway T1

Figure 8 shows a plot of Taxiway T1 (a taxiway at a U.S. Naval Air Station). Note the changes in grade that would not be acceptable on a runway. Table 9 contains the results of all analyses for Taxiway T1.

- The CG and CP vertical accelerations show excessive *g*'s at one location only.
- PI-25 results identified two areas of roughness.
- The 12-foot RSE results identified one area of roughness.

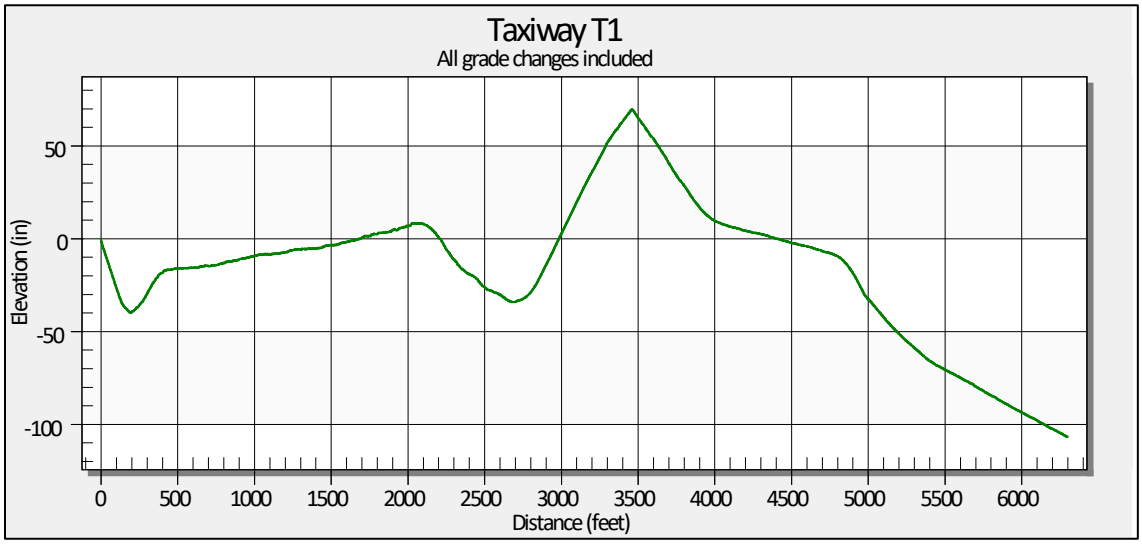


Figure 8. Full Length Plot of Taxiway T1 with All Grade Changes Included

Table 9. Analysis Results for Taxiway T1

| Section (ft) | CG | CP | PI -25 | 12-ft RSE |
|---|---|---|---|---|
| 0-500 | 0.45 | 0.45 | 25.14 | < ABS (4) |
| 501-1000 | <0.40 | <0.54 | 8.98 | < ABS (4) |
| 1001-1500 | <0.40 | <0.54 | 7.39 | < ABS (4) |
| 1500-2000 | <0.40 | <0.54 | 19.54 | < ABS (4) |
| 2001-2500 | <0.40 | <0.54 | 21.12 | < ABS (4) |
| 2501-3000 | <0.40 | <0.54 | 4.75 | < ABS (4) |
| 3001-3500 | <0.40 | <0.54 | 14.26 | < ABS (4) |
| 3501-4000 | <0.40 | <0.54 | 4.22 | < ABS (4) |
| 4001-4500 | <0.40 | <0.54 | 0.0 | < ABS (4) |
| 4501-5000 | <0.40 | <0.54 | 1.58 | < ABS (4) |
| 5001-5500 | <0.40 | <0.54 | 0.00 | < ABS (4) |
| 5501-6000 | <0.40 | <0.54 | 0.53 | < ABS (4) |
| 6001-6500 | <0.40 | <0.54 | 0.00 | < ABS (4) |

ABS = Absolute value

Over 70 runways and taxiways were analyzed using this process. The results of these analyses are contained in the following appendices.

- Appendix A—PST Profiles—Taxiways (Boeing 737-800 at 130,000 lb)
- Appendix B—PST Profiles—Runways (Boeing 737-800 at 130,000 lb)
- Appendix C—Commercial and Military Runways (Boeing 737-800 at 172,500 lb)
- Appendix D—Commercial and Military Taxiways (Boeing 737-800 at 172,500 lb)

## 5. CONCLUSIONS

The procedure developed was successful in locating and quantifying single- and multiple-event bumps and dips using profile data only. While the original objective of this research was specifically aimed at runways, the tools developed also work for taxiways. Four different assessment tools are used in locating all three types of roughness.

**Runways require all four assessment tools:**

- **Profile Index (PI)-100:** This tool is required to locate and quantify multiple bumps and dips in succession (Type 3 roughness). PI-100 is computed using a 100-foot-long simulated profilograph with a 1-inch blanking band (BB).

- **PI-25:** PI-25 is computed by simulating a standard 25-foot profilograph with a 0.4-inch BB. This tool locates and quantifies multiple-event Type 2 roughness.

- **Straightedge (RSE):** Deviation from a 12-foot RSE using a deviation threshold of 0.4-inches is computed primarily to detect Type 1 roughness. Single bumps and dips like a raised slab can be washed out when looking at an index such as PI-100, PI-25, or Boeing Bump Index (BBI) roughness over a 500-foot section. A deviation threshold of 0.4 inches was chosen because this value is consistent with the must grind threshold for new pavement acceptance. A 12-foot RSE length was selected because it is consistent with FAA Advisory Circular (AC) 150/5370-10H (P-401 and P-501).

- **Boeing Bump Index (BBI)**: BBI is computed to be consistent with the current FAA AC 150/5380-9. While BBI analysis is often conservative and will not detect multiple bump events, it is a useful tool for identifying single-event roughness with wavelengths greater than 100 feet.

**Taxiways require two assessment tools:**

- **PI-25:** PI-25 is computed by simulating a standard 25-foot profilograph with a 0.4-inch BB. This tool locates and quantifies multiple-event Type 2 roughness.

- **RSE:** Deviation from a 12-foot RSE using a deviation threshold of 0.4-inches is computed primarily to detect Type 1 roughness.

**Limits of Acceptability**:

Limits of acceptability were derived by applying the above tools to many measured profiles ranging in roughness levels from smooth to very rough. The values shown in Tables 10 and 11 were determined by comparing computer-simulated responses of the Boeing 737-800 to Boeing *g* criteria Table 1. These limits reflect a best fit for all the profiles analyzed. The limits were further evaluated using the Pilot Simulator Testing (PST) profile data and pilot subjective ratings. The color-coded limits reflect pavements or pavement sections that were labeled as acceptable, excessive, and unacceptable.

Table 10. Limits of Acceptability for Runways

| PI-100 (1-in. BB) | PI-25-Foot (0.4-in. BB) | 12-ft RSE | BBI |
|---|---|---|---|
| Red >35 | Red >35 | Red > (ABS 0.8) | Red > 1.2 Unacceptable |
| Yellow 20 to 35 | Yellow 20 to 35 | Yellow (ABS 0.4 to 0.8) | Yellow 1.0 to 1.2 Excessive |
| Green <20 | Green <20 | Green < (ABS 0.4) | Green < 1.0 Acceptable |

ABS = Absolute value

Table 11. Limits of Acceptability for Taxiways

| PI-25 (0.4-in. BB) | 12-ft RSE |
|---|---|
| Red >35 | Red > (ABS 0.8) |
| Yellow 20 to 35 | Yellow (ABS 0.4 to 0.80) |
| Green <20 | Green < (ABS 0.4) |

ABS = Absolute value

The limits of acceptability are the same for taxiways and runways, except taxiways require only PI-25 and 12-foot RSE assessments because of the low speeds on taxiways.

**Three-step screening procedure:** A three-step screening procedure was successful in identifying pavement sections that might require corrective action. Step 1 is to measure the profile, Step 2 screens the profile data to identify sections that are excessive or unacceptable. Step 3 requires the user to conduct further roughness evaluation for any pavement section that might need corrective action. ProFAA or other aircraft simulation software can be used to determine if, when, and what corrective action is needed for those pavement sections. In addition, aircraft simulation software can evaluate the effectiveness of the proposed repair.

## 6. RECOMMENDATIONS

It is recommended that the methods and tools developed in this research be incorporated into ProFAA. The primary objective of this BAA research was to develop the concept and pavement evaluation tools needed to locate and quantify multiple-event pavement roughness. The publicly available software program, ProVAL, was used to help in that development. The research was

successful in developing a method using profile data only. The next step is to incorporate the concept and tools developed into the FAA's software program, ProFAA.

It is recommended that a three-step process be used in ProFAA to assess the roughness levels for runways and taxiways using the tools developed in this BAA research to detect all three types of roughness.

- **Read-in profile data:** User to identify if the profile is a runway or taxiway.

- **Screen the profile:** If the profile is a runway, Step 2 would automatically trigger PI-100, PI-25, 12-foot RSE, and BBI analyses. If it is a taxiway, PI-25 and the 12-foot RSE analyses would automatically be triggered. These analysis tools will automatically determine if the pavement is acceptable, excessive, or unacceptable using profile data only. The results could be presented in a color-coded plot clearly identifying any 500-foot section that is excessive or unacceptable. Any pavement section found acceptable, as is likely in most cases, then the evaluation is complete. If any section is not found to be acceptable, the user would proceed to Step 3.

- **Assess for corrective action:** Additional analyses, such as aircraft simulation and engineering judgement, will be conducted to determine if, when, and what corrective action is required.

It is recommended that the limits of acceptability defined in Tables 10 and 11 for runways and taxiways developed in this BAA be used initially when incorporated into ProFAA. As more pavement profiles become available, the limits can be updated as needed. The limits shown in the tables are a best fit for all the pavements analyzed in this research and were based on Boeing *g* criteria.

It is recommended that FAA AC 150/5380-9 be revised to include process and tools developed in this research for multiple event runway and taxiway roughness detection.

Currently, the Boeing method in FAA AC 150/5380-9 suggests that pavement sections that are rated as unacceptable are subject for "immediate closure" of the affected area. It is recommended that the three-step process developed in this research be labeled as "requires immediate attention." The distinction between the two is that in the three-step method, it will be necessary to conduct a more intensive analysis before a decision is made for closure of the affected area.

## 7. OBSERVATIONS AND LESSONS LEARNED

Several observations were made, and lessons were learned while conducting this research. These observations and lessons learned are contained in Appendix E.

## 8. REFERENCES


Boeing Commercial Airplane Group, Airport Technology Organization. (1995, November). *Runway roughness measurement, quantification, and application - Boeing method* (Document No. D6-81746). https://www.boeingsuppliers.com/assets/pdf/commercial/airports/faqs/roughness.pdf

Brill, D. (2014, September 3). *FAA 40-year life pavement extension R&D* [Presentation]. XI ALACPA Seminar on Airport Pavements and IX FAA Workshop, Santiago, Chile. https://www.icao.int/sam/documents/2014-alacpa11/dia%203%20-%205_research%20on%2040-year%20life%20pavement%20extension%20-%20copy.pdf

Federal Aviation Administration (FAA). (2009, September 30). *Guidelines and procedures for measuring airfield pavement roughness*. (Advisory Circular [AC] 150/5380-9). https://www.faa.gov/airports/resources/advisory_circulars/index.cfm/go/document.current/documentNumber/150_5380-9

FAA. (2018, December 21). *Standard specifications for construction of airports* (AC 150/5370-10H). https://www.faa.gov/airports/resources/advisory_circulars/index.cfm/go/document.current/ocumentNumber/150_5370-10H

Hudspeth, S., Stapleton, S., Ballew, J., & Sparkman, J. (2017). *Final surface roughness study data collection* (DOT/FAA/TC-18/8). https://www.airporttech.tc.faa.gov/Products/Airport-Safety-Papers-Publications/Airport-Safety-Detail/boeing-737-800-final-surface-roughness-study-data-collection

APPENDIX A—PILOT SIMULATOR TEST PROFILES—TAXIWAYS

This appendix contains the results of Pilot Simulator Test (PST) taxiway analyses. The PST taxiway simulations were typically 1,100 feet in length, so each profile considered the first two 500-foot sections only. The responses show that the PST testing profiles became progressively rougher as the profile number increased. This is confirmed by the pilot rating. Figure A-1 is the rating form used by the Mike Monroney Aeronautical Center (MMAC) test pilots. This form was used for PST taxiways and PST runways shown in Appendix B of this report. All simulated responses were conducted with the Airport Pavement Roughness Assessment Software (APRas).

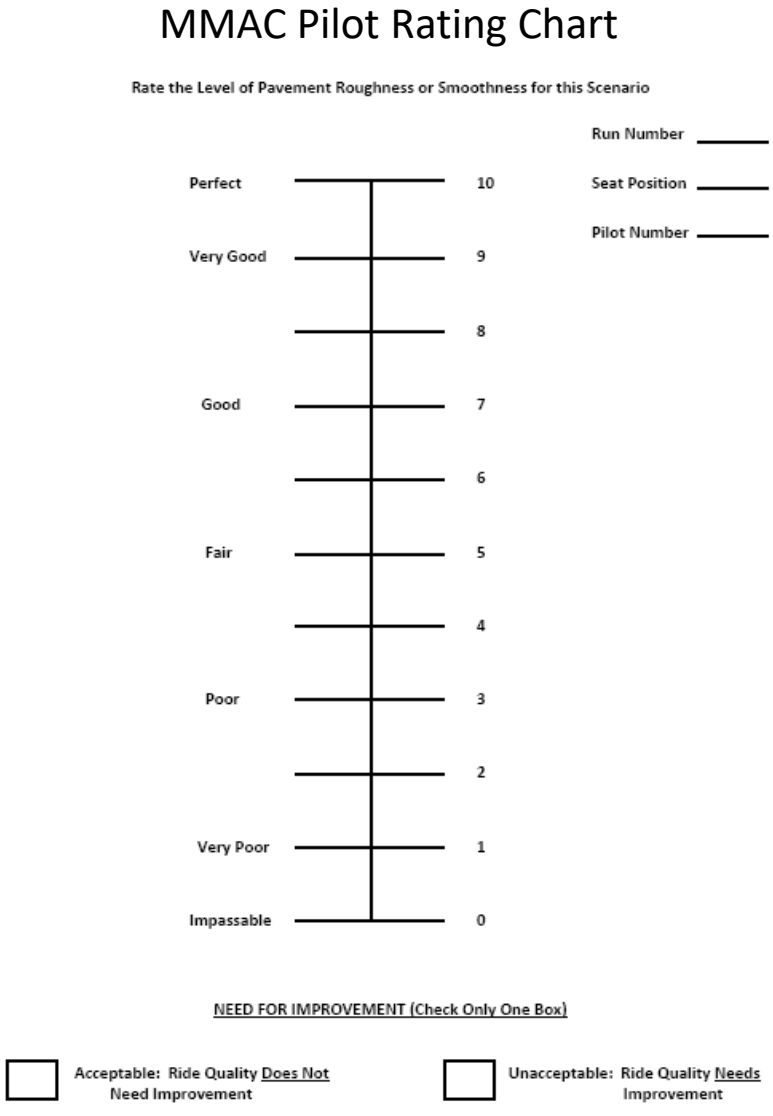


Figure A-1. Pilot Subjective Rating Form Provided by MMAC

PST 33 is a particularly interesting profile. Figure A-2 shows a plot of PST 33 along with PST 21 for comparison to a relatively smooth taxiway. PST 33 produced 0.81 *g*'s at the cockpit (CP) and

0.61 *g*'s at the center of gravity (CG). The sharp bump at 650 feet in section two caused the high response. Pavement Section 1 produced very mild response. The pilot rating for PST 33 was poor (1.63). This rating is for the full taxiway length.

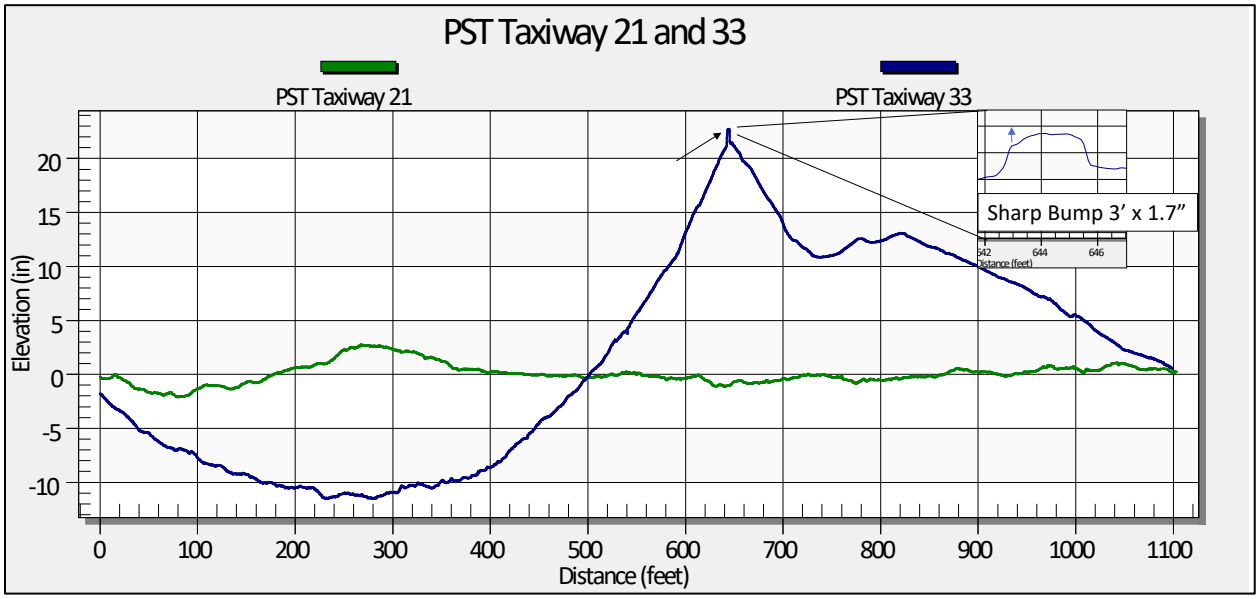


Figure A-2. Plot of PST 21 and PST 33

Both profile index (PI)-25 and the 12-foot straightedge (RSE) roughness assessment tools successfully located and quantified the sharp bump that caused the unacceptable response.

Once this discrete bump was identified, this Type 2 roughness would send the user to Step 3, where aircraft simulation would be used to determine what corrective action could be taken to eliminate the roughness and then design an optimized repair. All B737-800 PST taxiway simulations had a gross weight (GW) of 130,000 lb. Table A-1 the shows the threshold of acceptability for taxiways. Table A-2 shows the results. APRas used a CG location of 25.05% of the Mean Aerodynamic Chord.

Table A-1. Threshold of Acceptability for Taxiways

| *g* Criteria for Taxiways | PI-25<br>(0.40 BB) | 12-ft RSE |
|---|---|---|
| Red > 0.8 | Red > 35 | Red > ABS 0.8 |
| Yellow 0.40 to 0.8 | Yellow 20 to 35 | Yellow (ABS 0.4 to 0.8) |
| Green 0.4 | Green <20 | Green (ABS <0.4) |

ABS = Absolute value
BB = Blanking band
PI = Profile index

Table A-2. Results for PST—Taxiway

| Profile | Distance | 130,000 lb @ 20 Kts | | PI-25 | 12-ft RSE | Pilot Rating | |
|---|---|---|---|---|---|---|---|
| | | 737-800 CG | 737-800 CP | | | | |
| PST 5 | 1-500 | 0.05 | 0.05 | 0.00 | 0.00 | | 7.73 |
| | 501-1000 | 0.05 | 0.16 | 0.00 | 0.00 | | |
| PST 9 | 1-500 | 0.06 | 0.04 | 0.00 | 0.00 | | 7.36 |
| | 501-1000 | 0.28 | 0.36 | 32.07 | 0.72 | | |
| PST 12 | 1-500 | 0.18 | 0.21 | 29.36 | 0.00 | | 70.40 |
| | 501-1000 | 0.04 | 0.04 | 0.00 | 0.00 | | |
| PST 13 | 1-500 | 0.08 | 0.07 | 0.72 | 0.00 | | 6.63 |
| | 501-1000 | 0.07 | 0.1 | 11.00 | 0.00 | | |
| PST 15 | 1-500 | 0.24 | 0.21 | 60.49 | 0.65 | | 6.65 |
| | 501-1000 | 0.06 | 0.04 | 0.00 | 0.00 | | |
| PST 16 | 1-500 | 0.13 | 0.19 | 9.54 | 0.00 | | 6.66 |
| | 501-1000 | 0.05 | 0.07 | 11.70 | 0.00 | | |
| PST 20 | 1-500 | 0.26 | 0.42 | 11.59 | 0.71 | | 5.28 |
| | 501-1000 | 0.12 | 0.16 | 12.72 | 0.54 | | |
| PST 21 | 1-500 | 0.07 | 0.11 | 190.48 | 0.00 | | 5.58 |
| | 501-1000 | 0.10 | 0.09 | 12.23 | 0.00 | | |
| PST 22 | 1-500 | 0.12 | 0.15 | 30.23 | 0.00 | | 50.40 |
| | 501-1000 | 0.35 | 0.47 | 460.40 | 0.96 | | |
| PST 24 | 1-500 | 0.39 | 0.63 | 51.17 | 0.88 | | 6.08 |
| | 501-1000 | 0.06 | 0.09 | 20.49 | 0.00 | | |
| PST 26 | 1-500 | 0.20 | 0.27 | 410.41 | 0.63 | | 40.45 |
| | 501-1000 | 0.04 | 0.06 | 0.00 | 0.00 | | |
| PST 29 | 1-500 | 0.07 | 0.08 | 50.42 | 0.00 | | 4.73 |
| | 501-1000 | 0.41 | 0.55 | 77.62 | 1.10 | | |
| PST 33 | 1-500 | 0.09 | 0.14 | 28.16 | 0.00 | | 1.63 |
| | 501-1000 | 0.61 | 0.81 | 59.14 | 1.92 | | |
| PST 34 | 1-500 | 0.10 | 0.14 | 15.28 | 0.00 | | 1.98 |
| | 501-1000 | 0.67 | 0.81 | 54.91 | 10.40 | | |
| PST 35 | 1-500 | 0.10 | 0.25 | 48.74 | 0.47 | | 1.70 |
| | 501-1000 | 0.22 | 0.26 | 38.54 | 0.60 | | |
| PST 36 | 1-500 | 0.43 | 0.55 | 94.24 | 1.14 | | 0.87 |
| | 501-1000 | 0.31 | 0.501 | 66.00 | 1.29 | | |
| PST 37 | 1-500 | 0.43 | 0.56 | 69.32 | 1.36 | | 0.84 |
| | 501-1000 | 0.38 | 0.5 | 15.61 | 1.30 | | |

# APPENDIX B—PILOT SIMULATOR TEST PROFILES—RUNWAYS

This appendix contains the results of pilot simulator test (PST) runway analyses. The PST runway simulations were typically just over 5,000 feet in length, so each profile includes ten 500-foot sections. Pilot rating for each profile is listed in the last column of Table B-1. All B737-800 PST simulations had a gross weight (GW) of 130,000 lb. APR Consultants, Inc. (APR) computed and used a center of gravity (CG) location of 22.56% of the Mean Aerodynamic Chord. All simulated responses were conducted with the Airport Pavement Roughness Assessment Software (APRas).

A total of 12 PST runways were analyzed using profile index (PI)-100, PI-25, 12-foot straightedge (RSE), and the Boeing Bump Index (BBI) analysis tools.

It is interesting to note on PST 58 that pilots gave this runway a poor rating (4.0). Yet the *g* response was in the acceptable-slightly excessive range. This led to the lesson learned that pilots appear to be responding to aircraft pitch motion rather than *g* forces or gear loads. Figure E-1 in Appendix E of this report shows a plot of a 500-foot RSE that amplifies the multiple changes in grade that caused the frequent changes in pitch that were sensed by the pilots. Figure B-1 is a plot of the PST 58 profile, and Table B-2 shows the results.

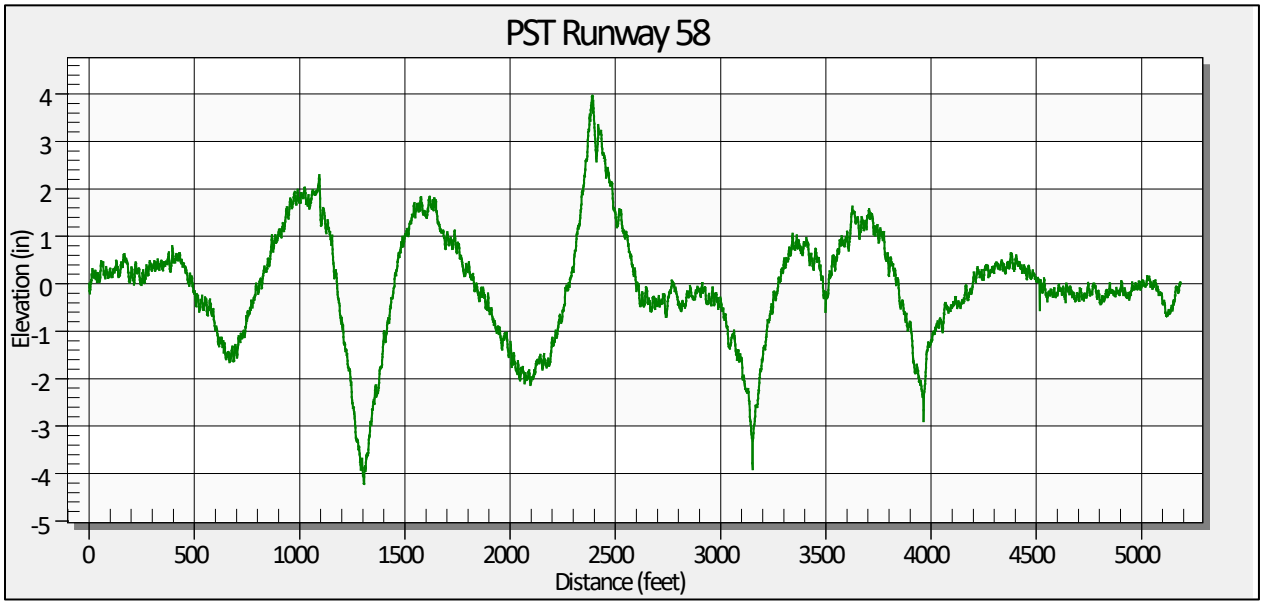


Figure B-1. Profile Plot of PST Runway 58

Table B-1. Limits of Acceptability

| PI-100 (1-in. BB) | PI-25-Ft (0.4-in. BB) | 12-ft RSE | BBI | MMAC Pilot Ratings |
|---|---|---|---|---|
| Red >35 | Red >35 | Red >(ABS 0.8) | Red >1.2 Unacceptable | Red >2 Needs Repair |
| Yellow 20 to 35 | Yellow 20 to 35 | Yellow (ABS 0.4 to 0.8) | Yellow 1.0 to 1.2 Excessive | Yellow <6.5 to 2 Poor |
| Green <20 | Green <20 | Green < (ABS 0.4) | Green <1.0 Acceptable | Green 10 to7 Acceptable |

ABS = Absolute value
BB = Blanking band
MMAC = Mike Monroney Aeronautical Center
PI = Profile Index

Table B-2. Results of PST for Runways

| PST Profile | Section (ft) | Peak CG | Peak CP | PI-100 | PI-25 | 12-ft RSE (in.) | BBI | Overall Pilot Rating |
|---|---|---|---|---|---|---|---|---|
| 41 | 0-500 | <0.54 | <0.54 | 0.00 | 0.00 | ABS <0.4 | Acceptable | 8.69 |
| | 501-1000 | <0.54 | <0.54 | 0.00 | 0.00 | ABS <0.4 | Acceptable | |
| | 1001-1500 | <0.54 | <0.54 | 0.00 | 0.00 | ABS <0.4 | Acceptable | |
| | 1501-2000 | <0.54 | <0.54 | 0.00 | 0.00 | ABS <0.4 | Acceptable | |
| | 2001-2500 | <0.54 | <0.54 | 0.00 | 0.00 | ABS <0.4 | Acceptable | |
| | 2501-3000 | <0.54 | <0.54 | 0.00 | 0.00 | ABS <0.4 | Acceptable | |
| | 3001-3500 | <0.54 | <0.54 | 0.00 | 0.00 | ABS <0.4 | Acceptable | |
| | 3501-4000 | <0.54 | <0.54 | 0.00 | 0.00 | ABS <0.4 | Acceptable | |
| | 4001-4500 | <0.54 | <0.54 | 0.00 | 0.00 | ABS <0.4 | Acceptable | |
| | 4501-5000 | <0.54 | <0.54 | 0.00 | 0.00 | ABS <0.4 | Acceptable | |
| | 5001-5500 | <0.54 | <0.54 | 0.00 | 0.00 | ABS <0.4 | Acceptable | |
| 45 | 0-500 | <0.54 | <0.54 | 0.00 | 0.17 | ABS <0.4 | Acceptable | 6.98 |
| | 501-1000 | <0.54 | <0.54 | 0.00 | 0.00 | ABS <0.4 | Acceptable | |
| | 1001-1500 | <0.54 | <0.54 | 0.00 | 0.97 | ABS <0.4 | Acceptable | |
| | 1501-2000 | <0.54 | <0.54 | 0.00 | 0.29 | ABS <0.4 | Acceptable | |
| | 2001-2500 | <0.54 | <0.54 | 0.00 | 0.00 | ABS <0.4 | Acceptable | |
| | 2501-3000 | <0.54 | <0.54 | 0.00 | 0.00 | ABS <0.4 | Acceptable | |
| | 3001-3500 | <0.54 | <0.54 | 2.72 | 40.45 | ABS <0.4 | Acceptable | |
| | 3501-4000 | <0.54 | <0.54 | 1.37 | 1.72 | ABS <0.4 | Acceptable | |
| | 4001-4500 | <0.54 | <0.54 | 0.00 | 0.00 | ABS <0.4 | Acceptable | |
| | 4501-5000 | <0.54 | <0.54 | 0.00 | 30.48 | ABS <0.4 | Acceptable | |
| | 5001-5500 | <0.54 | <0.54 | 0.00 | 0.00 | ABS <0.4 | Acceptable | |
| 54 | 0-500 | <0.54 | <0.54 | 14.73 | 13.26 | ABS <0.4 | Acceptable | 5.2 |
| | 501-1000 | <0.54 | <0.54 | 9.27 | 7.15 | ABS <0.4 | Acceptable | |
| | 1001-1500 | 0.56 | 0.88 | 39.03 | 16.11 | -0.70 | Excessive 1.2 | |
| | 1501-2000 | <0.54 | <0.54 | 0.00 | 0.00 | ABS <0.4 | Acceptable | |
| | 2001-2500 | <0.54 | <0.54 | 0.00 | 0.00 | ABS <0.4 | Acceptable | |

| PST Profile | Section (ft) | Peak CG | Peak CP | PI-100 | PI-25 | 12-ft RSE (in.) | BBI | Overall Pilot Rating |
|---|---|---|---|---|---|---|---|---|
| 54 | 2501-3000 | <0.54 | <0.54 | 6.99 | 7.12 | ABS <0.4 | Acceptable | 5.2 |
| | 3001-3500 | <0.54 | <0.54 | 5.87 | 0.98 | ABS <0.4 | Acceptable | |
| | 3501-4000 | <0.54 | <0.54 | 5.2 | 0.87 | ABS <0.4 | Acceptable | |
| | 4001-4500 | <0.54 | <0.54 | 3.94 | 1.18 | ABS <0.4 | Acceptable | |
| | 4501-5000 | <0.54 | <0.54 | 0.00 | 0.00 | ABS <0.4 | Acceptable | |
| | 5001-5500 | <0.54 | <0.54 | 0.00 | 0.00 | ABS <0.4 | Acceptable | |
| 58 | 0-500 | <0.54 | <0.54 | 0.00 | 7.95 | ABS <0.4 | Acceptable | 4.04 |
| | 501-1000 | <0.54 | <0.54 | 1.35 | 4.71 | ABS <0.4 | Acceptable | |
| | 1001-1500 | <0.54 | <0.54 | 17.32 | 19.17 | 0.53 | Acceptable | |
| | 1501-2000 | <0.54 | <0.54 | 0.89 | 8.01 | ABS <0.4 | Acceptable | |
| | 2001-2500 | <0.54 | <0.54 | 130.48 | 17.53 | ABS <0.4 | Acceptable | |
| | 2501-3000 | <0.54 | <0.54 | 0.00 | 8.56 | ABS <0.4 | Acceptable | |
| | 3001-3500 | <0.54 | 0.55 | 23.65 | 150.47 | -0.44 | Acceptable | |
| | 3501-4000 | <0.54 | 0.58 | 8.1 | 22.63 | ABS <0.4 | Acceptable | |
| | 4001-4500 | <0.54 | <0.54 | 0.00 | 5.03 | ABS <0.4 | Acceptable | |
| | 4501-5000 | <0.54 | <0.54 | 0.00 | 0.48 | ABS <0.4 | Acceptable | |
| | 5001-5500 | <0.54 | <0.54 | 0.00 | 0.55 | ABS <0.4 | Acceptable | |
| PST 61 | 0-500 | <0.54 | 0.55 | 33.04 | 10.02 | ABS <0.4 | Acceptable | 4.31 |
| | 501-1000 | <0.54 | <0.54 | 9.61 | 9.17 | ABS <0.4 | Acceptable | |
| | 1001-1500 | <0.54 | <0.54 | 13.32 | 10.40 | ABS <0.4 | Acceptable | |
| | 1501-2000 | <0.54 | <0.54 | 0.93 | 40.45 | ABS <0.4 | Acceptable | |
| | 2001-2500 | <0.54 | <0.54 | 0.43 | 2.04 | ABS <0.4 | Acceptable | |
| | 2501-3000 | <0.54 | <0.54 | 0.00 | 0.00 | ABS <0.4 | Acceptable | |
| | 3001-3500 | <0.54 | <0.54 | 0.00 | 0.96 | ABS <0.4 | Acceptable | |
| | 3501-4000 | <0.54 | <0.54 | 1.89 | 0.55 | ABS <0.4 | Acceptable | |
| | 4001-4500 | <0.54 | <0.54 | 0.78 | 7.27 | ABS <0.4 | Acceptable | |
| | 4501-5000 | <0.54 | <0.54 | 0.00 | 0.50 | ABS <0.4 | Acceptable | |
| | 5001-5500 | <0.54 | <0.54 | 0.00 | 0.00 | ABS <0.4 | Acceptable | |

| PST Profile | Section (ft) | Peak CG | Peak CP | PI-100 | PI-25 | 12-ft RSE (in.) | BBI | Overall Pilot Rating |
|---|---|---|---|---|---|---|---|---|
| PST 62 | 0-500 | <0.54 | <0.54 | 8.74 | 10.91 | ABS <0.4 | Acceptable | 3.16 |
| | 501-1000 | <0.54 | <0.54 | 20.06 | 26.28 | ABS <0.4 | Acceptable | |
| | 1001-1500 | <0.54 | <0.54 | 9.52 | 14.30 | ABS <0.4 | Acceptable | |
| | 1501-2000 | <0.54 | <0.54 | 12.55 | 39.59 | ABS <0.4 | Acceptable | |
| | 2001-2500 | <0.54 | <0.54 | 3.98 | 13.89 | ABS <0.4 | Acceptable | |
| | 2501-3000 | <0.54 | <0.54 | 1.52 | 18.68 | ABS <0.4 | Acceptable | |
| | 3001-3500 | <0.54 | <0.54 | 2.16 | 16.52 | ABS <0.4 | Acceptable | |
| | 3501-4000 | <0.54 | <0.54 | 0.00 | 2.00 | ABS <0.4 | Acceptable | |
| | 4001-4500 | <0.54 | <0.54 | 0.00 | 3.35 | ABS <0.4 | Acceptable | |
| | 4501-5000 | <0.54 | <0.54 | 13.01 | 4.56 | ABS <0.4 | Acceptable | |
| | 5001-5500 | <0.54 | <0.54 | 0.00 | 9.39 | ABS <0.4 | Acceptable | |
| PST 68 | 0-500 | <0.54 | <0.54 | 0.00 | 3.62 | ABS <0.4 | Acceptable | 4.92 |
| | 501-1000 | <0.54 | <0.54 | 0.00 | 0.30 | ABS <0.4 | Acceptable | |
| | 1001-1500 | <0.54 | <0.54 | 70.45 | 20.43 | ABS <0.4 | Acceptable | |
| | 1501-2000 | <0.54 | <0.54 | 1.73 | 9.92 | ABS <0.4 | Acceptable | |
| | 2001-2500 | <0.54 | <0.54 | 6.1 | 13.98 | 0.41 | Acceptable | |
| | 2501-3000 | <0.54 | <0.54 | 0.00 | 4.38 | ABS <0.4 | Acceptable | |
| | 3001-3500 | <0.54 | <0.54 | 0.00 | 10.40 | ABS <0.4 | Acceptable | |
| | 3501-4000 | <0.54 | <0.54 | 0.00 | 2.50 | ABS <0.4 | Acceptable | |
| | 4001-4500 | <0.54 | <0.54 | 0.47 | 4.54 | ABS <0.4 | Acceptable | |
| | 4501-5000 | <0.54 | <0.54 | 0.00 | 1.26 | ABS <0.4 | Acceptable | |
| | 5001-5500 | <0.54 | <0.54 | 0.00 | 80.48 | ABS <0.4 | Acceptable | |
| PST 71 | 0-500 | <0.54 | 0.72 | 25.79 | 9.28 | ABS <0.4 | Acceptable | 1.53 |
| | 501-1000 | <0.54 | <0.54 | 21.76 | 20.59 | 0.45 | Acceptable | |
| | 1001-1500 | <0.54 | <0.54 | 35.86 | 42.24 | 0.49 | Acceptable | |
| | 1501-2000 | 0.68 | 0.68 | 44.28 | 20.59 | 0.66 | Excessive 1.2 | |
| | 2001-2500 | 0.67 | 0.67 | 43.36 | 20.59 | 0.48 | Acceptable | |
| | 2501-3000 | 0.77 | 0.94 | 55.12 | 36.96 | 0.47 | Unacceptable 1.6 | |

| PST Profile | Section (ft) | Peak CG | Peak CP | PI-100 | PI-25 | 12-ft RSE (in.) | BBI | Overall Pilot Rating |
|---|---|---|---|---|---|---|---|---|
| PST 71 | 3001-3500 | <0.54 | <0.54 | 17.29 | 7.39 | ABS <0.4 | Acceptable | 1.53 |
| | 3501-4000 | <0.54 | <0.54 | 110.45 | 16.9 | 0.61 | Acceptable | |
| | 4001-4500 | <0.54 | 0.78 | 37.21 | 26.93 | 0.51 | Acceptable | |
| | 4501-5000 | 0.62 | <0.54 | 25.7 | 9.5 | ABS <0.4 | Acceptable | |
| PST 73 | 0-500 | 0.78 | 0.95 | 49.27 | 50.76 | 0.49 | Excessive 1.0 | 0.96 |
| | 501-1000 | <0.54 | <0.54 | 39.73 | 49.63 | 0.4 | Acceptable | |
| | 1001-1500 | <0.54 | <0.54 | 19.11 | 34.85 | 0.4 | Acceptable | |
| | 1501-2000 | <0.54 | 0.72 | 470.42 | 40.66 | 0.47 | Excessive 1.1 | |
| | 2001-2500 | <0.54 | <0.54 | 25.19 | 50.69 | ABS <0.4 | Acceptable | |
| | 2501-3000 | 0.64 | 0.59 | 56.9 | 57.02 | 0.56 | Acceptable | |
| | 3001-3500 | <0.54 | 0.59 | 39.18 | 59.14 | 0.39 | Acceptable | |
| | 3501-4000 | 0.68 | 0.69 | 45.72 | 740.45 | 0.45 | Excessive 1.1 | |
| | 4001-4500 | <0.54 | <0.54 | 40.47 | 42.77 | 0.4 | Excessive 1.1 | |
| | 4501-5000 | 0.73 | 0.61 | 38.66 | 42.77 | ABS <0.4 | Acceptable | |
| | 5001-5500 | <0.54 | <0.54 | 16.06 | 310.42 | ABS <0.4 | Acceptable | |
| PST 75 | 0-500 | <0.54 | <0.54 | 99.33 | 57.87 | 0.43 | Unacceptable 1.6 | 1.15 |
| | 501-1000 | <0.54 | 0.61 | 73.26 | 57.79 | 0.46 | Excessive 1.2 | |
| | 1001-1500 | 0.9 | 10.41 | 26.87 | 48.34 | 0.44 | Acceptable | |
| | 1501-2000 | <0.54 | 0.72 | 27.98 | 61.09 | 0.47 | Acceptable | |
| | 2001-2500 | 0.68 | 0.81 | 38.25 | 72.08 | ABS <0.4 | Acceptable | |
| | 2501-3000 | 0.99 | 1.09 | 27.34 | 44.35 | ABS <0.4 | Acceptable | |
| | 3001-3500 | 1.03 | 1.01 | 17.08 | 51.82 | 0.43 | Acceptable | |
| PST 75 | 3501-4000 | -0.72 | -0.92 | 32.36 | 610.41 | 0.51 | Acceptable | 1.15 |
| | 4001-4500 | 0.68 | 0.85 | 0.97 | 41.86 | 0.57 | Acceptable | |
| | 4501-5000 | 0.65 | 0.58 | 6.01 | 48.78 | 0.41 | Acceptable | |
| | 5001-5500 | <0.54 | 0.67 | 0.00 | 54.70 | 0.43 | Acceptable | |
| PST 76 | 0-500 | <0.54 | <0.54 | 38.12 | 67.14 | 0.43 | Acceptable | 0.8 |
| | 501-1000 | <0.54 | 0.7 | 67.61 | 88.18 | 0.69 | Acceptable | |
| | 1001-1500 | 0.57 | 0.71 | 62.65 | 72.34 | 0.56 | Excessive 1.2 | |

| PST Profile | Section (ft) | Peak CG | Peak CP | PI-100 | PI-25 | 12-ft RSE (in.) | BBI | Overall Pilot Rating |
|---|---|---|---|---|---|---|---|---|
| PST 76 | 1501-2000 | 0.57 | <0.54 | 9.58 | 22.18 | 0.47 | Acceptable | 0.8 |
| | 2001-2500 | 0.57 | <0.54 | 26.54 | 26.93 | ABS <0.4 | Acceptable | |
| | 2501-3000 | <0.54 | 0.67 | 53.72 | 22.7 | ABS <0.4 | Acceptable | |
| | 3001-3500 | 1.03 | <0.59 | 60.45 | 38.02 | 0.48 | Acceptable | |
| | 3501-4000 | 0.57 | 0.7 | 100.33 | 54.91 | 0.49 | Acceptable | |
| | 4001-4500 | 0.97 | 1.25 | 70.02 | 53.33 | 0.42 | Acceptable | |
| | 4501-5000 | 0.55 | 0.97 | 61.71 | 53.86 | 0.41 | Acceptable | |
| | 5001-5500 | <0.54 | <0.54 | 62.62 | 37.59 | 0.43 | Acceptable | |
| PST 77 | 0-500 | <0.54 | <0.54 | 12.1 | 34.93 | 0.43 | Acceptable | 0.51 |
| | 501-1000 | <0.54 | 0.61 | 84.85 | 56.5 | 0.58 | Excessive 1.0 | |
| | 1001-1500 | 0.89 | 10.41 | 100.05 | 62.83 | 0.52 | Excessive 1.1 | |
| | 1501-2000 | <0.54 | 0.69 | 65.03 | 68.11 | 0.71 | Acceptable | |
| | 2001-2500 | 0.69 | 0.79 | 77.52 | 83.95 | 0.63 | Excessive 1.04 | |
| | 2501-3000 | 0.73 | 1.01 | 115.05 | 740.45 | -0.48 | Acceptable | |
| | 3001-3500 | 1.03 | 0.99 | 84.65 | 67.58 | ABS <0.4 | Unacceptable 2.03 | |
| | 3501-4000 | 0.57 | -0.94 | 79.97 | 97.15 | ABS <0.4 | Excessive 1.05 | |
| | 4001-4500 | 0.71 | 0.69 | 50.41 | 40.13 | ABS <0.4 | Acceptable | |
| | 4501-5000 | <0.54 | <0.54 | 38.95 | 40.66 | ABS <0.4 | Excessive 1.08 | |
| | 5001-5500 | <0.54 | 0.68 | 64.56 | 550.44 | ABS <0.4 | Excessive 1.1 | |

ABS = Absolute value
BBI = Boeing Bump Index
CG = Center of gravity
CP = Cockpit
PI = Profile index
RSE = (Rolling) Straightedge

# APPENDIX C—COMMERCIAL AND MILITARY RUNWAYS

This appendix contains the results of commercial and military runway analyses. All simulated responses were conducted with the Airport Pavement Roughness Assessment Software (APRas).

More than 40 commercial and military runway profiles were evaluated. Several were measured with a high-speed profiler, but most were measured with the Auto Rod & Level–ER (AR&L–ER) true profiler. The profiles for R7 and R8 were measured with an Ames high speed inertial profiler and the AR&L–ER. The profile analysis results show that either measurement device would have produced the same end results. R7 was smooth-new asphalt runway. R8 is a Portland concrete cement (PCC) runway with a mild discrete bump.

R4 and R12 are rough GA runways.

R13 is an as-built runway with topographical profile data measured on 25-foot increments. This runway failed the BBI assessment. Evaluation of this runway determined that a runway intersection did not meet design standards.

R24 shows the results when using the centerline (CL), 12.5 feet right of the CL, and 25 feet right of the CL. This runway intersected with another runway. Running the three different lines of survey show the impact of the crown of an intersecting runway as you move away from the CL. (Figure C-1).

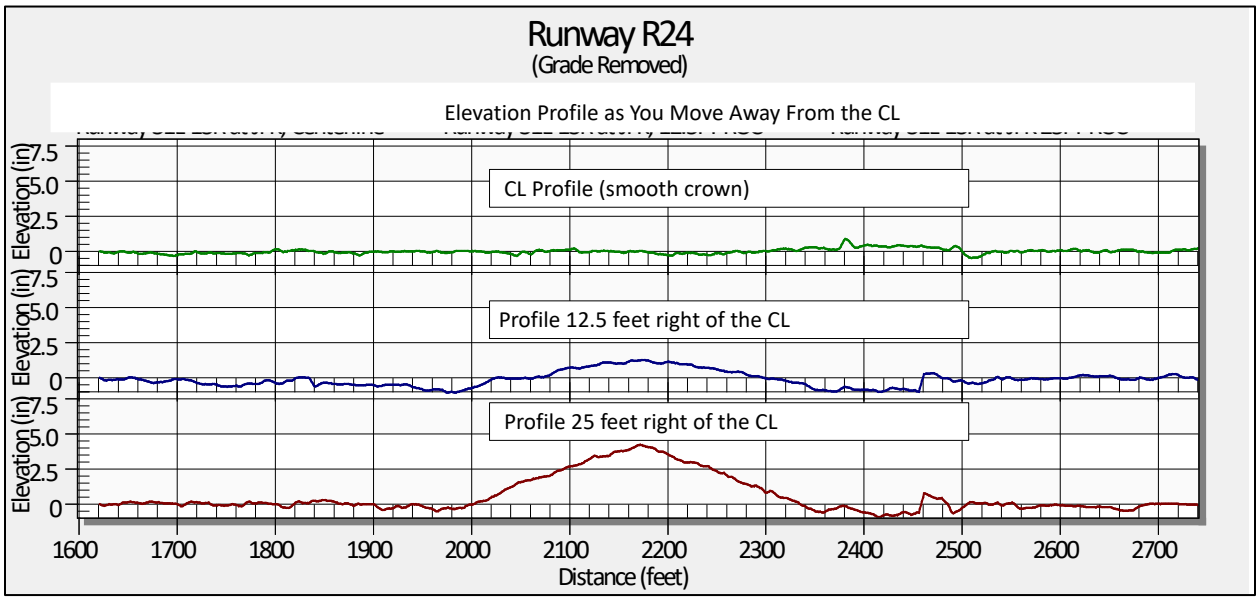


Figure C-1. Impact of Intersection Crown on Longitudinal Profile

Table C-1. Limits of Acceptability

| Boeing Criteria (CG) | PI-100 | PI-25 (0.4 BB) | 12-Foot RSE | BBI |
|---|---|---|---|---|
| Red >0.80 | Red >35 | Red >35 | Red >(ABS 0.8) | Red >1.2 Unacceptable |
| Yellow 0.54 to 0.80 | Yellow 20 to 35 | Yellow 20 to 35 | Yellow (ABS 0.4 to .8) | Yellow 1.0 to 1.2 Excessive |
| Green <0.54 | Green <20 | Green <20 | Green <(ABS 0.4) | Green <1.0 Acceptable |

ABS = Absolute value
BB = Blanking band
BBI = Boeing Bump Index
CG = Center of gravity
PI = Profile index
RSE = (Rolling) Straightedge

Table C-2. Commercial and Military Runways

| Runway | Section (ft) | CG | CP | PI-100 | PI-25 | 12-ft RSE | BBI |
|---|---|---|---|---|---|---|---|
| R1 | 0-500 | 0.7 | 0.92 | 113.01 | 19.13 | < ABS (4) | Acceptable |
| | 501-1000 | 0.6 | 0.81 | 52.01 | 2.11 | < ABS (4) | Acceptable |
| | 1001-1500 | <0.54 | <0.54 | 5.11 | 2.11 | < ABS (4) | Acceptable |
| | 1500-2000 | <0.54 | <0.54 | 12.11 | 2.64 | < ABS (4) | Acceptable |
| | 2001-2500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 2501-3000 | <0.54 | <0.54 | 0.83 | 1.06 | < ABS (4) | Acceptable |
| | 3001-3500 | <0.54 | <0.54 | 5.07 | 0.00 | < ABS (4) | Acceptable |
| | 3501-4000 | <0.54 | <0.54 | 0.87 | 0.00 | < ABS (4) | Acceptable |
| | 4001-4500 | <0.54 | <0.54 | 0.41 | 0.00 | < ABS (4) | Acceptable |
| | 4501-5000 | <0.54 | <0.54 | 0.27 | 0.00 | < ABS (4) | Acceptable |
| | 5001-5500 | <0.54 | 0.62 | 1.25 | 0.53 | < ABS (4) | Acceptable |
| | 5501-6000 | <0.54 | <0.54 | 3.21 | 0.00 | < ABS (4) | Acceptable |
| | 6001-6500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 6501-7000 | <0.54 | <0.54 | 0.75 | 0.00 | < ABS (4) | Acceptable |
| | 7001-7500 | <0.54 | <0.54 | 0.00 | 6.34 | < ABS (4) | Acceptable |
| | 7501-8000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 8001-8500 | <0.54 | <0.54 | 20.42 | 0.00 | < ABS (4) | Acceptable |
| | 8501-9000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 9001-9500 | <0.54 | <0.54 | 3.29 | 6.86 | < ABS (4) | Acceptable |
| | 9501-10000 | <0.54 | <0.54 | 6.26 | 550.44 | 0.052 | Acceptable |
| | 10001-10500 | 0.59 | 0.85 | 59.51 | 38.02 | < ABS (4) | Acceptable |
| | 10501-11000 | <0.54 | <0.54 | 17.17 | 33.26 | < ABS (4) | Acceptable |
| R2 | 0-500 | 0.61 | 0.7 | 80.21 | 33.01 | < ABS (4) | 1.15 |
| | 501-1000 | 0.83 | 0.71 | 22.92 | 180.49 | < ABS (4) | 10.44 |
| | 1001-1500 | 1.01 | 1.15 | 87.25 | 41.24 | 0.43 | 1.34 |
| | 1500-2000 | 1.11 | 0.91 | 47.02 | 38.03 | 0.41 | 1.38 |
| | 2001-2500 | 0.72 | 1.1 | 44.27 | 25.32 | < ABS (4) | 1.17 |
| | 2501-3000 | <0.54 | 0.62 | 14.13 | 70.48 | < ABS (4) | 1.17 |
| | 3001-3500 | 0.94 | 1 | 61.76 | 21.77 | < ABS (4) | 1.17 |
| | 3501-4000 | <0.54 | 0.57 | 20.07 | 2.19 | < ABS (4) | Acceptable |
| | 4001-4500 | <0.54 | 0.58 | 230.44 | 30.47 | < ABS (4) | Acceptable |
| | 4501-5000 | <0.54 | 0.9 | 66.97 | 380.4 | < ABS (4) | 1.11 |
| | 5001-5500 | 0.98 | 1 | 73.59 | 68.59 | 0.61 | 10.47 |
| R3 | 0-500 | <0.54 | <0.54 | 0.00 | 1.09 | < ABS (4) | Acceptable |
| | 501-1000 | <0.54 | <0.54 | 3.26 | 1.06 | < ABS (4) | Acceptable |
| | 1001-1500 | <0.54 | <0.54 | 6.88 | 3.17 | < ABS (4) | Acceptable |
| | 1500-2000 | 0.65 | 0.81 | 26.16 | 5.28 | < ABS (4) | Acceptable |
| | 2001-2500 | 0.55 | 0.79 | 38.88 | 6.86 | < ABS (4) | Acceptable |
| | 2501-3000 | <0.54 | <0.54 | 23.84 | 4.22 | < ABS (4) | Acceptable |
| | 3001-3500 | <0.54 | <0.54 | 39.37 | 5.28 | < ABS (4) | Acceptable |

| Runway | Section (ft) | CG | CP | PI-100 | PI-25 | 12-ft RSE | BBI |
|---|---|---|---|---|---|---|---|
| R3 | 3501-4000 | <0.54 | <0.54 | 12.97 | 7.92 | < ABS (4) | Acceptable |
| | 4001-4500 | <0.54 | <0.54 | 0.00 | 0.53 | < ABS (4) | Acceptable |
| | 4501-5000 | <0.54 | <0.54 | 7.28 | 1.58 | < ABS (4) | Acceptable |
| | 5001-5500 | <0.54 | <0.54 | 2 | 80.45 | < ABS (4) | Acceptable |
| | 5501-6000 | <0.54 | <0.54 | 2.02 | 5.28 | < ABS (4) | Acceptable |
| | 6001-6500 | <0.54 | <0.54 | 1.96 | 2.11 | < ABS (4) | Acceptable |
| | 6501-7000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 7001-7500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 7501-8000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 8001-8500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 8501-9000 | <0.54 | <0.54 | 0.34 | 0.53 | < ABS (4) | Acceptable |
| | 9001-9500 | <0.54 | <0.54 | 0.48 | 7.39 | < ABS (4) | Acceptable |
| | 9501-10000 | <0.54 | <0.54 | 1.68 | 1.58 | 0.42 | Acceptable |
| | 10001-10500 | <0.54 | <0.54 | 0.00 | 0.53 | < ABS (4) | Acceptable |
| | 10501-11000 | <0.54 | 0.69 | 14.31 | 0.53 | < ABS (4) | Acceptable |
| R4 | 0-500 | <0.54 | <0.54 | 6.96 | 20.22 | < ABS (4) | Acceptable |
| | 501-1000 | <0.54 | <0.54 | 4.78 | 5.64 | < ABS (4) | Acceptable |
| | 1001-1500 | <0.54 | <0.54 | 5.35 | 24.64 | 0.41 | Acceptable |
| | 1500-2000 | <0.54 | <0.54 | 9.34 | 20.87 | < ABS (4) | Acceptable |
| | 2001-2500 | <0.54 | 0.65 | 7.65 | 28.05 | 0.47 | Acceptable |
| | 2501-3000 | <0.54 | <0.54 | 2.79 | 14.81 | < ABS (4) | Acceptable |
| | 3001-3500 | <0.54 | <0.54 | 20.41 | 8.85 | 0.45 | Acceptable |
| | 3501-4000 | <0.54 | <0.54 | 0.93 | 5.28 | < ABS (4) | Acceptable |
| | 4001-4500 | <0.54 | <0.54 | 80.41 | 8.68 | < ABS (4) | Acceptable |
| | 4501-5000 | <0.54 | <0.54 | 7 | 16.13 | < ABS (4) | Acceptable |
| | 5001-5500 | <0.54 | <0.54 | 0.54 | 9.72 | < ABS (4) | Acceptable |
| | 5501-6000 | <0.54 | <0.54 | 3.78 | 140.4 | < ABS (4) | Acceptable |
| | 6001-6500 | <0.54 | <0.54 | 0 | 6.14 | < ABS (4) | Acceptable |
| R5 | 0-500 | <0.54 | 0.6 | 48.07 | 38.31 | 0.44 | Acceptable |
| | 501-1000 | <0.54 | 0.77 | 37.56 | 57.53 | 0.48 | Acceptable |
| | 1001-1500 | 0.64 | 0.73 | 57.6 | 60.92 | 0.43 | Acceptable |
| | 1500-2000 | 0.63 | 1.1 | 39.94 | 48.23 | 0.43 | Acceptable |
| | 2001-2500 | 1.05 | 0.68 | 74.27 | 55.35 | 0.41 | 1.18 |
| | 2501-3000 | <0.54 | <0.54 | 31.25 | 50.24 | 0.41 | Acceptable |
| | 3001-3500 | <0.54 | <0.54 | 360.48 | 420.45 | 0.47 | Acceptable |
| | 3501-4000 | <0.54 | <0.54 | 6.89 | 5.72 | < ABS (4) | Acceptable |
| R6 | 0-500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 501-1000 | <0.54 | <0.54 | 40.4 | 0.00 | < ABS (4) | Acceptable |
| | 1001-1500 | <0.54 | 0.73 | 18.7 | 2.64 | < ABS (4) | Acceptable |
| | 1500-2000 | <0.54 | <0.54 | 4.66 | 3.17 | < ABS (4) | Acceptable |
| | 2001-2500 | 0.71 | 0.92 | 57.01 | 8.98 | < ABS (4) | Acceptable |

| Runway | Section (ft) | CG | CP | PI-100 | PI-25 | 12-ft RSE | BBI |
|---|---|---|---|---|---|---|---|
| R6 | 2501-3000 | <0.54 | <0.54 | 6.24 | 2.64 | < ABS (4) | Acceptable |
| | 3001-3500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 3501-4000 | <0.54 | <0.54 | 10.37 | 4.22 | < ABS (4) | Acceptable |
| | 4001-4500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 4501-5000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 5001-5500 | <0.54 | <0.54 | 20.4 | 0.00 | < ABS (4) | Acceptable |
| | 5501-6000 | <0.54 | <0.54 | 1.91 | 2.64 | < ABS (4) | Acceptable |
| | 6001-6500 | <0.54 | <0.54 | 0.58 | 0.00 | < ABS (4) | Acceptable |
| | 6501-7000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 7001-7500 | <0.54 | <0.54 | 40.42 | 0.53 | < ABS (4) | Acceptable |
| | 7501-8000 | <0.54 | <0.54 | 7.16 | 2.11 | < ABS (4) | Acceptable |
| | 8001-8500 | <0.54 | <0.54 | 8.39 | 0.53 | < ABS (4) | Acceptable |
| | 8501-9000 | <0.54 | <0.54 | 1.18 | 2.11 | < ABS (4) | Acceptable |
| | 9001-9500 | <0.54 | <0.54 | 0.00 | 3.7 | < ABS (4) | Acceptable |
| | 9501-10000 | <0.54 | <0.54 | 2.83 | 0.00 | < ABS (4) | Acceptable |
| | 10001-10500 | <0.54 | <0.54 | 1.77 | 0.00 | < ABS (4) | Acceptable |
| | 10501-11000 | <0.54 | <0.54 | 0.00 | 1.58 | < ABS (4) | Acceptable |
| | 11001-11500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 11501-12000 | <0.54 | <0.54 | 13.62 | 5.61 | < ABS (4) | Acceptable |
| R7 AR&L | 0-500 | <0.54 | <0.54 | 0.00 | 2.73 | < ABS (4) | Acceptable |
| | 501-1000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 1001-1500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 1500-2000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 2001-2500 | <0.54 | <0.54 | 0.42 | 0.00 | < ABS (4) | Acceptable |
| | 2501-3000 | <0.54 | <0.54 | 0.45 | 0.00 | < ABS (4) | Acceptable |
| | 3001-3500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 3501-4000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 4001-4500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 4501-5000 | <0.54 | <0.54 | 0.37 | 0.00 | < ABS (4) | Acceptable |
| | 5001-5500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 5501-6000 | <0.54 | <0.54 | 0.33 | 0.00 | < ABS (4) | Acceptable |
| | 6001-6500 | <0.54 | <0.54 | 0.00 | 0.53 | < ABS (4) | Acceptable |
| | 6501-7000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 7001-7500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 7501-8000 | <0.54 | <0.54 | 5.37 | 0.55 | < ABS (4) | Acceptable |
| R7 AMES | 0-500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 501-1000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 1001-1500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 1500-2000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 2001-2500 | <0.54 | <0.54 | 0.06 | 0.00 | < ABS (4) | Acceptable |
| | 2501-3000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 3001-3500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |

| Runway | Section (ft) | CG | CP | PI-100 | PI-25 | 12-ft RSE | BBI |
|---|---|---|---|---|---|---|---|
| R7 AMES | 3501-4000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 4001-4500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 4501-5000 | <0.54 | <0.54 | 0.37 | 0.00 | < ABS (4) | Acceptable |
| | 5001-5500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 5501-6000 | <0.54 | <0.54 | 0.47 | 0.00 | < ABS (4) | Acceptable |
| | 6001-6500 | <0.54 | <0.54 | 0.00 | 1.06 | < ABS (4) | Acceptable |
| | 6501-7000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 7001-7500 | <0.54 | <0.54 | 0.37 | 0.00 | < ABS (4) | Acceptable |
| | 7501-8000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| R8 AR&L | 0-500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 501-1000 | <0.54 | <0.54 | 0.46 | 0.53 | < ABS (4) | Acceptable |
| | 1001-1500 | <0.54 | <0.54 | 0.00 | 1.58 | < ABS (4) | Acceptable |
| | 1500-2000 | <0.54 | <0.54 | 0.00 | 0.53 | < ABS (4) | Acceptable |
| | 2001-2500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 2501-3000 | <0.54 | <0.54 | 12.6 | 5.28 | < ABS (4) | Acceptable |
| | 3001-3500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 3501-4000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| R8 Ames | 0-500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 501-1000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 1001-1500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 1500-2000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 2001-2500 | <0.54 | <0.54 | 0.06 | 0.00 | < ABS (4) | Acceptable |
| | 2501-3000 | <0.54 | <0.54 | 13.87 | 5.28 | < ABS (4) | Acceptable |
| | 3001-3500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 3501-4000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| R9 | 0-500 | <0.54 | <0.54 | 6.26 | 25.51 | < ABS (4) | Acceptable |
| | 501-1000 | <0.54 | 0.59 | 23.73 | 38.54 | < ABS (4) | Acceptable |
| | 1001-1500 | <0.54 | <0.54 | 3.2 | 19.33 | < ABS (4) | Acceptable |
| | 1500-2000 | <0.54 | <0.54 | 8.19 | 25.06 | 0.48 | Acceptable |
| | 2001-2500 | <0.54 | <0.54 | 13.92 | 23.32 | 0.41 | Acceptable |
| | 2501-3000 | <0.54 | <0.54 | 90.43 | 43.98 | 0.41 | Acceptable |
| | 3001-3500 | <0.54 | <0.54 | 12.8 | 27.94 | < ABS (4) | Acceptable |
| | 3501-4000 | <0.54 | <0.54 | 70.48 | 19.11 | < ABS (4) | Acceptable |
| | 4001-4500 | <0.54 | <0.54 | 5.53 | 42.39 | 0.42 | Acceptable |
| | 4501-5000 | <0.54 | <0.54 | 18.94 | 33.18 | < ABS (4) | Acceptable |
| | 5001-5500 | <0.54 | <0.54 | 21.09 | 140.48 | < ABS (4) | Acceptable |
| | 5501-6000 | <0.54 | <0.54 | 30.92 | 60.71 | 0.45 | Acceptable |
| | 6001-6500 | <0.54 | <0.54 | 15.08 | 20.78 | < ABS (4) | Acceptable |
| | 6501-7000 | <0.54 | <0.54 | 7.77 | 36.25 | 0.69 | Acceptable |
| | 7001-7500 | <0.54 | 0.71 | 23.16 | 20.35 | < ABS (4) | Acceptable |
| | 7501-8000 | <0.54 | <0.54 | 9.86 | 170.49 | < ABS (4) | Acceptable |

| Runway | Section (ft) | CG | CP | PI-100 | PI-25 | 12-ft RSE | BBI |
|---|---|---|---|---|---|---|---|
| R9 | 8001-8500 | <0.54 | 0.75 | 7.61 | 8.57 | < ABS (4) | Acceptable |
| | 8501-9000 | <0.54 | <0.54 | 23.03 | 17.55 | 0.41 | Acceptable |
| | 9001-9500 | <0.54 | <0.54 | 13.38 | 14.57 | < ABS (4) | Acceptable |
| | 9501-10000 | <0.54 | <0.54 | 12.01 | 23.06 | < ABS (4) | Acceptable |
| | 10001-10500 | <0.54 | <0.54 | 60.43 | 21.61 | 0.43 | Acceptable |
| | 10501-11000 | <0.54 | <0.54 | 8.21 | 170.42 | < ABS (4) | Acceptable |
| | 11001-11500 | <0.54 | <0.54 | 6.36 | 16.26 | 0.46 | Acceptable |
| R10 | 0-500 | <0.54 | 0.56 | 11.02 | 17.25 | < ABS (4) | Acceptable |
| | 501-1000 | <0.54 | <0.54 | 2.11 | 110.49 | 0.42 | Acceptable |
| | 1001-1500 | <0.54 | <0.54 | 8.95 | 14.65 | < ABS (4) | Acceptable |
| | 1500-2000 | <0.54 | <0.54 | 10.41 | 80.48 | < ABS (4) | Acceptable |
| | 2001-2500 | <0.54 | <0.54 | 6.63 | 10.91 | < ABS (4) | Acceptable |
| | 2501-3000 | <0.54 | <0.54 | 1.52 | 20.33 | < ABS (4) | Acceptable |
| | 3001-3500 | <0.54 | <0.54 | 10.46 | 25 | < ABS (4) | Acceptable |
| | 3501-4000 | <0.54 | <0.54 | 10.46 | 21.93 | < ABS (4) | Acceptable |
| | 4001-4500 | <0.54 | <0.54 | 16.65 | 22.6 | 0.42 | Acceptable |
| | 4501-5000 | <0.54 | <0.54 | 0.71 | 15.7 | < ABS (4) | Acceptable |
| | 5001-5500 | <0.54 | <0.54 | 2.28 | 10.67 | < ABS (4) | Acceptable |
| | 5501-6000 | <0.54 | <0.54 | 13.92 | 32.71 | < ABS (4) | Acceptable |
| | 6001-6500 | <0.54 | <0.54 | 5.75 | 10.79 | < ABS (4) | Acceptable |
| | 6501-7000 | <0.54 | <0.54 | 140.41 | 32.73 | < ABS (4) | Acceptable |
| | 7001-7500 | <0.54 | <0.54 | 4.75 | 9.2 | < ABS (4) | Acceptable |
| | 7501-8000 | <0.54 | <0.54 | 10.41 | 24.72 | 0.41 | Acceptable |
| | 8001-8500 | <0.54 | <0.54 | 0.67 | 6.86 | < ABS (4) | Acceptable |
| | 8501-9000 | <0.54 | <0.54 | 0.92 | 5.5 | < ABS (4) | Acceptable |
| | 9001-9500 | <0.54 | <0.54 | 4.62 | 19.31 | < ABS (4) | Acceptable |
| | 9501-10000 | <0.54 | <0.54 | 8.97 | 37.29 | < ABS (4) | Acceptable |
| | 10001-10500 | <0.54 | <0.54 | 4.52 | 5.97 | < ABS (4) | Acceptable |
| | 10501-11000 | <0.54 | <0.54 | 1.82 | 9.84 | < ABS (4) | Acceptable |
| | 11001-11500 | <0.54 | <0.54 | 7.02 | 240.47 | < ABS (4) | Acceptable |
| | 11501-12000 | <0.54 | <0.54 | 14.58 | 31.31 | < ABS (4) | Acceptable |
| R11 | 0-500 | <0.54 | <0.54 | 11.02 | 1.09 | < ABS (4) | Acceptable |
| | 501-1000 | <0.54 | <0.54 | 2.11 | 3.17 | < ABS (4) | Acceptable |
| | 1001-1500 | 0.59 | 0.59 | 8.95 | 4.22 | < ABS (4) | Acceptable |
| | 1500-2000 | <0.54 | <0.54 | 10.41 | 3.17 | < ABS (4) | Acceptable |
| | 2001-2500 | <0.54 | <0.54 | 6.63 | 0.53 | < ABS (4) | Acceptable |
| | 2501-3000 | <0.54 | <0.54 | 1.52 | 1.06 | < ABS (4) | Acceptable |
| | 3001-3500 | <0.54 | <0.54 | 10.46 | 1.06 | < ABS (4) | Acceptable |
| | 3501-4000 | <0.54 | <0.54 | 10.46 | 1.58 | < ABS (4) | Acceptable |
| | 4001-4500 | <0.54 | <0.54 | 16.65 | 0.00 | < ABS (4) | Acceptable |

| Runway | Section (ft) | CG | CP | PI-100 | PI-25 | 12-ft RSE | BBI |
|---|---|---|---|---|---|---|---|
| R11 | 4501-5000 | <0.54 | <0.54 | 0.71 | 1.58 | < ABS (4) | Acceptable |
| | 5001-5500 | <0.54 | <0.54 | 2.28 | 5.6 | < ABS (4) | Acceptable |
| R12 | 0-500 | <0.54 | 0.7 | 44.59 | 63.65 | 0.45 | Unacceptable |
| | 501-1000 | <0.54 | 0.7 | 15.26 | 27.63 | < ABS (4) | Unacceptable |
| | 1001-1500 | <0.54 | <0.54 | 17.88 | 15.12 | < ABS (4) | Acceptable |
| | 1500-2000 | 0.6 | 0.79 | 230.48 | 170.49 | < ABS (4) | Acceptable |
| | 2001-2500 | 0.7 | 0.8 | 110.47 | 6.95 | < ABS (4) | Acceptable |
| | 2501-3000 | <0.54 | <0.54 | 12.35 | 30.4 | 0.41 | Acceptable |
| | 3001-3500 | <0.54 | <0.54 | 20.96 | 22.84 | 0.43 | Acceptable |
| | 3501-4000 | <0.54 | <0.54 | 21.35 | 11.07 | < ABS (4) | Acceptable |
| | 4001-4500 | <0.54 | <0.54 | 12.59 | 6.18 | < ABS (4) | Acceptable |
| | 4501-5000 | <0.54 | 0.7 | 16.02 | 20.24 | < ABS (4) | Acceptable |
| | 5001-5500 | <0.54 | 0.77 | 25.93 | 13.08 | < ABS (4) | Acceptable |
| R13 | 0-500 | <0.54 | <0.54 | 10.4 | 0.00 | < ABS (4) | Acceptable |
| | 501-1000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 1001-1500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 1500-2000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 2001-2500 | <0.54 | <0.54 | 0.63 | 0.1 | < ABS (4) | Acceptable |
| | 2501-3000 | <0.54 | <0.54 | 0.86 | 2.76 | < ABS (4) | Acceptable |
| | 3001-3500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 3501-4000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 4001-4500 | <0.54 | <0.54 | 3.86 | 0.00 | < ABS (4) | Unacceptable |
| | 4501-5000 | <0.54 | <0.54 | 0.52 | 0.00 | < ABS (4) | Acceptable |
| | 5001-5500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 5501-6000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 6001-6500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 6501-7000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 7001-7500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 7501-8000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 8001-8500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 8501-9000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 9001-9500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 9501-10000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| R40 | 0-500 | <0.54 | <0.54 | 60.42 | 0.00 | < ABS (4) | Acceptable |
| | 501-1000 | <0.54 | <0.54 | 1.27 | 0.5 | < ABS (4) | Acceptable |
| | 1001-1500 | <0.54 | <0.54 | 50.43 | 3.31 | < ABS (4) | Acceptable |
| | 1500-2000 | <0.54 | <0.54 | 0.7 | 4.05 | < ABS (4) | Acceptable |
| | 2001-2500 | <0.54 | <0.54 | 23.12 | 0.92 | < ABS (4) | Acceptable |
| | 2501-3000 | 0.65 | 0.75 | 0.00 | 4.21 | < ABS (4) | Acceptable |
| | 3001-3500 | <0.54 | <0.54 | 0.00 | 1.02 | < ABS (4) | Acceptable |
| | 3501-4000 | <0.54 | <0.54 | 0.00 | 1.15 | < ABS (4) | Acceptable |

| Runway | Section (ft) | CG | CP | PI-100 | PI-25 | 12-ft RSE | BBI |
|---|---|---|---|---|---|---|---|
| R40 | 4001-4500 | <0.54 | <0.54 | 0.000 | 1.59 | < ABS (4) | Acceptable |
| R14 | 0-500 | <0.54 | <0.54 | 12.14 | 9.71 | < ABS (4) | Acceptable |
| | 501-1000 | <0.54 | <0.54 | 0.00 | 0.03 | < ABS (4) | Acceptable |
| | 1001-1500 | <0.54 | <0.54 | 0.09 | 0.95 | < ABS (4) | Acceptable |
| | 1500-2000 | <0.54 | <0.54 | 6.19 | 8.3 | < ABS (4) | Acceptable |
| | 2001-2500 | <0.54 | <0.54 | 0.46 | 0.59 | < ABS (4) | Acceptable |
| | 2501-3000 | <0.54 | <0.54 | 0.00 | 10.43 | < ABS (4) | Acceptable |
| | 3001-3500 | <0.54 | <0.54 | 2.63 | 1.11 | < ABS (4) | Acceptable |
| | 3501-4000 | <0.54 | <0.54 | 1.6 | 10.49 | < ABS (4) | Acceptable |
| | 4001-4500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 4501-5000 | <0.54 | <0.54 | 6.03 | 5.57 | < ABS (4) | Acceptable |
| | 5001-5500 | <0.54 | <0.54 | 0.00 | 10.44 | < ABS (4) | Acceptable |
| | 5501-6000 | <0.54 | <0.54 | 0.00 | 0.11 | < ABS (4) | Acceptable |
| | 6001-6500 | <0.54 | <0.54 | 1.95 | 4.55 | < ABS (4) | Acceptable |
| | 6501-7000 | <0.54 | <0.54 | 0.96 | 90.42 | < ABS (4) | Acceptable |
| | 7001-7500 | <0.54 | <0.54 | 0.00 | 9.66 | < ABS (4) | Acceptable |
| | 7501-8000 | <0.54 | <0.54 | 0.00 | 2.05 | < ABS (4) | Acceptable |
| | 8001-8500 | <0.54 | <0.54 | 0.00 | 0.33 | < ABS (4) | Acceptable |
| | 8501-9000 | <0.54 | <0.54 | 0.00 | 3.71 | < ABS (4) | Acceptable |
| R15 | 0-500 | <0.54 | <0.54 | 4.01 | 0.00 | < ABS (4) | Acceptable |
| | 501-1000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 1001-1500 | <0.54 | <0.54 | 1.29 | 2.61 | < ABS (4) | Acceptable |
| | 1500-2000 | <0.54 | <0.54 | 0.45 | 1.11 | < ABS (4) | Acceptable |
| | 2001-2500 | <0.54 | <0.54 | 0.61 | 0.32 | < ABS (4) | Acceptable |
| | 2501-3000 | <0.54 | <0.54 | 4.3 | 3.15 | < ABS (4) | Acceptable |
| | 3001-3500 | <0.54 | <0.54 | 0.00 | 1.03 | < ABS (4) | Acceptable |
| | 3501-4000 | <0.54 | <0.54 | 0.36 | 2.07 | < ABS (4) | Acceptable |
| | 4001-4500 | <0.54 | <0.54 | 3.99 | 8.63 | < ABS (4) | Acceptable |
| | 4501-5000 | <0.54 | 0.72 | 24.66 | 14.67 | 0.4563745 | Excessive |
| | 5001-5500 | 0.57 | 0.79 | 6.56 | 8.78 | < ABS (4) | Acceptable |
| | 5501-6000 | <0.54 | <0.54 | 8.01 | 13.18 | < ABS (4) | Acceptable |
| | 6001-6500 | <0.54 | 0.6 | 48.13 | 26.27 | < ABS (4) | Acceptable |
| | 6501-7000 | <0.54 | <0.54 | 17.94 | 22.72 | 0.4097796 | Acceptable |
| R16 | 0-500 | <0.54 | <0.54 | 30.4 | 1.08 | < ABS (4) | Acceptable |
| | 501-1000 | <0.54 | <0.54 | 0.00 | 0.85 | < ABS (4) | Acceptable |
| | 1001-1500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 1500-2000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 2001-2500 | <0.54 | <0.54 | 0.58 | 1.67 | < ABS (4) | Acceptable |
| | 2501-3000 | <0.54 | <0.54 | 0.00 | 1.11 | < ABS (4) | Acceptable |
| | 3001-3500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 3501-4000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 4001-4500 | <0.54 | <0.54 | 0.00 | 2 | < ABS (4) | Acceptable |

| Runway | Section (ft) | CG | CP | PI-100 | PI-25 | 12-ft RSE | BBI |
|---|---|---|---|---|---|---|---|
| R16 | 4501-5000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 5001-5500 | <0.54 | <0.54 | 0.00 | 0.89 | < ABS (4) | Acceptable |
| | 5501-6000 | <0.54 | <0.54 | 0.00 | 0.9 | < ABS (4) | Acceptable |
| | 6001-6500 | <0.54 | <0.54 | 0.02 | 1.13 | < ABS (4) | Acceptable |
| | 6501-7000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 7001-7500 | <0.54 | <0.54 | 0.16 | 0.79 | < ABS (4) | Acceptable |
| | 7501-8000 | <0.54 | <0.54 | 0.00 | 1.04 | < ABS (4) | Acceptable |
| | 8001-8500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 8501-9000 | <0.54 | <0.54 | 0.00 | 2.38 | < ABS (4) | Acceptable |
| | 9001-9500 | <0.54 | <0.54 | 0.76 | 3.34 | < ABS (4) | Acceptable |
| | 9501-10000 | <0.54 | <0.54 | 0.00 | 0.15 | < ABS (4) | Acceptable |
| R17 | 0-500 | <0.54 | 0.78 | 14.63 | 9.56 | < ABS (4) | Acceptable |
| | 501-1000 | <0.54 | 0.72 | 0.00 | 8.87 | < ABS (4) | Acceptable |
| | 1001-1500 | <0.54 | <0.54 | 0.4 | 0.78 | < ABS (4) | Acceptable |
| | 1500-2000 | <0.54 | <0.54 | 0.00 | 1.77 | < ABS (4) | Acceptable |
| | 2001-2500 | <0.54 | <0.54 | 0.00 | 130.43 | < ABS (4) | Acceptable |
| | 2501-3000 | <0.54 | <0.54 | 0.00 | 1.33 | < ABS (4) | Acceptable |
| | 3001-3500 | <0.54 | <0.54 | 4.79 | 1.97 | < ABS (4) | Acceptable |
| | 3501-4000 | <0.54 | <0.54 | 4.02 | 11.71 | < ABS (4) | Acceptable |
| | 4001-4500 | <0.54 | <0.54 | 1.53 | 5.62 | < ABS (4) | Acceptable |
| | 4501-5000 | <0.54 | <0.54 | 180.47 | 12.58 | < ABS (4) | Acceptable |
| | 5001-5500 | <0.54 | <0.54 | 18.14 | 90.4 | < ABS (4) | Acceptable |
| | 5501-6000 | <0.54 | <0.54 | 21.51 | 20.86 | 0.64 | Acceptable |
| | 6001-6500 | <0.54 | <0.54 | 0.72 | 3.09 | < ABS (4) | Acceptable |
| | 6501-7000 | <0.54 | <0.54 | 40.42 | 10.75 | 0.65 | Acceptable |
| R18 | 0-500 | <0.54 | <0.54 | 0.00 | 20.49 | 0.42 | Acceptable |
| | 501-1000 | <0.54 | <0.54 | 10.81 | 19.18 | < ABS (4) | Acceptable |
| | 1001-1500 | <0.54 | <0.54 | 10.22 | 11.73 | < ABS (4) | Acceptable |
| | 1500-2000 | <0.54 | <0.54 | 0.52 | 0.54 | < ABS (4) | Acceptable |
| | 2001-2500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 2501-3000 | <0.54 | <0.54 | 0.00 | 0.96 | < ABS (4) | Acceptable |
| | 3001-3500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 3501-4000 | <0.54 | <0.54 | 0.61 | 1.27 | < ABS (4) | Acceptable |
| | 4001-4500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 4501-5000 | <0.54 | <0.54 | 0.64 | 0.00 | < ABS (4) | Acceptable |
| | 5001-5500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 5501-6000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 6001-6500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 6501-7000 | <0.54 | <0.54 | 1.31 | 0.00 | < ABS (4) | Acceptable |
| R19 | 0-500 | <0.54 | 0.59 | 2.93 | 5.08 | < ABS (4) | Acceptable |
| | 501-1000 | <0.54 | 0.69 | 37.91 | 18.05 | < ABS (4) | Acceptable |
| | 1001-1500 | <0.54 | <0.54 | 6.14 | 6.83 | < ABS (4) | Acceptable |

| Runway | Section (ft) | CG | CP | PI-100 | PI-25 | 12-ft RSE | BBI |
|---|---|---|---|---|---|---|---|
| R19 | 1500-2000 | <0.54 | <0.54 | 0.13 | 0.31 | < ABS (4) | Acceptable |
| | 2001-2500 | <0.54 | <0.54 | 1.85 | 1.28 | < ABS (4) | Acceptable |
| | 2501-3000 | <0.54 | 0.76 | 9.57 | 6.72 | < ABS (4) | Acceptable |
| | 3001-3500 | <0.54 | 0.56 | 5.11 | 1.83 | < ABS (4) | Acceptable |
| | 3501-4000 | 0.57 | 0.68 | 18.62 | 40.45 | < ABS (4) | Acceptable |
| | 4001-4500 | <0.54 | <0.54 | 1.67 | 6.1 | < ABS (4) | Acceptable |
| | 4501-5000 | <0.54 | <0.54 | 3.01 | 4.09 | < ABS (4) | Acceptable |
| | 5001-5500 | <0.54 | <0.54 | 0.56 | 0.2 | < ABS (4) | Acceptable |
| | 5501-6000 | <0.54 | <0.54 | 0.01 | 0.44 | < ABS (4) | Acceptable |
| | 6001-6500 | <0.54 | <0.54 | 5.56 | 2.81 | < ABS (4) | Acceptable |
| | 6501-7000 | <0.54 | 0.62 | 16.7 | 9.25 | < ABS (4) | Acceptable |
| | 7001-7500 | <0.54 | <0.54 | 0.00 | 0.34 | < ABS (4) | Acceptable |
| | 7501-8000 | <0.54 | <0.54 | 2.72 | 8.35 | < ABS (4) | Acceptable |
| | 8001-8500 | <0.54 | <0.54 | 3.76 | 4.62 | < ABS (4) | Acceptable |
| | 8501-9000 | <0.54 | <0.54 | 1.23 | 2.81 | < ABS (4) | Acceptable |
| | 9001-9500 | <0.54 | <0.54 | 0.00 | 3.6 | < ABS (4) | Acceptable |
| | 9501-10000 | <0.54 | <0.54 | 8.09 | 8.24 | < ABS (4) | Acceptable |
| | 10001-10500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 10501-11000 | <0.54 | <0.54 | 0.00 | 0.2 | < ABS (4) | Acceptable |
| | 11001-11500 | <0.54 | <0.54 | 0.00 | 0.61 | < ABS (4) | Acceptable |
| | 11501-12000 | <0.54 | <0.54 | 0.00 | 3.37 | < ABS (4) | Acceptable |
| R20 | 0-500 | <0.54 | <0.54 | 1.98 | 3.76 | < ABS (4) | Acceptable |
| | 501-1000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 1001-1500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 1500-2000 | <0.54 | <0.54 | 13.14 | 7.59 | < ABS (4) | Acceptable |
| | 2001-2500 | <0.54 | <0.54 | 2.33 | 3.71 | < ABS (4) | Acceptable |
| | 2501-3000 | <0.54 | <0.54 | 3.74 | 1.73 | < ABS (4) | Acceptable |
| | 3001-3500 | <0.54 | <0.54 | 6.77 | 2.28 | < ABS (4) | Acceptable |
| | 3501-4000 | <0.54 | <0.54 | 4.3 | 0.52 | < ABS (4) | Acceptable |
| | 4001-4500 | <0.54 | <0.54 | 0.00 | 0.15 | < ABS (4) | Acceptable |
| | 4501-5000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 5001-5500 | <0.54 | <0.54 | 0.7 | 0.17 | < ABS (4) | Acceptable |
| | 5501-6000 | <0.54 | <0.54 | 0.42 | 0.22 | < ABS (4) | Acceptable |
| R21 | 0-500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 501-1000 | <0.54 | <0.54 | 0.00 | 0.47 | < ABS (4) | Acceptable |
| | 1001-1500 | <0.54 | <0.54 | 0.00 | 0.05 | < ABS (4) | Acceptable |
| | 1500-2000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 2001-2500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 2501-3000 | <0.54 | <0.54 | 0.00 | 0.89 | < ABS (4) | Acceptable |
| | 3001-3500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 3501-4000 | <0.54 | <0.54 | 1.82 | 1.39 | < ABS (4) | Acceptable |
| | 4001-4500 | <0.54 | <0.54 | 30.44 | 2.67 | < ABS (4) | Acceptable |

| Runway | Section (ft) | CG | CP | PI-100 | PI-25 | 12-ft RSE | BBI |
|---|---|---|---|---|---|---|---|
| R21 | 4501-5000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 5001-5500 | <0.54 | <0.54 | 0.00 | 0.04 | < ABS (4) | Acceptable |
| | 5501-6000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 6001-6500 | <0.54 | <0.54 | 0.00 | 0.06 | < ABS (4) | Acceptable |
| | 6501-7000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 7001-7500 | <0.54 | <0.54 | 0.00 | 0.02 | < ABS (4) | Acceptable |
| | 7501-8000 | <0.54 | <0.54 | 0.00 | 0.44 | < ABS (4) | Acceptable |
| | 8001-8500 | <0.54 | <0.54 | 0.00 | 2.22 | < ABS (4) | Acceptable |
| | 8501-9000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 9001-9500 | <0.54 | <0.54 | 1.97 | 20.41 | < ABS (4) | Acceptable |
| | 9501-10000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 10001-10500 | <0.54 | <0.54 | 2.22 | 1.91 | < ABS (4) | Acceptable |
| | 10501-11000 | <0.54 | <0.54 | 1.29 | 1.56 | < ABS (4) | Acceptable |
| | 11001-11500 | <0.54 | <0.54 | 0.00 | 2.03 | < ABS (4) | Acceptable |
| | 11501-12000 | <0.54 | <0.54 | 4.98 | 3.56 | < ABS (4) | Acceptable |
| R22 | 0-500 | <0.54 | <0.54 | 0.00 | 1.15 | < ABS (4) | Acceptable |
| | 501-1000 | <0.54 | <0.54 | 0.00 | 3.66 | < ABS (4) | Acceptable |
| | 1001-1500 | <0.54 | <0.54 | 0.00 | 1.83 | < ABS (4) | Acceptable |
| | 1500-2000 | <0.54 | <0.54 | 0.00 | 1.36 | < ABS (4) | Acceptable |
| | 2001-2500 | <0.54 | <0.54 | 0.00 | 5.91 | < ABS (4) | Acceptable |
| | 2501-3000 | <0.54 | <0.54 | 0.00 | 4.13 | < ABS (4) | Acceptable |
| | 3001-3500 | <0.54 | <0.54 | 8.95 | 13.85 | < ABS (4) | Acceptable |
| | 3501-4000 | <0.54 | <0.54 | 0.93 | 4.12 | < ABS (4) | Acceptable |
| | 214001-4500 | <0.54 | <0.54 | 0.00 | 1.52 | < ABS (4) | Acceptable |
| | 4501-5000 | <0.54 | <0.54 | 10.48 | 5.36 | < ABS (4) | Acceptable |
| | 5001-5500 | <0.54 | <0.54 | 1.26 | 1.23 | < ABS (4) | Acceptable |
| | 5501-6000 | <0.54 | <0.54 | 8.62 | 3.5 | < ABS (4) | Acceptable |
| | 6001-6500 | <0.54 | <0.54 | 1.01 | 2.21 | < ABS (4) | Acceptable |
| | 6501-7000 | <0.54 | <0.54 | 1.32 | 1.76 | < ABS (4) | Acceptable |
| | 7001-7500 | <0.54 | <0.54 | 0.00 | 3.91 | < ABS (4) | Acceptable |
| | 7501-8000 | <0.54 | <0.54 | 5.64 | 12.75 | < ABS (4) | Acceptable |
| | 8001-8500 | <0.54 | <0.54 | 0.00 | 2.55 | < ABS (4) | Acceptable |
| R23 | 0-500 | <0.54 | <0.54 | 40.45 | 2.26 | < ABS (4) | Acceptable |
| | 501-1000 | <0.54 | <0.54 | 0.21 | 1.73 | < ABS (4) | Acceptable |
| | 1001-1500 | <0.54 | <0.54 | 0.00 | 0.8 | < ABS (4) | Acceptable |
| | 1500-2000 | <0.54 | <0.54 | 0.00 | 1.37 | < ABS (4) | Acceptable |
| | 2001-2500 | <0.54 | <0.54 | 0.00 | 2.06 | < ABS (4) | Acceptable |
| | 2501-3000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 3001-3500 | <0.54 | <0.54 | 0.00 | 0.49 | < ABS (4) | Acceptable |
| | 3501-4000 | <0.54 | <0.54 | 0.00 | 0.59 | < ABS (4) | Acceptable |
| | 4001-4500 | <0.54 | <0.54 | 0.00 | 1.38 | < ABS (4) | Acceptable |
| | 4501-5000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |

| Runway | Section (ft) | CG | CP | PI-100 | PI-25 | 12-ft RSE | BBI |
|---|---|---|---|---|---|---|---|
| R23 | 5001-5500 | <0.54 | <0.54 | 0.41 | 0.5 | < ABS (4) | Acceptable |
| | 5501-6000 | <0.54 | <0.54 | 0.00 | 0.34 | < ABS (4) | Acceptable |
| | 6001-6500 | <0.54 | <0.54 | 0.00 | 0.12 | < ABS (4) | Acceptable |
| | 6501-7000 | <0.54 | <0.54 | 0.00 | 0.65 | < ABS (4) | Acceptable |
| | 7001-7500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 7501-8000 | <0.54 | <0.54 | 3.03 | 1 | < ABS (4) | Acceptable |
| | 8001-8500 | <0.54 | <0.54 | 0.00 | 1.35 | < ABS (4) | Acceptable |
| | 8501-9000 | <0.54 | <0.54 | 0.00 | 1.56 | < ABS (4) | Acceptable |
| | 9001-9500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 9501-10000 | <0.54 | <0.54 | 0.39 | 1.81 | < ABS (4) | Acceptable |
| R24 | 0-500 | <0.54 | <0.54 | 0.00 | 0.61 | < ABS (4) | Acceptable |
| | 501-1000 | <0.54 | <0.54 | 0.00 | 0.91 | < ABS (4) | Acceptable |
| | 1001-1500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 1500-2000 | <0.54 | <0.54 | 0.00 | 0.38 | < ABS (4) | Acceptable |
| | 2001-2500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 2501-3000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 3001-3500 | <0.54 | <0.54 | 0.00 | 0.58 | < ABS (4) | Acceptable |
| | 3501-4000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 4001-4500 | <0.54 | <0.54 | 0.00 | 0.18 | < ABS (4) | Acceptable |
| | 4501-5000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 5001-5500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 5501-6000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 6001-6500 | <0.54 | <0.54 | 1.15 | 0.00 | < ABS (4) | Acceptable |
| | 6501-7000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 7001-7500 | <0.54 | <0.54 | 1.36 | 2.36 | < ABS (4) | Acceptable |
| | 7501-8000 | <0.54 | <0.54 | 0.00 | 0.13 | < ABS (4) | Acceptable |
| | 8001-8500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 8501-9000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 9001-9500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 9501-10000 | <0.54 | <0.54 | 0.00 | 2.14 | < ABS (4) | Acceptable |
| | 10001-10500 | <0.54 | <0.54 | 0.00 | 4 | < ABS (4) | Acceptable |
| | 10501-11000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 11001-11500 | <0.54 | <0.54 | 0.00 | 40.48 | < ABS (4) | Acceptable |
| | 11501-12000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 12001-12005 | <0.54 | <0.54 | 40.41 | 2.67 | 0.486 | Acceptable |
| | 12501-13000 | <0.54 | <0.54 | 0.99 | 6.7 | < ABS (4) | Acceptable |
| | 13001-13005 | <0.54 | <0.54 | 0.00 | 0.21 | < ABS (4) | Acceptable |
| | 13501-14000 | <0.54 | <0.54 | 0.00 | 2.6 | < ABS (4) | Acceptable |
| R25 | 0-500 | <0.54 | <0.54 | 16.81 | 18.16 | < ABS (4) | Acceptable |
| | 501-1000 | <0.54 | <0.54 | 21.78 | 19.77 | < ABS (4) | Acceptable |
| | 1001-1500 | <0.54 | <0.54 | 26.98 | 140.47 | 0.65 | Acceptable |
| | 1500-2000 | 0.66 | 0.85 | 44.65 | 25.34 | -0.46 | Excessive (1.19) |

| Runway | Section (ft) | CG | CP | PI-100 | PI-25 | 12-ft RSE | BBI |
|---|---|---|---|---|---|---|---|
| R25 | 2001-2500 | <0.54 | <0.54 | 310.48 | 13.73 | 0.43 | Acceptable |
| | 2501-3000 | <0.54 | <0.54 | 14.87 | 10.68 | -0.47 | Acceptable |
| | 3001-3500 | <0.54 | <0.54 | 13.29 | 21.32 | 0.73 | Acceptable |
| | 3501-4000 | <0.54 | <0.54 | 56.87 | 460.43 | -0.70 | Excessive (1.17) |
| R26 | 0-500 | <0.54 | <0.54 | 3.11 | 13.95 | < ABS (4) | Acceptable |
| | 501-1000 | <0.54 | <0.54 | 0.64 | 11.7 | < ABS (4) | Acceptable |
| | 1001-1500 | <0.54 | <0.54 | 14.88 | 17.6 | < ABS (4) | Acceptable |
| | 1500-2000 | <0.54 | <0.54 | 0.00 | 1.66 | < ABS (4) | Acceptable |
| | 2001-2500 | <0.54 | <0.54 | 8.88 | 10.97 | 0.41 | Acceptable |
| | 2501-3000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 3001-3500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 3501-4000 | <0.54 | <0.54 | 0.00 | 0.29 | < ABS (4) | Acceptable |
| | 4001-4500 | <0.54 | 0.58 | 0.00 | 0.26 | < ABS (4) | Acceptable |
| | 4501-5000 | 0.58 | 0..77 | 24.62 | 22.21 | 0.50 | Acceptable |
| | 5001-5500 | <0.54 | <0.54 | 20.01 | 13.97 | < ABS (4) | Acceptable |
| | 5501-6000 | <0.54 | <0.54 | 1.04 | 0.24 | < ABS (4) | Acceptable |
| | 6001-6500 | <0.54 | <0.54 | 0.26 | 0.00 | < ABS (4) | Acceptable |
| | 6501-7000 | <0.54 | <0.54 | 0.1 | 0.00 | < ABS (4) | Acceptable |
| | 7001-7500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 7501-8000 | <0.54 | <0.54 | 0.00 | 0.22 | < ABS (4) | Acceptable |
| | 8001-8500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 8501-9000 | <0.54 | <0.54 | 1.87 | 0.00 | < ABS (4) | Acceptable |
| | 9001-9500 | <0.54 | <0.54 | 3.87 | 0.00 | < ABS (4) | Acceptable |
| | 9501-10000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 10001-10500 | <0.54 | <0.54 | 2.03 | 3 | < ABS (4) | Acceptable |
| | 10501-11000 | <0.54 | <0.54 | 3.38 | 9.3 | 0.46 | Acceptable |
| | 11001-11500 | <0.54 | <0.54 | 0.00 | 0.56 | < ABS (4) | Acceptable |
| | 11501-12000 | <0.54 | <0.54 | 0.00 | 2.78 | < ABS (4) | Acceptable |
| R27 | 0-500 | <0.54 | <0.54 | 0.00 | 4.92 | < ABS (4) | Acceptable |
| | 501-1000 | <0.54 | <0.54 | 0.31 | 8.12 | < ABS (4) | Acceptable |
| | 1001-1500 | <0.54 | <0.54 | 0.00 | 2.01 | < ABS (4) | Acceptable |
| | 1500-2000 | <0.54 | <0.54 | 0.00 | 1.97 | < ABS (4) | Acceptable |
| | 2001-2500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 2501-3000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 3001-3500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 3501-4000 | <0.54 | <0.54 | 0.00 | 0.17 | < ABS (4) | Acceptable |
| | 4001-4500 | <0.54 | <0.54 | 0.32 | 4.88 | < ABS (4) | Acceptable |
| | 4501-5000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 5001-5500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 5501-6000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 6001-6500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 6501-7000 | <0.54 | <0.54 | 0.00 | 1.31 | < ABS (4) | Acceptable |

| Runway | Section (ft) | CG | CP | PI-100 | PI-25 | 12-ft RSE | BBI |
|---|---|---|---|---|---|---|---|
| R27 | 7001-7500 | <0.54 | <0.54 | 12.13 | 5.09 | < ABS (4) | Acceptable |
| | 7501-8000 | <0.54 | <0.54 | 10.41 | 8.37 | < ABS (4) | Acceptable |
| | 8001-8500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 8501-9000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 9001-9500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 9501-10000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 10001-10500 | <0.54 | <0.54 | 0.00 | 0.75 | < ABS (4) | Acceptable |
| | 10501-11000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| R28 | 0-500 | 0.75 | 0.79 | 54.2 | 4.92 | < ABS (4) | 1.025 |
| | 501-1000 | <0.54 | <0.54 | 0.83 | 8.12 | 0.46 | Acceptable |
| | 1001-1500 | <0.54 | 0.7 | 25.02 | 2.01 | < ABS (4) | Acceptable |
| | 1500-2000 | <0.54 | 0.58 | 3.99 | 1.97 | < ABS (4) | Acceptable |
| | 2001-2500 | <0.54 | <0.54 | 0.59 | 0.00 | < ABS (4) | Acceptable |
| | 2501-3000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 3001-3500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 3501-4000 | <0.54 | <0.54 | 0.00 | 0.17 | < ABS (4) | Acceptable |
| | 4001-4500 | <0.54 | <0.54 | 0.00 | 4.88 | < ABS (4) | Acceptable |
| | 4501-5000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 5001-5500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 5501-6000 | <0.54 | 0.65 | 9.94 | 0.00 | < ABS (4) | Acceptable |
| | 6001-6500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 6501-7000 | <0.54 | <0.54 | 0.00 | 1.31 | < ABS (4) | Acceptable |
| | 7001-7500 | <0.54 | <0.54 | 0.00 | 5.09 | < ABS (4) | Acceptable |
| | 7501-8000 | <0.54 | <0.54 | 0.00 | 8.37 | < ABS (4) | Acceptable |
| | 8001-8500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 8501-9000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 9001-9500 | <0.54 | <0.54 | 4.66 | 0.00 | < ABS (4) | Acceptable |
| | 9501-10000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 10001-10500 | <0.54 | <0.54 | 0.00 | 0.75 | < ABS (4) | Acceptable |
| | 10501-11000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 11001-11500 | <0.54 | <0.54 | 1.93 | 0.00 | < ABS (4) | Acceptable |
| | 11501-12000 | <0.54 | <0.54 | 3.99 | 0.00 | < ABS (4) | Acceptable |
| R29 | 0-500 | <0.54 | 0.66 | 12.29 | 13.66 | < ABS (4) | Acceptable |
| | 501-1000 | <0.54 | 0.84 | 270.45 | 22.18 | 0.42 | Acceptable |
| | 1001-1500 | <0.54 | 0.73 | 8.88 | 5.81 | < ABS (4) | Acceptable |
| | 1500-2000 | <0.54 | <0.54 | 1.29 | 80.45 | < ABS (4) | Acceptable |
| | 2001-2500 | <0.54 | <0.54 | 1.39 | 0.53 | < ABS (4) | Acceptable |
| | 2501-3000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 3001-3500 | <0.54 | <0.54 | 3.56 | 3.17 | < ABS (4) | Acceptable |
| | 3501-4000 | <0.54 | <0.54 | 2.09 | 0.53 | < ABS (4) | Acceptable |
| | 4001-4500 | <0.54 | <0.54 | 6.73 | 8.98 | 0.600 | Acceptable |
| | 4501-5000 | <0.54 | <0.54 | 0.00 | 1.58 | < ABS (4) | Acceptable |

| Runway | Section (ft) | CG | CP | PI-100 | PI-25 | 12-ft RSE | BBI |
|---|---|---|---|---|---|---|---|
| R29 | 5001-5500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 5501-6000 | <0.54 | <0.54 | 1.54 | 1.58 | < ABS (4) | Acceptable |
| | 6001-6500 | <0.54 | <0.54 | 0.00 | 0.53 | < ABS (4) | Acceptable |
| | 6501-7000 | <0.54 | <0.54 | 4.31 | 5.81 | < ABS (4) | Acceptable |
| | 7001-7500 | <0.54 | 0.75 | 13.93 | 15.84 | < ABS (4) | Acceptable |
| | 7501-8000 | <0.54 | 0.68 | 11.05 | 16.9 | < ABS (4) | Acceptable |
| | 8001-8500 | <0.54 | 0.57 | 5.29 | 13.73 | < ABS (4) | Acceptable |
| | 8501-9000 | <0.54 | <0.54 | 0.37 | 5.81 | < ABS (4) | Acceptable |
| | 9001-9500 | <0.54 | <0.54 | 0.00 | 2.64 | < ABS (4) | Acceptable |
| | 9501-10000 | <0.54 | <0.54 | 0.00 | 2.11 | < ABS (4) | Acceptable |
| | 10001-10500 | <0.54 | <0.54 | 0.15 | 2.11 | < ABS (4) | Acceptable |
| | 10501-11000 | <0.54 | <0.54 | 0.00 | 1.06 | < ABS (4) | Acceptable |
| | 11001-11500 | <0.54 | <0.54 | 0.11 | 16.37 | 0.43 | Acceptable |
| | 11501-12000 | <0.54 | 0.57 | 6.11 | 34.36 | 0.41 | Acceptable |
| R30 | 0-500 | <0.54 | <0.54 | 8.54 | 8.20 | < ABS (4) | Acceptable |
| | 501-1000 | <0.54 | 0.64 | 4.30 | 16.90 | < ABS (4) | Acceptable |
| | 1001-1500 | <0.54 | 0.61 | 3.24 | 8.98 | < ABS (4) | Acceptable |
| | 1500-2000 | <0.54 | <0.54 | 0.00 | 6.86 | < ABS (4) | Acceptable |
| | 2001-2500 | <0.54 | <0.54 | 4.08 | 11.09 | 0.450 | Acceptable |
| | 2501-3000 | <0.54 | <0.54 | 15.89 | 270.46 | 0.42 | Acceptable |
| | 3001-3500 | <0.54 | <0.54 | 2.34 | 14.78 | < ABS (4) | Acceptable |
| | 3501-4000 | <0.54 | <0.54 | 7.28 | 12.14 | 0.42 | Acceptable |
| | 4001-4500 | <0.54 | <0.54 | 0.54 | 1.58 | < ABS (4) | Acceptable |
| | 4501-5000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 5001-5500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 5501-6000 | <0.54 | <0.54 | 0.00 | 1.06 | < ABS (4) | Acceptable |
| | 6001-6500 | <0.54 | <0.54 | 2.15 | 0.53 | < ABS (4) | Acceptable |
| | 6501-7000 | <0.54 | <0.54 | 14.89 | 2.11 | < ABS (4) | Acceptable |
| | 7001-7500 | <0.54 | <0.54 | 0.00 | 3.70 | < ABS (4) | Acceptable |
| | 7501-8000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 8001-8500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 8501-9000 | <0.54 | <0.54 | 0.00 | 1.06 | < ABS (4) | Acceptable |
| | 9001-9500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 9501-10000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 10001-10500 | <0.54 | <0.54 | 16.60 | 14.78 | 0.49 | 1.00 |
| | 10501-11000 | <0.54 | <0.54 | 5.11 | 9.16 | < ABS (4) | Acceptable |
| R31 | 0-500 | <0.54 | <0.54 | 0.95 | 50.47 | 0.572 | Acceptable |
| | 501-1000 | <0.54 | 0.62 | 0.22 | 9.5 | < ABS (4) | Acceptable |
| | 1001-1500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 1500-2000 | <0.54 | <0.54 | 2.67 | 10.03 | 0.414 | Acceptable |
| | 2001-2500 | <0.54 | <0.54 | 1.72 | 13.73 | 0.555 | Acceptable |
| | 2501-3000 | <0.54 | <0.54 | 0.00 | 2.64 | < ABS (4) | Acceptable |

| Runway | Section (ft) | CG | CP | PI-100 | PI-25 | 12-ft RSE | BBI |
|---|---|---|---|---|---|---|---|
| R31 | 3001-3500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 3501-4000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 4001-4500 | <0.54 | <0.54 | 0.75 | 3.17 | < ABS (4) | Acceptable |
| | 4501-5000 | <0.54 | <0.54 | 0.00 | 0 | < ABS (4) | Acceptable |
| | 5001-5500 | <0.54 | <0.54 | 0.00 | 2.64 | < ABS (4) | Acceptable |
| | 5501-6000 | <0.54 | <0.54 | 0.07 | 1.06 | < ABS (4) | Acceptable |
| | 6001-6500 | <0.54 | <0.54 | 0.52 | 2.64 | < ABS (4) | Acceptable |
| | 6501-7000 | <0.54 | <0.54 | 5.23 | 5.28 | 0.448 | Acceptable |
| | 7001-7500 | <0.54 | 0.62 | 2.39 | 2.11 | < ABS (4) | Acceptable |
| | 7501-8000 | <0.54 | <0.54 | 1.75 | 11.09 | < ABS (4) | Acceptable |
| | 8001-8500 | <0.54 | <0.54 | 0.00 | 3.17 | < ABS (4) | Acceptable |
| | 8501-9000 | <0.54 | <0.54 | 0.63 | 1.06 | < ABS (4) | Acceptable |
| | 9001-9500 | <0.54 | <0.54 | 1.58 | 6.34 | < ABS (4) | Acceptable |
| | 9501-10000 | <0.54 | <0.54 | 0.95 | 4.75 | < ABS (4) | Acceptable |
| R32 | 0-500 | <0.54 | <0.54 | 6.72 | 3.83 | < ABS (4) | Acceptable |
| | 501-1000 | <0.54 | <0.54 | 0.98 | 2.11 | < ABS (4) | Acceptable |
| | 1001-1500 | <0.54 | <0.54 | 0.55 | 0.53 | < ABS (4) | Acceptable |
| | 1500-2000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 2001-2500 | <0.54 | <0.54 | 0.00 | 0.53 | < ABS (4) | Acceptable |
| | 2501-3000 | <0.54 | <0.54 | 3.14 | 2.64 | < ABS (4) | Acceptable |
| | 3001-3500 | <0.54 | <0.54 | 70.41 | 2.11 | < ABS (4) | Acceptable |
| | 3501-4000 | <0.54 | <0.54 | 0.51 | 2.64 | < ABS (4) | Acceptable |
| | 4001-4500 | <0.54 | <0.54 | 0.00 | 0.53 | < ABS (4) | Acceptable |
| | 4501-5000 | 0.73 | 0.89 | 40.93 | 12.67 | < ABS (4) | Acceptable |
| | 5001-5500 | 0.67 | 0.72 | 0.00 | 1.06 | < ABS (4) | Acceptable |
| | 5501-6000 | 0.34 | 0.46 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 6001-6500 | 0.54 | 0.65 | 10.95 | 6.86 | < ABS (4) | Acceptable |
| | 6501-7000 | 0.57 | 0.62 | 1.75 | 1.06 | < ABS (4) | Acceptable |
| | 7001-7500 | 0.46 | 0.48 | 1.77 | 3.17 | < ABS (4) | Acceptable |
| | 7501-8000 | 0.63 | 0.71 | 130.42 | 1.6 | < ABS (4) | Acceptable |
| R33 | 0-500 | <0.54 | <0.54 | 1.63 | 4.37 | < ABS (4) | Acceptable |
| | 501-1000 | <0.54 | <0.54 | 0.16 | 0.00 | < ABS (4) | Acceptable |
| | 1001-1500 | 0.78 | 1.13 | 39.26 | 15.31 | < ABS (4) | 1.15 |
| | 1500-2000 | <0.54 | 0.66 | 3.00 | 3.17 | < ABS (4) | Acceptable |
| | 2001-2500 | <0.54 | <0.54 | 5.13 | 7.92 | < ABS (4) | Acceptable |
| | 2501-3000 | <0.54 | <0.54 | 0.53 | 0.00 | < ABS (4) | Acceptable |
| | 3001-3500 | <0.54 | <0.54 | 170.48 | 5.28 | < ABS (4) | Acceptable |
| | 3501-4000 | <0.54 | <0.54 | 8.35 | 1.06 | < ABS (4) | Acceptable |
| | 4001-4500 | <0.54 | <0.54 | 9.94 | 4.75 | < ABS (4) | Acceptable |
| | 4501-5000 | <0.54 | <0.54 | 15.50 | 3.17 | < ABS (4) | 1.06 |
| | 5001-5500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| R34 | 0-500 | <0.54 | <0.54 | 1.31 | 2.19 | < ABS (4) | Acceptable |

| Runway | Section (ft) | CG | CP | PI-100 | PI-25 | 12-ft RSE | BBI |
|---|---|---|---|---|---|---|---|
| R34 | 501-1000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 1001-1500 | 0.60 | 0.92 | 29.22 | 10.56 | < ABS (4) | 1.01 |
| | 1500-2000 | <0.54 | <0.54 | 1.16 | 0.53 | < ABS (4) | Acceptable |
| | 2001-2500 | <0.54 | <0.54 | 2.00 | 4.22 | < ABS (4) | Acceptable |
| | 2501-3000 | <0.54 | <0.54 | 0.00 | 1.06 | < ABS (4) | Acceptable |
| | 3001-3500 | <0.54 | <0.54 | 14.96 | 5.81 | < ABS (4) | Acceptable |
| | 3501-4000 | <0.54 | <0.54 | 70.46 | 1.06 | < ABS (4) | Acceptable |
| | 4001-4500 | <0.54 | <0.54 | 60.44 | 2.64 | < ABS (4) | Acceptable |
| | 4501-5000 | <0.54 | <0.54 | 14.62 | 3.70 | < ABS (4) | 1.08 |
| | 5001-5500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| R35 | 0-500 | 1.6 | 2.2 | 90.2 | 42.63 | 0.8 | 10.4 |
| | 501-1000 | <0.54 | <0.54 | 70.44 | 14.78 | < ABS (4) | Acceptable |
| R36 | 0-500 | <0.54 | <0.54 | 3.27 | 3.28 | < ABS (4) | Acceptable |
| | 501-1000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 1001-1500 | <0.54 | <0.54 | 0.43 | 0.00 | < ABS (4) | Acceptable |
| | 1500-2000 | <0.54 | 0.59 | 3.52 | 0.00 | < ABS (4) | Acceptable |
| | 2001-2500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 2501-3000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 3001-3500 | <0.54 | <0.54 | 1.65 | 2.11 | < ABS (4) | Acceptable |
| | 3501-4000 | <0.54 | <0.54 | 10.03 | 0.00 | < ABS (4) | Acceptable |
| | 4001-4500 | <0.54 | <0.54 | 0.00 | 1.06 | < ABS (4) | Acceptable |
| | 4501-5000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 5001-5500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 5501-6000 | <0.54 | <0.54 | 2.17 | 1.06 | < ABS (4) | Acceptable |
| | 6001-6500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 6501-7000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 7001-7500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 7501-8000 | <0.54 | <0.54 | 0.52 | 0.00 | < ABS (4) | Acceptable |
| | 8001-8500 | <0.54 | <0.54 | 0.00 | 1.06 | < ABS (4) | Acceptable |
| | 8501-9000 | <0.54 | <0.54 | 4.75 | 0.00 | < ABS (4) | Acceptable |
| | 9001-9500 | <0.54 | <0.54 | 0.69 | 0.00 | < ABS (4) | Acceptable |
| | 9501-10000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 10001-10500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 10501-11000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 11001-11500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 11501-12000 | <0.54 | <0.54 | 4.52 | 0.00 | < ABS (4) | Acceptable |
| R37 | 0-500 | <0.54 | 0.57 | 120.45 | 7.11 | 0.45 | Acceptable |
| | 501-1000 | <0.54 | 0.57 | 3.86 | 1.58 | < ABS (4) | Acceptable |
| | 1001-1500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 1500-2000 | <0.54 | <0.54 | 0.82 | 0.00 | < ABS (4) | Acceptable |
| | 2001-2500 | <0.54 | 0.56 | 6.13 | 4.75 | < ABS (4) | Acceptable |
| | 2501-3000 | <0.54 | <0.54 | 3.94 | 12.67 | < ABS (4) | Acceptable |

| Runway | Section (ft) | CG | CP | PI-100 | PI-25 | 12-ft RSE | BBI |
|---|---|---|---|---|---|---|---|
| R37 | 3001-3500 | <0.54 | <0.54 | 10.57 | 26.93 | < ABS (4) | Acceptable |
| | 3501-4000 | 0.57 | 0.72 | 34.99 | 13.2 | < ABS (4) | Acceptable |
| | 4001-4500 | <0.54 | <0.54 | 17.63 | 4.75 | < ABS (4) | Acceptable |
| | 4501-5000 | <0.54 | <0.54 | 0.00 | 1.06 | < ABS (4) | Acceptable |
| | 5001-5500 | <0.54 | <0.54 | 4.74 | 7.39 | < ABS (4) | Acceptable |
| | 5501-6000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 6001-6500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 6501-7000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 7001-7500 | <0.54 | <0.54 | 0.87 | 3.17 | < ABS (4) | Acceptable |
| | 7501-8000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| R38-AR&L | 0-500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 501-1000 | <0.54 | <0.54 | 0.00 | 0.55 | < ABS (4) | Acceptable |
| | 1001-1500 | <0.54 | <0.54 | 0.21 | 0.00 | < ABS (4) | Acceptable |
| | 1500-2000 | <0.54 | <0.54 | 9.18 | 1.06 | < ABS (4) | Acceptable |
| | 2001-2500 | <0.54 | <0.54 | 4.95 | 0.00 | < ABS (4) | Acceptable |
| | 2501-3000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 3001-3500 | <0.54 | <0.54 | 0.45 | 0.00 | < ABS (4) | Acceptable |
| | 3501-4000 | <0.54 | <0.54 | 1.07 | 1.58 | < ABS (4) | Acceptable |
| | 4001-4500 | <0.54 | <0.54 | 8.08 | 2.64 | < ABS (4) | Acceptable |
| | 4501-5000 | <0.54 | <0.54 | 5.51 | 0.53 | < ABS (4) | Acceptable |
| | 5001-5500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 5501-6000 | <0.54 | <0.54 | 3 | 0.00 | < ABS (4) | Acceptable |
| | 6001-6500 | <0.54 | <0.54 | 0.00 | 1.58 | < ABS (4) | Acceptable |
| | 6501-7000 | <0.54 | 0.72 | 11.7 | 4.75 | < ABS (4) | Acceptable |
| | 7001-7500 | <0.54 | <0.54 | 0 | 2.11 | < ABS (4) | Acceptable |
| | 7501-8000 | <0.54 | <0.54 | 3.17 | 80.45 | < ABS (4) | Acceptable |
| | 8001-8500 | <0.54 | <0.54 | 36.93 | 11.09 | < ABS (4) | Acceptable |
| | 8501-9000 | 0.65 | 0.99 | 56.33 | 3.17 | < ABS (4) | Acceptable |
| | 9001-9500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 9501-10000 | <0.54 | <0.54 | 0.00 | 2.11 | < ABS (4) | Acceptable |
| | 10001-10500 | <0.54 | <0.54 | 6.22 | 4.22 | < ABS (4) | Acceptable |
| | 10501-11000 | <0.54 | <0.54 | 2.6 | 0.00 | < ABS (4) | Acceptable |
| | 11001-11500 | <0.54 | <0.54 | 0.00 | 2.12 | < ABS (4) | Acceptable |
| | 11501-12000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| R38-Inertial | 0-500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 501-1000 | <0.54 | <0.54 | 0.00 | 0.55 | < ABS (4) | Acceptable |
| | 1001-1500 | <0.54 | <0.54 | 0.21 | 0.00 | < ABS (4) | Acceptable |
| | 1500-2000 | <0.54 | <0.54 | 9.18 | 1.06 | < ABS (4) | Acceptable |
| | 2001-2500 | <0.54 | <0.54 | 4.95 | 0.00 | < ABS (4) | Acceptable |
| | 2501-3000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 3001-3500 | <0.54 | <0.54 | 0.45 | 0.00 | < ABS (4) | Acceptable |
| | 3501-4000 | <0.54 | <0.54 | 1.07 | 1.58 | < ABS (4) | Acceptable |

| Runway | Section (ft) | CG | CP | PI-100 | PI-25 | 12-ft RSE | BBI |
|---|---|---|---|---|---|---|---|
| R38-Inertial | 4001-4500 | <0.54 | <0.54 | 8.08 | 2.64 | < ABS (4) | Acceptable |
| | 4501-5000 | <0.54 | <0.54 | 5.51 | 0.53 | < ABS (4) | Acceptable |
| | 5001-5500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 5501-6000 | <0.54 | <0.54 | 3 | 0.00 | < ABS (4) | Acceptable |
| | 6001-6500 | <0.54 | <0.54 | 0.00 | 1.58 | < ABS (4) | Acceptable |
| | 6501-7000 | <0.54 | <0.54 | 11.7 | 4.75 | < ABS (4) | Acceptable |
| | 7001-7500 | <0.54 | <0.54 | 0.00 | 2.11 | < ABS (4) | Acceptable |
| | 7501-8000 | <0.54 | <0.54 | 19.08 | 80.45 | < ABS (4) | Acceptable |
| | 8001-8500 | 0.61 | 0.86 | 48.36 | 11.09 | < ABS (4) | Acceptable |
| | 8501-9000 | <0.54 | <0.54 | 17.08 | 3.17 | < ABS (4) | Acceptable |
| | 9001-9500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 9501-10000 | <0.54 | <0.54 | 0.00 | 2.11 | < ABS (4) | Acceptable |
| | 10001-10500 | <0.54 | <0.54 | 6.22 | 4.22 | < ABS (4) | Acceptable |
| | 10501-11000 | <0.54 | <0.54 | 2.6 | 0.00 | < ABS (4) | Acceptable |
| | 11001-11500 | <0.54 | <0.54 | 0.00 | 2.12 | < ABS (4) | Acceptable |
| | 11501-12000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| R39 | 0-500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 501-1000 | <0.54 | <0.54 | 0.87 | 0.55 | < ABS (4) | Acceptable |
| | 1001-1500 | <0.54 | <0.54 | 1.96 | 0.00 | < ABS (4) | Acceptable |
| | 1500-2000 | <0.54 | <0.54 | 14.23 | 1.06 | < ABS (4) | Acceptable |
| | 2001-2500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 2501-3000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 3001-3500 | <0.54 | <0.54 | 2.15 | 0.00 | < ABS (4) | Acceptable |
| | 3501-4000 | <0.54 | <0.54 | 0.63 | 1.58 | < ABS (4) | Acceptable |
| | 4001-4500 | <0.54 | <0.54 | 3.2 | 2.64 | < ABS (4) | Acceptable |
| | 4501-5000 | <0.54 | <0.54 | 0.00 | 0.53 | < ABS (4) | Acceptable |
| | 5001-5500 | 0.55 | 0.8 | 13.86 | 0.00 | < ABS (4) | 1.18 |
| | 5501-6000 | <0.54 | <0.54 | 1.92 | 0.00 | < ABS (4) | Acceptable |
| | 6001-6500 | <0.54 | <0.54 | 0.53 | 1.58 | < ABS (4) | Acceptable |
| | 6501-7000 | <0.54 | <0.54 | 0.24 | 4.75 | < ABS (4) | Acceptable |
| | 7001-7500 | <0.54 | <0.54 | 20.48 | 2.11 | < ABS (4) | Acceptable |
| | 7501-8000 | <0.54 | <0.54 | 0.24 | 80.45 | < ABS (4) | Acceptable |
| | 8001-8500 | <0.54 | <0.54 | 0.46 | 11.09 | < ABS (4) | Acceptable |
| | 8501-9000 | <0.54 | <0.54 | 0.00 | 3.17 | < ABS (4) | Acceptable |
| | 9001-9500 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| | 9501-10000 | <0.54 | <0.54 | 1.21 | 2.11 | < ABS (4) | Acceptable |
| | 10001-10500 | <0.54 | <0.54 | 3.58 | 4.22 | < ABS (4) | Acceptable |
| | 10501-11000 | <0.54 | <0.54 | 0.00 | 0.00 | < ABS (4) | Acceptable |
| R40 | 0-500 | <0.54 | <0.54 | 60.42 | 0.00 | < ABS (4) | Acceptable |
| | 501-1000 | <0.54 | <0.54 | 1.27 | 0.5 | < ABS (4) | Acceptable |
| | 1001-1500 | <0.54 | <0.54 | 50.43 | 3.31 | < ABS (4) | Acceptable |
| | 1500-2000 | <0.54 | <0.54 | 0.7 | 4.05 | < ABS (4) | Acceptable |

| Runway | Section (ft) | CG | CP | PI-100 | PI-25 | 12-ft RSE | BBI |
|---|---|---|---|---|---|---|---|
| R40 | 2001-2500 | 0.62 | 0.69 | 23.12 | 0.92 | < ABS (4) | Acceptable |
| | 2501-3000 | <0.54 | <0.54 | 0.00 | 4.21 | < ABS (4) | Acceptable |
| | 3001-3500 | <0.54 | <0.54 | 0.00 | 1.02 | < ABS (4) | Acceptable |
| | 3501-4000 | <0.54 | <0.54 | 0.00 | 1.15 | < ABS (4) | Acceptable |
| | 4001-4500 | <0.54 | <0.54 | 0.00 | 1.59 | < ABS (4) | Acceptable |

ABS = Absolute value
BBI = Boeing Bump Index
CG = Center of gravity
CP = Cockpit
PI = Profile index
RSE = (Rolling) Straightedge

# APPENDIX D—COMMERCIAL AND MILITARY TAXIWAYS

This appendix contains the results of commercial and military taxiway analyses. All simulated responses were conducted with the Airport Pavement Roughness Assessment Software (APRas).

More than 21 commercial and military taxiway profiles were evaluated. Several were measured with a high-speed profiler, but most were measured with the Auto Rod & Level–ER (AR&L–ER) true profiler.

T6 through T11 were measured with a high-speed inertial profiler (MACTEC South Dakota Profiler). There were occasional acceleration and deceleration errors evident on these profiles. Those sections produced unreliable results.

Table D-1. Limits of Acceptability

| Vertical Acceleration (*g*'s) | PI-25 ( 0.4-in. BB) | 12-ft RSE |
|---|---|---|
| Red >0.80 | Red >35 | Red > (ABS 0.8) |
| Yellow 0.40 to 0.80 | Yellow 20 to 35 | Yellow (ABS 0.4 to 0.80) |
| Green <00.4 | Green <20 | Green < (ABS 0.4) |

ABS = Absolute Value
BB = Blanking band
PI = Profile index
RSE = (Rolling) Straightedge

Table D-2. Commercial and Military Taxiways

| Profile | Section (ft) | CG | CP | PI-25 | 12-ft RSE |
|---|---|---|---|---|---|
| T1 | 0-500 | <0.40 | 0.45 | 25.14 | <0.4 |
| | 501-1000 | <0.40 | <0.40 | 8.98 | <0.4 |
| | 1001-1500 | <0.40 | <0.40 | 7.39 | <0.4 |
| | 1500-2000 | <0.40 | <0.40 | 19.54 | <0.4 |
| | 2001-2500 | <0.40 | <0.40 | 21.12 | <0.4 |
| | 2501-3000 | <0.40 | <0.40 | 4.75 | <0.4 |
| | 3001-3500 | <0.40 | <0.40 | 14.26 | 0.48 |
| | 3501-4000 | <0.40 | <0.40 | 4.22 | <0.4 |
| | 4001-4500 | <0.40 | <0.40 | 0.00 | <0.4 |
| | 4501-5000 | <0.40 | <0.40 | 1.58 | <0.4 |
| | 5001-5500 | <0.40 | <0.40 | 0.00 | <0.4 |
| | 5501-6000 | <0.40 | <0.40 | 0.53 | <0.4 |
| | 6001-6500 | <0.40 | <0.40 | 0.00 | <0.4 |
| T2 | 0-500 | <0.40 | <0.40 | 8.2 | 0.43 |
| | 501-1000 | <0.40 | <0.40 | 3.7 | <0.4 |
| | 1001-1500 | <0.40 | <0.40 | 2.64 | <0.4 |
| | 1500-2000 | <0.40 | <0.40 | 19.54 | <0.4 |
| | 2001-2500 | <0.40 | <0.40 | 1.06 | <0.4 |

| Profile | Section (ft) | CG | CP | PI-25 | 12-ft RSE |
|---|---|---|---|---|---|
| T2 | 2501-3000 | <0.40 | <0.40 | 5.81 | <0.4 |
| | 3001-3500 | <0.40 | <0.40 | 6.86 | <0.4 |
| | 3501-4000 | <0.40 | <0.40 | 11.62 | <0.4 |
| | 4001-4500 | <0.40 | <0.40 | 3.28 | <0.4 |
| T3 | 0-500 | <0.40 | <0.40 | 1.09 | <0.4 |
| | 501-1000 | <0.40 | <0.40 | 3.17 | <0.4 |
| | 1001-1500 | <0.40 | <0.40 | 6.86 | <0.4 |
| | 1500-2000 | <0.40 | <0.40 | 2.11 | <0.4 |
| | 2001-2500 | <0.40 | <0.40 | 10.03 | <0.4 |
| | 2501-3000 | <0.40 | <0.40 | 0.00 | <0.4 |
| T4 | 0-500 | <0.40 | <0.40 | 2.73 | <0.4 |
| | 501-1000 | <0.40 | <0.40 | 5.81 | <0.4 |
| | 1001-1500 | <0.40 | <0.40 | 0.00 | <0.4 |
| | 1500-2000 | <0.40 | <0.40 | 0.53 | <0.4 |
| | 2001-2500 | <0.40 | <0.40 | 0.00 | <0.4 |
| | 2501-3000 | <0.40 | <0.40 | 29.03 | <0.4 |
| T5 | 0-500 | <0.40 | 0.45 | 39.27 | 0.59 |
| | 501-1000 | <0.40 | <0.40 | 24.85 | <0.4 |
| | 1001-1500 | <0.40 | <0.40 | 27.96 | 0.52 |
| | 1500-2000 | <0.40 | <0.40 | 4.23 | <0.4 |
| | 2001-2500 | <0.40 | <0.40 | 15.3 | <0.4 |
| | 2501-3000 | <0.40 | <0.40 | 1.58 | <0.4 |
| | 3001-3500 | <0.40 | <0.40 | 16.39 | <0.4 |
| | 3501-4000 | <0.40 | <0.40 | 23.21 | 0.86 |
| | 4001-4500 | <0.40 | <0.40 | 4.22 | <0.4 |
| | 4501-5000 | <0.40 | <0.40 | 4.76 | <0.4 |
| | 5001-5500 | <0.40 | <0.40 | 3.69 | <0.4 |
| | 5501-6000 | <0.40 | <0.40 | 2.64 | <0.4 |
| | 6001-6500 | <0.40 | <0.40 | 21.1 | 0.63 |
| | 6501-7000 | <0.40 | <0.40 | 45.37 | 0.55 |
| | 7001-7500 | <0.40 | <0.40 | 23.79 | <0.4 |
| | 7501-8000 | <0.40 | <0.40 | 31.66 | 0.46 |
| | 8001-8500 | <0.40 | <0.40 | 16.92 | <0.4 |
| | 8501-9000 | <0.40 | <0.40 | 55.92 | 0.69 |
| | 9001-9500 | <0.40 | <0.40 | 20.05 | <0.4 |
| | 9501-10000 | <0.40 | <0.40 | 65.2 | 0.60 |
| T6 | 0-500 | <0.40 | <0.40 | NA | <0.4 |
| | 501-1000 | <0.40 | <0.40 | 12.69 | <0.4 |
| | 1001-1500 | <0.40 | <0.40 | 6.86 | <0.4 |
| | 1500-2000 | <0.40 | <0.40 | 9.52 | <0.4 |
| | 2001-2500 | <0.40 | <0.40 | 10.55 | <0.4 |
| | 2501-3000 | <0.40 | <0.40 | 24.8 | 0.73 |

| Profile | Section (ft) | CG | CP | PI-25 | 12-ft RSE |
|---|---|---|---|---|---|
| T6 | 3001-3500 | <0.40 | <0.40 | 17.97 | <0.4 |
| | 3501-4000 | <0.40 | <0.40 | 13.19 | <0.4 |
| | 4001-4500 | <0.40 | <0.40 | 5.8 | <0.4 |
| | 4501-5000 | <0.40 | <0.40 | 16.39 | <0.4 |
| | 5001-5500 | <0.40 | <0.40 | 15.3 | <0.4 |
| | 5501-6000 | <0.40 | 0.44 | 20.09 | 0.75 |
| | 6001-6500 | <0.40 | <0.40 | 26.38 | <0.4 |
| | 6501-7000 | <0.40 | <0.40 | 27.95 | 0.57 |
| | 7001-7500 | <0.40 | <0.40 | 33.31 | <0.4 |
| | 7501-8000 | <0.40 | <0.40 | 31.13 | <0.4 |
| | 8001-8500 | <0.40 | <0.40 | 360.48 | <0.4 |
| | 8501-9000 | <0.40 | <0.40 | 12.13 | <0.4 |
| | 9001-9500 | <0.40 | <0.40 | 62.78 | 0.89 |
| | 9501-10000 | <0.40 | <0.40 | 16.85 | <0.4 |
| T7 | 0-500 | <0.40 | <0.40 | NA | 0.64 |
| | 501-1000 | <0.40 | <0.40 | 32.25 | <0.4 |
| | 1001-1500 | <0.40 | <0.40 | 44.32 | <0.4 |
| | 1500-2000 | <0.40 | <0.40 | 170.45 | 0.44 |
| | 2001-2500 | <0.40 | <0.40 | 4.75 | <0.4 |
| | 2501-3000 | <0.40 | <0.40 | 16.88 | <0.4 |
| | 3001-3500 | <0.40 | <0.40 | 2.64 | <0.4 |
| | 3501-4000 | <0.40 | <0.40 | 1.06 | <0.4 |
| | 4001-4500 | <0.40 | <0.40 | 12.66 | <0.4 |
| | 4501-5000 | <0.40 | <0.40 | 11.63 | <0.4 |
| | 5001-5500 | <0.40 | <0.40 | 10.02 | <0.4 |
| | 5501-6000 | <0.40 | <0.40 | 25.38 | <0.4 |
| | 6001-6500 | <0.40 | <0.40 | 360.4 | 0.58 |
| | 6501-7000 | <0.40 | <0.40 | 280.49 | <0.4 |
| | 7001-7500 | <0.40 | <0.40 | 5.82 | <0.4 |
| | 7501-8000 | <0.40 | <0.40 | 25.32 | 0.46 |
| | 8001-8500 | <0.40 | <0.40 | 46 | 0.61 |
| | 8501-9000 | <0.40 | <0.40 | 320.41 | 0.44 |
| | 9001-9500 | <0.40 | <0.40 | 33.15 | <0.4 |
| T8 | 0-500 | <0.40 | <0.40 | 48 | <0.4 |
| | 501-1000 | <0.40 | <0.40 | 51.81 | 0.72 |
| | 1001-1500 | <0.40 | <0.40 | 61.2 | 0.71 |
| | 1500-2000 | <0.40 | <0.40 | 81.94 | 1.1 |
| | 2001-2500 | <0.40 | <0.40 | 13.19 | <0.4 |
| | 2501-3000 | <0.40 | <0.40 | 33.77 | 0.5 |
| | 3001-3500 | <0.40 | <0.40 | 59.74 | 1.01 |
| | 3501-4000 | <0.40 | <0.40 | 45.37 | <0.4 |
| | 4001-4500 | <0.40 | <0.40 | 19.52 | <0.4 |

| Profile | Section (ft) | CG | CP | PI-25 | 12-ft RSE |
|---|---|---|---|---|---|
| T8 | 4501-5000 | <0.40 | <0.40 | 7.93 | <0.4 |
| | 5001-5500 | <0.40 | <0.40 | 43.26 | 0.67 |
| | 5501-6000 | <0.40 | <0.40 | 22.72 | <0.4 |
| T9 | 0-500 | <0.40 | <0.40 | 0.55 | <0.4 |
| | 501-1000 | <0.40 | <0.40 | 2.11 | <0.4 |
| | 1001-1500 | <0.40 | <0.40 | 0.00 | <0.4 |
| | 1500-2000 | <0.40 | <0.40 | 3.17 | <0.4 |
| | 2001-2500 | <0.40 | <0.40 | 6.86 | <0.4 |
| | 2501-3000 | <0.40 | <0.40 | 24.27 | 0.85 |
| | 3001-3500 | <0.40 | <0.40 | 2.64 | <0.4 |
| | 3501-4000 | <0.40 | <0.40 | 7.39 | <0.4 |
| | 4001-4500 | <0.40 | <0.40 | 4.75 | <0.4 |
| | 4501-5000 | <0.40 | <0.40 | 1.59 | <0.4 |
| | 5001-5500 | <0.40 | <0.40 | 0.53 | <0.4 |
| | 5501-6000 | <0.40 | <0.40 | 2.11 | <0.4 |
| | 6001-6500 | <0.40 | <0.40 | 4.75 | <0.4 |
| | 6501-7000 | <0.40 | <0.40 | 5.28 | <0.4 |
| | 7001-7500 | <0.40 | <0.40 | 0.00 | <0.4 |
| | 7501-8000 | <0.40 | <0.40 | 0.00 | <0.4 |
| T10 | 0-500 | <0.40 | <0.40 | 96 | 0.55 |
| | 501-1000 | <0.40 | <0.40 | 98.86 | 0.92 |
| | 1001-1500 | <0.40 | <0.40 | 41.15 | 0.55 |
| | 1500-2000 | <0.40 | <0.40 | 11.63 | 0.46 |
| | 2001-2500 | <0.40 | <0.40 | 5.8 | <0.4 |
| | 2501-3000 | <0.40 | <0.40 | 41.15 | 0.62 |
| | 3001-3500 | <0.40 | <0.40 | 19.56 | 0.41 |
| | 3501-4000 | <0.40 | <0.40 | 22.69 | <0.4 |
| | 4001-4500 | <0.40 | <0.40 | 24.27 | <0.4 |
| | 4501-5000 | <0.40 | <0.40 | 160.45 | <0.4 |
| T11 | 0-500 | <0.40 | <0.40 | NA | <0.4 |
| | 501-1000 | <0.40 | <0.40 | 21.68 | <0.4 |
| | 1001-1500 | <0.40 | <0.40 | 30.07 | 0.46 |
| | 1500-2000 | <0.40 | <0.40 | 20.09 | <0.4 |
| | 2001-2500 | <0.40 | <0.40 | 18.99 | 0.53 |
| | 2501-3000 | <0.40 | 0.41 | 13.19 | 0.46 |
| | 3001-3500 | <0.40 | <0.40 | 10.57 | <0.4 |
| | 3501-4000 | <0.40 | <0.40 | 35.88 | 0.65 |
| | 4001-4500 | <0.40 | <0.40 | 35.35 | 0.74 |
| | 4501-5000 | <0.40 | <0.40 | 260.43 | <0.4 |
| | 5001-5500 | <0.40 | <0.40 | 37.98 | 0.51 |

| Profile | Section (ft) | CG | CP | PI-25 | 12-ft RSE |
|---|---|---|---|---|---|
| T11 | 5501-6000 | <0.40 | <0.40 | 47.58 | 0.52 |
| | 6001-6500 | <0.40 | <0.40 | 29.79 | <0.4 |
| T12 | 0-500 | <0.40 | <0.40 | 9.84 | <0.4 |
| | 501-1000 | <0.40 | <0.40 | 1.58 | <0.4 |
| | 1001-1500 | <0.40 | <0.40 | 0.00 | <0.4 |
| | 1500-2000 | <0.40 | <0.40 | 1.06 | <0.4 |
| | 2001-2500 | <0.40 | <0.40 | 4.75 | <0.4 |
| | 2501-3000 | <0.40 | <0.40 | 1.06 | <0.4 |
| | 3001-3500 | <0.40 | <0.40 | 2.64 | <0.4 |
| | 3501-4000 | <0.40 | <0.40 | 4.22 | <0.4 |
| | 4001-4500 | <0.40 | <0.40 | 21.12 | 0.51 |
| | 4501-5000 | <0.40 | <0.40 | 14.26 | <0.4 |
| | 5001-5500 | <0.40 | <0.40 | 2.11 | <0.4 |
| | 5501-6000 | <0.40 | <0.40 | 4.22 | <0.4 |
| | 6001-6500 | <0.40 | <0.40 | 3.7 | <0.4 |
| | 6501-7000 | <0.40 | <0.40 | 7.92 | <0.4 |
| | 7001-7500 | <0.40 | <0.40 | 9.5 | <0.4 |
| | 7501-8000 | <0.40 | <0.40 | 5.38 | <0.4 |
| T13 | 0-500 | <0.40 | <0.40 | 7.65 | <0.4 |
| | 501-1000 | <0.40 | 0.43 | 47.53 | 0.44 |
| | 1001-1500 | <0.40 | <0.40 | 18.99 | <0.4 |
| | 1500-2000 | <0.40 | <0.40 | 15.84 | <0.4 |
| | 2001-2500 | <0.40 | <0.40 | 21.65 | <0.4 |
| | 2501-3000 | <0.40 | <0.40 | 68.65 | <0.4 |
| | 3001-3500 | <0.40 | <0.40 | 29.57 | <0.4 |
| | 3501-4000 | <0.40 | <0.40 | 17.94 | <0.4 |
| | 4001-4500 | <0.40 | <0.40 | 3.7 | <0.4 |
| | 4501-5000 | <0.40 | <0.40 | 3.17 | <0.4 |
| | 5001-5500 | <0.40 | <0.40 | 1.06 | <0.4 |
| | 5501-6000 | <0.40 | <0.40 | 5.81 | <0.4 |
| | 6001-6500 | <0.40 | <0.40 | 0.53 | <0.4 |
| | 6501-7000 | <0.40 | <0.40 | 3.7 | <0.4 |
| | 7001-7500 | <0.40 | <0.40 | 2.11 | <0.4 |
| | 7501-8000 | <0.40 | <0.40 | 1.06 | <0.4 |
| | 8001-8500 | <0.40 | <0.40 | 11.09 | <0.4 |
| | 8501-9000 | <0.40 | <0.40 | 4.22 | <0.4 |
| | 9001-9500 | <0.40 | <0.40 | 6.34 | <0.4 |
| | 9501-10000 | <0.40 | <0.40 | 5.28 | <0.4 |
| | 10001-10500 | <0.40 | <0.40 | 25.35 | 0.42 |
| | 10501-11000 | <0.40 | <0.40 | 30.47 | <0.4 |
| T14 | 0-500 | <0.40 | <0.40 | 8.75 | <0.4 |
| | 501-1000 | <0.40 | <0.40 | 0.00 | <0.4 |

| Profile | Section (ft) | CG | CP | PI-25 | 12-ft RSE |
|---|---|---|---|---|---|
| T14 | 1001-1500 | <0.40 | <0.40 | 6.34 | <0.4 |
| | 1500-2000 | <0.40 | <0.40 | 1.06 | <0.4 |
| | 2001-2500 | <0.40 | <0.40 | 9.5 | <0.4 |
| | 2501-3000 | <0.40 | <0.40 | 0.00 | <0.4 |
| | 3001-3500 | <0.40 | <0.40 | 2.64 | <0.4 |
| | 3501-4000 | <0.40 | <0.40 | 0.00 | <0.4 |
| | 4001-4500 | <0.40 | <0.40 | 0.00 | <0.4 |
| | 4501-5000 | <0.40 | <0.40 | 0.00 | <0.4 |
| | 5001-5500 | <0.40 | <0.40 | 4.75 | <0.4 |
| | 5501-6000 | <0.40 | <0.40 | 5.81 | <0.4 |
| | 6001-6500 | <0.40 | <0.40 | 1.58 | <0.4 |
| | 6501-7000 | <0.40 | <0.40 | 16.37 | <0.4 |
| | 7001-7500 | <0.40 | <0.40 | 0.00 | <0.4 |
| | 7501-8000 | <0.40 | <0.40 | 2.9 | <0.4 |
| T15 | 0-500 | <0.40 | <0.40 | 1.64 | <0.4 |
| | 501-1000 | <0.40 | <0.40 | 0.53 | 0.44 |
| | 1001-1500 | <0.40 | <0.40 | 0.00 | <0.4 |
| | 1500-2000 | <0.40 | <0.40 | 0.53 | <0.4 |
| | 2001-2500 | <0.40 | <0.40 | 0.53 | <0.4 |
| | 2501-3000 | <0.40 | <0.40 | 1.06 | <0.4 |
| | 3001-3500 | <0.40 | <0.40 | 0.79 | <0.4 |
| T32 | 0-500 | <0.40 | <0.40 | 9.28 | <0.4 |
| | 501-1000 | <0.40 | <0.40 | 4.75 | <0.4 |
| | 1001-1500 | <0.40 | <0.40 | 8.98 | <0.4 |
| | 1500-2000 | <0.40 | <0.40 | 5.81 | <0.4 |
| | 2001-2500 | <0.40 | <0.40 | 4.22 | <0.4 |
| | 2501-3000 | <0.40 | <0.40 | 2.11 | <0.4 |
| | 3001-3500 | <0.40 | <0.40 | 2.64 | <0.4 |
| | 3501-4000 | <0.40 | <0.40 | 0.00 | <0.4 |
| | 4001-4500 | <0.40 | <0.40 | 3.7 | <0.4 |
| | 4501-5000 | <0.40 | <0.40 | 11.62 | <0.4 |
| | 5001-5500 | <0.40 | <0.40 | 5.81 | <0.4 |
| | 5501-6000 | <0.40 | <0.40 | 3.7 | <0.4 |
| | 6001-6500 | <0.40 | <0.40 | 170.42 | 0.43 |
| | 6501-7000 | <0.40 | <0.40 | 3.5 | <0.4 |
| T33 | 0-500 | <0.40 | <0.40 | 14.19 | <0.4 |
| | 501-1000 | <0.40 | <0.40 | 21.12 | <0.4 |
| | 1001-1500 | <0.40 | <0.40 | 2.64 | <0.4 |
| | 1500-2000 | <0.40 | <0.40 | 10.56 | <0.4 |
| | 2001-2500 | <0.40 | <0.40 | 180.48 | <0.4 |
| | 2501-3000 | <0.40 | <0.40 | 2.64 | <0.4 |
| | 3001-3500 | <0.40 | <0.40 | 80.45 | <0.4 |

| Profile | Section (ft) | CG | CP | PI-25 | 12-ft RSE |
|---|---|---|---|---|---|
| T33 | 3501-4000 | <0.40 | <0.40 | 5.28 | <0.4 |
| | 4001-4500 | <0.40 | <0.40 | 5.81 | <0.4 |
| | 4501-5000 | <0.40 | <0.40 | 11.62 | <0.4 |
| | 5001-5500 | <0.40 | <0.40 | 6.34 | <0.4 |
| | 5501-6000 | <0.40 | <0.40 | 5.28 | <0.4 |
| | 6001-6500 | <0.40 | <0.40 | 0.53 | <0.4 |
| | 6501-7000 | <0.40 | <0.40 | 30.43 | <0.4 |
| T34 | 0-500 | <0.40 | <0.40 | 30.57 | <0.4 |
| | 501-1000 | <0.40 | <0.40 | 3.63 | <0.4 |
| T35 | 0-500 | <0.40 | <0.40 | 16.38 | <0.4 |
| | 501-1000 | <0.40 | 0.43 | 4.75 | <0.4 |
| | 1001-1500 | <0.40 | <0.40 | 3.17 | <0.4 |
| | 1500-2000 | <0.40 | <0.40 | 2.11 | <0.4 |
| | 2001-2500 | <0.40 | <0.40 | 3.17 | <0.4 |
| | 2501-3000 | <0.40 | <0.40 | 0.00 | <0.4 |
| | 3001-3500 | <0.40 | <0.40 | 0.00 | <0.4 |
| | 3501-4000 | <0.40 | <0.40 | 0.00 | <0.4 |
| | 4001-4500 | <0.40 | <0.40 | 0.00 | <0.4 |
| | 4501-5000 | <0.40 | <0.40 | 0.00 | <0.4 |
| | 5001-5500 | <0.40 | <0.40 | 1.06 | <0.4 |
| | 5501-6000 | <0.40 | <0.40 | 1.06 | <0.4 |
| | 6001-6500 | <0.40 | <0.40 | 0.00 | <0.4 |
| | 6501-7000 | <0.40 | <0.40 | 0.00 | <0.4 |
| | 7001-7500 | <0.40 | <0.40 | 52.27 | 0.58 |
| | 7501-8000 | <0.40 | <0.40 | 31.68 | 0.58 |
| | 8001-8500 | <0.40 | <0.40 | 35.38 | 0.56 |
| | 8501-9000 | <0.40 | <0.40 | 17.95 | 0.41 |
| | 9001-9500 | <0.40 | <0.40 | 19.01 | <0.4 |
| | 9501-10000 | <0.40 | <0.40 | 54.38 | 0.54 |
| | 10001-10500 | <0.40 | <0.40 | 1.58 | <0.4 |
| | 10501-11000 | <0.40 | <0.40 | 23.67 | 0.46 |
| T36 | 0-500 | <0.40 | <0.40 | 12.01 | <0.4 |
| | 501-1000 | <0.40 | 0.43 | 5.28 | <0.4 |
| | 1001-1500 | <0.40 | <0.40 | 1.06 | <0.4 |
| | 1500-2000 | <0.40 | <0.40 | 2.64 | <0.4 |
| | 2001-2500 | <0.40 | <0.40 | 13.2 | <0.4 |
| | 2501-3000 | <0.40 | <0.40 | 7.92 | <0.4 |
| | 3001-3500 | <0.40 | <0.40 | 1.58 | <0.4 |
| | 3501-4000 | <0.40 | <0.40 | 1.58 | <0.4 |
| | 4001-4500 | <0.40 | <0.40 | 7.92 | <0.4 |
| | 4501-5000 | <0.40 | <0.40 | 2.64 | <0.4 |
| | 5001-5500 | <0.40 | <0.40 | 1.06 | <0.4 |

| Profile | Section (ft) | CG | CP | PI-25 | 12-ft RSE |
|---|---|---|---|---|---|
| T36 | 5501-6000 | <0.40 | <0.40 | 4.75 | <0.4 |
| | 6001-6500 | <0.40 | <0.40 | 2.11 | <0.4 |
| | 6501-7000 | <0.40 | <0.40 | 42.24 | 0.66 |
| | 7001-7500 | <0.40 | <0.40 | 1.58 | <0.4 |
| | 7501-8000 | <0.40 | <0.40 | 0.00 | <0.4 |
| | 8001-8500 | <0.40 | <0.40 | 12.67 | <0.4 |
| | 8501-9000 | <0.40 | <0.40 | 13.2 | <0.4 |
| | 9001-9500 | <0.40 | <0.40 | 9.5 | <0.4 |
| | 9501-10000 | <0.40 | <0.40 | 23.23 | <0.4 |
| | 10001-10500 | <0.40 | <0.40 | 13.73 | 0.42 |
| | 10501-11000 | <0.40 | <0.40 | 80.45 | <0.4 |
| T37 | 0-500 | <0.40 | <0.40 | 12.01 | <0.4 |
| | 501-1000 | <0.40 | 0.43 | 6.86 | <0.4 |
| | 1001-1500 | <0.40 | <0.40 | 9.5 | <0.4 |
| | 1500-2000 | <0.40 | <0.40 | 5.28 | <0.4 |
| | 2001-2500 | <0.40 | <0.40 | 7.39 | <0.4 |
| | 2501-3000 | <0.40 | <0.40 | 170.42 | <0.4 |
| | 3001-3500 | <0.40 | <0.40 | 8.98 | <0.4 |
| | 3501-4000 | <0.40 | <0.40 | 4.75 | <0.4 |
| | 4001-4500 | <0.40 | <0.40 | 5.81 | <0.4 |
| | 4501-5000 | <0.40 | <0.40 | 15.5 | <0.4 |

CG = Center of gravity
CP = Cockpit
PI = Profile index
RSE = (Rolling) Straightedge

# APPENDIX E—OBSERVATIONS AND LESSONS LEARNED

This appendix contains a summary of the observations and lessons learned while conducting this research.

Section Length: APR Consultants, Inc. (APR)'s initial approach in this investigation was to use a section length of 1,000 feet. An investigation was initiated to determine what is the best section length to use for profile index (PI)-100 calculations. The advantage of 1,000-foot sections is that there will be fewer overlap concerns and fewer computations. The advantage of 500-foot sections is that there is less averaging that could dilute the PI-100 and PI-25 level when only two to three bump events are involved. It was concluded that the 500-foot section is a better choice because most multiple-event runways that APR has analyzed are two to three events. Plus, if there are more than three events, the 500-foot section lengths will still detect them, but in the next pavement section.

Other lengths might have worked but would have required a different blanking band (BB) and different limits defining acceptable, excessive, and unacceptable.

When analyzing one particular runway, a single bump located around 2,500 feet down the runway straddled two 500-foot sections. As a result, the PI-100 *did not* register as (yellow) excessive. However, results of the Boeing 737 simulations suggested that it should have been considered excessive. If the 500-foot sections were shifted by 250 feet, the PI-100 would have found it to be (yellow) excessive. This is a rare case, but emphasizes the point that, in special situations, it might be necessary to shift the starting location of the first section.

When this runway was assessed with ProFAA, that section produced a Boeing Bump Index (BBI) = 0.69 (acceptable). The excessive threshold for BBI starts at 1.0.

PI-100 Blanking Band: The purpose of the 1-inch BB is to ignore Type 3 roughness content that is benign. The primary reason 1 inch was chosen is that, for 30 years, APR has successfully used 1 inch as a threshold to detect long wavelength roughness. It has proven to be a reasonable choice. Other values could be used for a BB but that would just impact the limits of acceptability that have been established. It was necessary to have a consistent process using a reasonable threshold for a BB. One inch was selected for this reason.

APR has evaluated many airport pavements using a 100-foot simulated straightedge (SE) with a 1-inch deviation threshold to detect objectionable long wavelength (Type 3) roughness. These previous evaluations were supportive in establishing the limits defining acceptable, excessive, and unacceptable.

PI-25 Blanking Band: A 0.4-inch BB was chosen for the PI-25 because it is consistent with the must grind limit used for new pavement acceptance (FAA, 2018.) The default BB used in ProVAL and ProFAA is 0.2 inches and is intended to reflect the new pavement acceptance criteria in FAA Advisory Circular 150/5370-10H. This roughness evaluation method is intended for in-service pavements. Using a 0.2-inch BB would find many in-service pavements excessive when compared to new pavement acceptance criteria. Again, a different BB could be used, but the limits of

acceptability would be different. All pavements analyzed in this research used a consistent 0.4-inch blanking band.

12-ft Straightedge (RSE): A 12-foot RSE was used to detect single bumps and dips that could be washed out when looking at roughness over an entire section. A deviation threshold of 0.4 inches was chosen because this value is defined as a must grind for new pavement acceptance. A 12-foot length was selected because it is consistent with FAA Advisory Circular 150/5370 (P-401 and P-501). The straightedge program used in ProVAL is labeled as a rolling straightedge (RSE).

MMAC PST Simulation Observations

**Observation 1**

All B737-800 PST simulations had a gross weight (GW) of 130,000 lbs. APR computed the center of gravity (CG) location using the static loads on the nose landing gear (NLG) and main landing gear (MLG) at T = 0.0. There were two CG locations that were found in the PST runs.

Runs S01 to S40: Taxiway Simulations: (20 knots).

NLG Static Force = 8,492 lb, and MLG Static Force 60,311 lb

- This translates to a CG of 25.04% Mean Aerodynamic Chord (MAC):
- A is the distance from the MLG to the CG
- B is the distance from the NLG to the CG

Runs S41 to S98: Runway Simulations (100 knots)

NLG Static Force = 7,969 lb, and MLG Static Force 51,392 lb

- This translates to a CG of 22.56% MAC

- This is a *more forward CG* than above which would typically increase cockpit response.

The B737-800 data provided by APR to the FAA contained both CG locations so comparisons to any PST result can be conducted. It is necessary to modify the ProFAA source code when the CG data are changed. ProFAA does not allow for changes in CG or GW without modifying the source code. It is recommended that the final B737-800 version be installed permanently in ProFAA to be closer to maximum takeoff GW of 172,500 lb with a CG at 25% MAC.

**Observation 2**

The NLG force in PST 77 (a rough runway located in Russia) produced a positive value. The peak load was (-22,063 lb). Minimum load was (+2,840 lb). That suggests that the NLG tire is off the ground. Since this is not possible, it prompts the question, how does the simulator treat this situation? Both ProFAA and APRas simulations show NLG force of 0.0 when the NLG tire leaves the ground. It also prompts the question, did pilots have elevator control or was aerodynamic lift

included or not in the simulator tests? These factors are important, particularly for the 100-knot taxi tests if comparisons are to be made with ProFAA and APRas.

**Observation regarding pilot subjective ratings in the MMAC PST simulations.**

PST pilot subjective ratings for runways did not correlate well with gear forces in Phase 1. For example, the average pilot rating for PST 58 was fair to poor (4.04). After investigation, it was determined that pilots were objecting more about excessive pitch motion in the cockpit (CP), not *g* forces. Figure E-1 is a plot of profile PST 58 being traversed with a 500-foot SE. Note the long wavelength content of this profile, with abrupt changes to the SE deviations approximately every 250 feet. This will cause CP pitch motion. The measured gear forces shown in the insert table do not support the pilot subjective ratings. In simple terms, aircraft accelerations predict mild responses to the measured profile whereas feedback from the pilot study suggest this pavement contains significant pavement roughness. The CP *g* values are lower than the Boeing *g* criteria of 0.8 *g* for unacceptable. Consequently, it can be concluded that the PST pilot ratings for runways reflect aircraft pitch motion on Type 3 roughness more than they reflect gear loads.

The perception of roughness can differ from the actual aircraft dynamic response (*g*'s) as seen in the PST subjective ratings. The perception of roughness may also differ on a taxiway versus a runway. During takeoff and landing, other forces, such as thrust, braking, and reverse thrust, will tend to minimize the perception of pavement roughness.

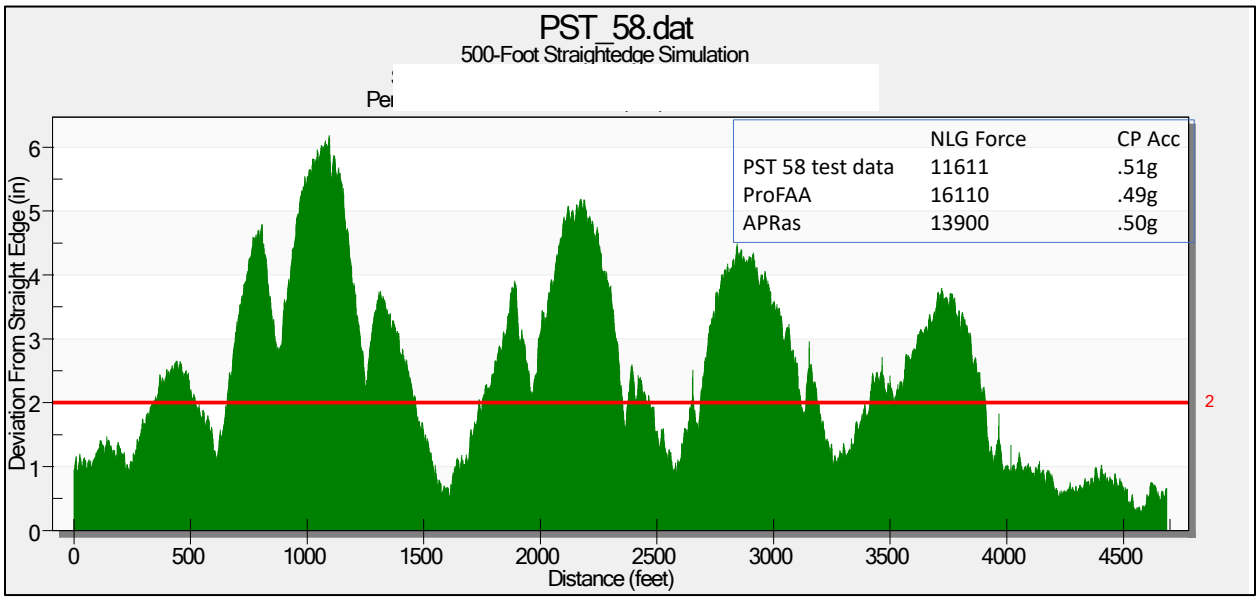


Figure E-1. Plot of PST 58 Using a 500-Foot Straightedge

**Observations made when reviewing ProFAA source code.**

ProFAA simulations were made on a perfectly smooth runway. It was observed that the combined static loads do not add up to the total aircraft weight. It was also determined that aerodynamic lift is not included in ProFAA simulations. In addition, investigation into ProFAA shows that ProFAA

gear forces are not in equilibrium at T=0.0. They are assumed to be 0.0 pounds, whereas they should be static values.

Dr. Wang of GDIT states, "Since the algorithms and parameters used in the program have not been documented, it is hard to improve and update the computing procedures." Dr. Wang ran into the same issues that APR found when reviewing the ProFAA source code.

Finally, the ProFAA equations of motion (EOM) do not allow for a variable speed, which is required for takeoff and landing simulations. In addition, the current source code does not include a horizontal translation degree of freedom which would be required for thrust, reverse thrust, wheel brake forces, and other factors needed to update ProFAA.

What ProFAA has labeled as "Extend Force" is really the internal force in the strut when it is fully extended. It basically is the pre-charge pressure multiplied by the strut piston area. The current version of ProFAA uses one line of survey when analyzing a pavement for roughness. When the subject runway has an intersecting runway in its profile, a right or left profile should be used for the analysis to determine the impact the intersection's profile has on the main landing gear. The crown at the intersection will be larger off the centerline causing more aircraft response.

Inertial Profiler Cut-off Wavelength

*Can high speed inertial profilers measure long wavelength roughness?*

Figure E-2 contains a PSD (Power Spectral Density) plot showing that an inertial profiler is consistent with a true profiler up to wavelengths 220 feet long for the two profiles shown. This implies that the inertial profiler will capture wavelengths that generally produce rigid body aircraft response (Type 3 roughness). It can be seen that the inertial unit values drop off after 220 feet. It is recommended that additional profiles be compared to validate inertial profilers for long wavelength roughness assessment.

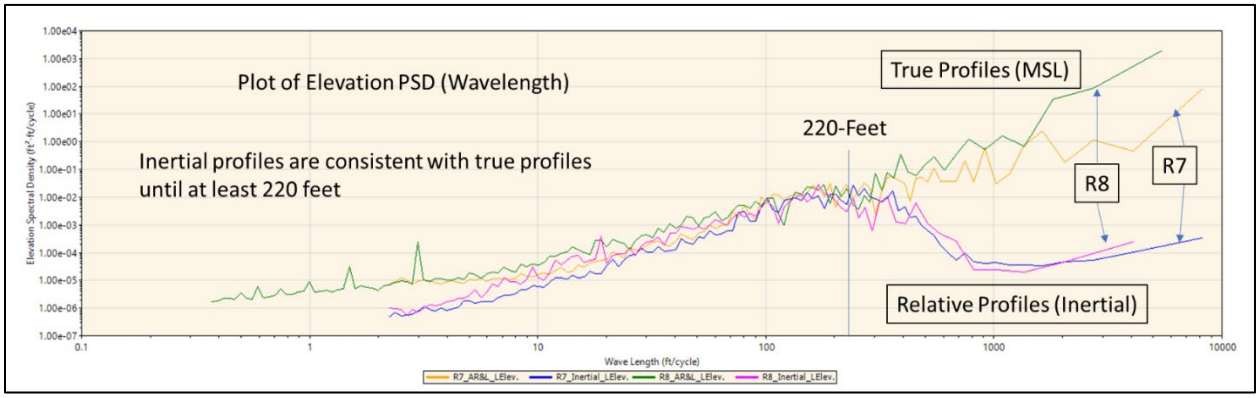


Figure E-2. Plot Showing Inertial Profiler Cut-off Wavelength

Inertial Profiler Data and Simulated Aircraft Response

Can high-speed inertial profilers produce the same simulated aircraft response as true profilers such as the SurPRO or the AR&L? Figure E-3 shows a plot of a profile measured at Wright-Patterson Air Force Base (AFB) Profile in 2016 using APR's AR&L. Figure E-4 shows a plot of the same profile using an AMES high-speed inertial profiler. The test conditions were very controlled, and the site offered areas with and without grade changes, and a mild bump event that could be used to compare the different profiler results to known roughness. The discrete bump, located near 2,600 feet, offered an opportunity to produce a mild aircraft response. Figures E-5 and E-6 show the predicted response for the 172,500-pound Boeing 737-800 traveling at 100 knots. The responses at the CP and the CG were almost identical for both profilers. For this test condition the inertial and true profile data produced the same simulation results.

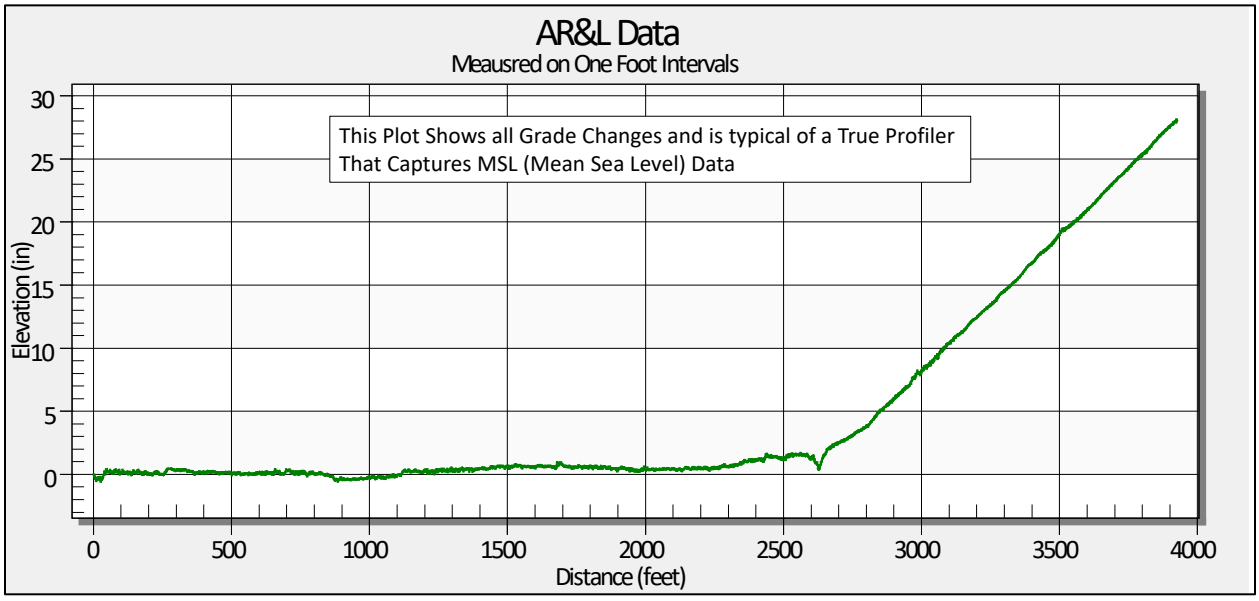


Figure E-3. Plot of Wright-Patterson AFB Runway 05L 23R Using a True Profiler

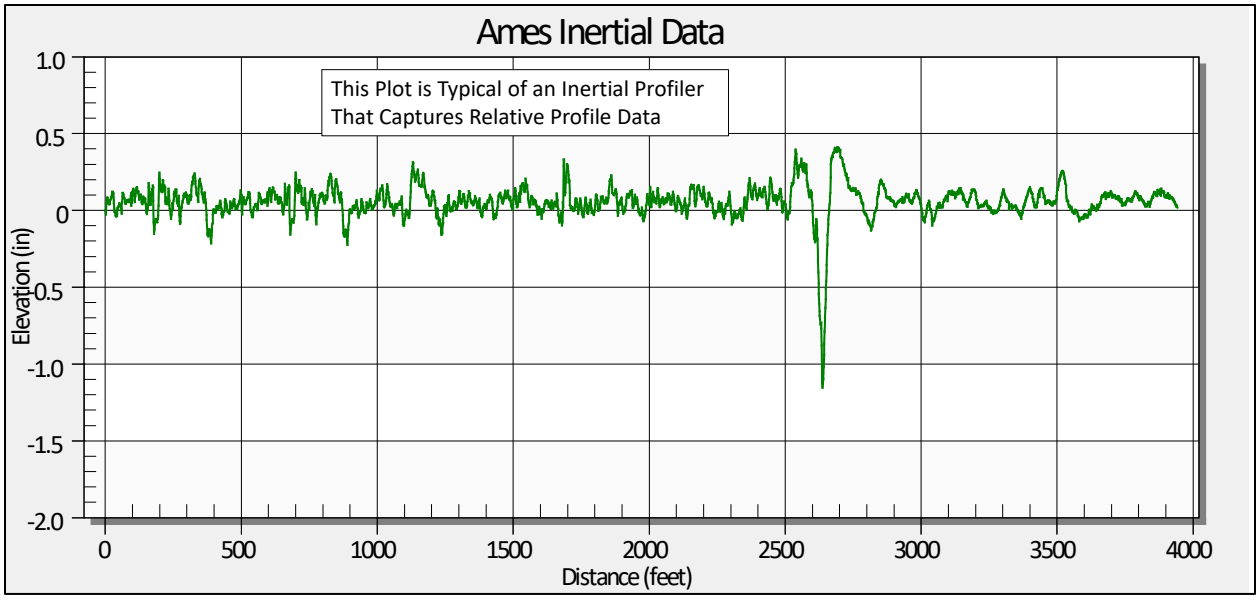


Figure E-4. Plot of Wright-Patterson AFB Runway 05L 23R Using an Ames Inertial Profiler

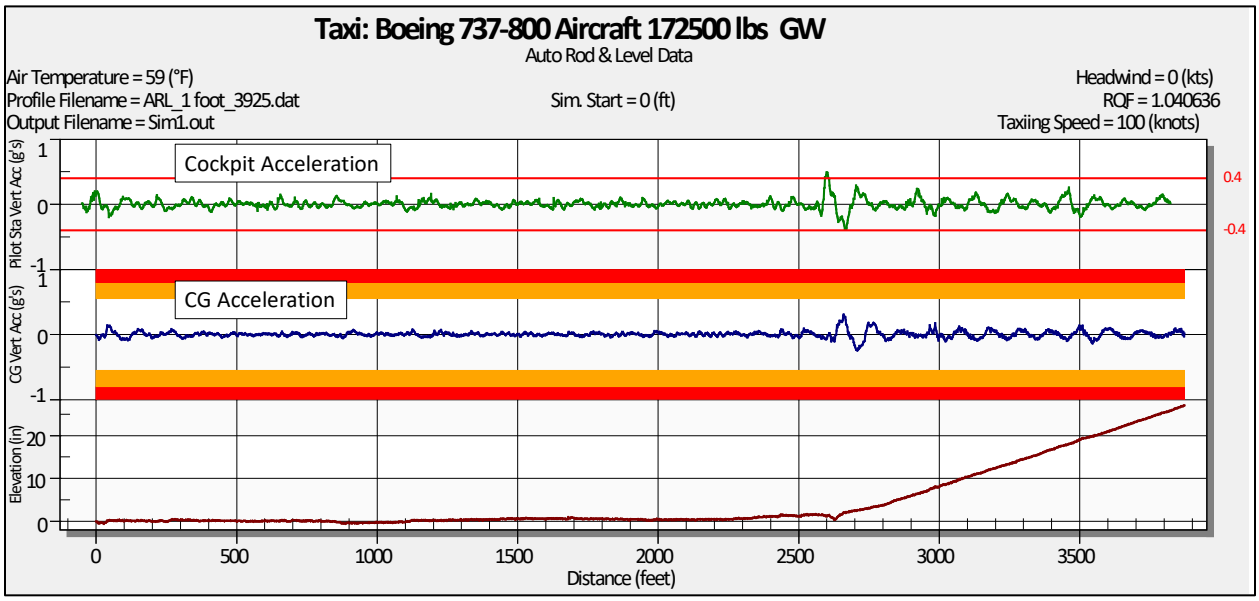


Figure E-5. Boeing 737-800 Response Using an Auto Rod and Level

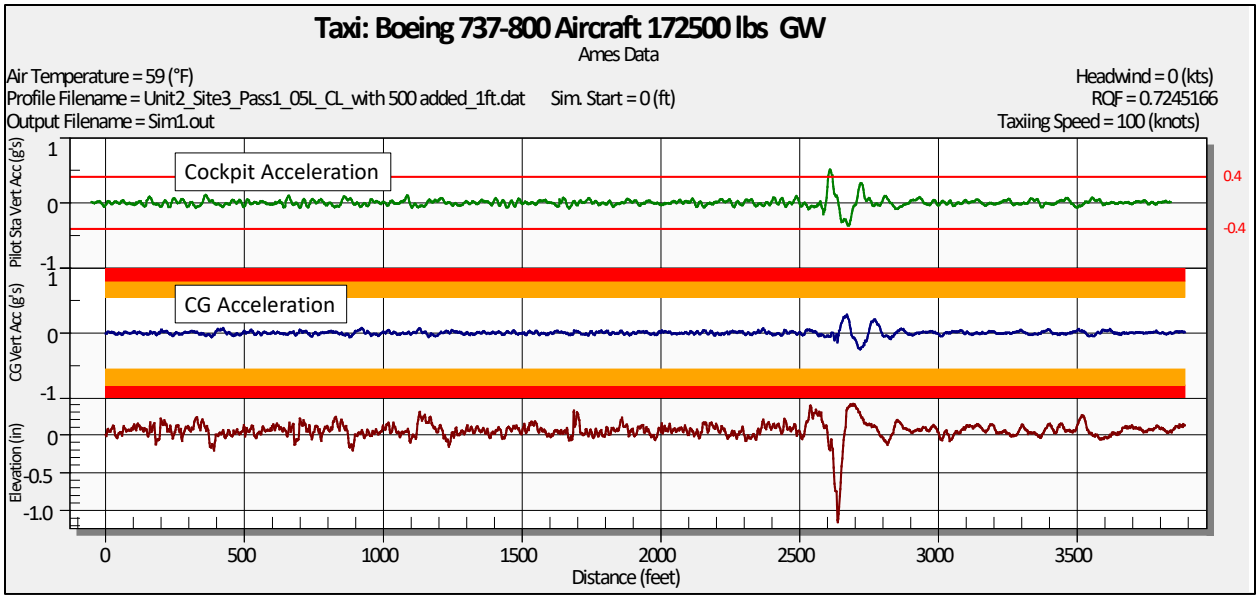


Figure E-6. Boeing 737-800 Response Using an AMES Inertial Profiler

Inertial profilers can have acceleration errors while reaching their operational speed. They can also have deceleration errors when stopping. It is important to recognize these errors and not use the profile data recorded during these periods as they will impact the results. These errors are usually obvious. Figure E-7 shows an inertial profiler measurement with acceleration and deceleration errors and how it impacted a Boeing 737-800 simulation.

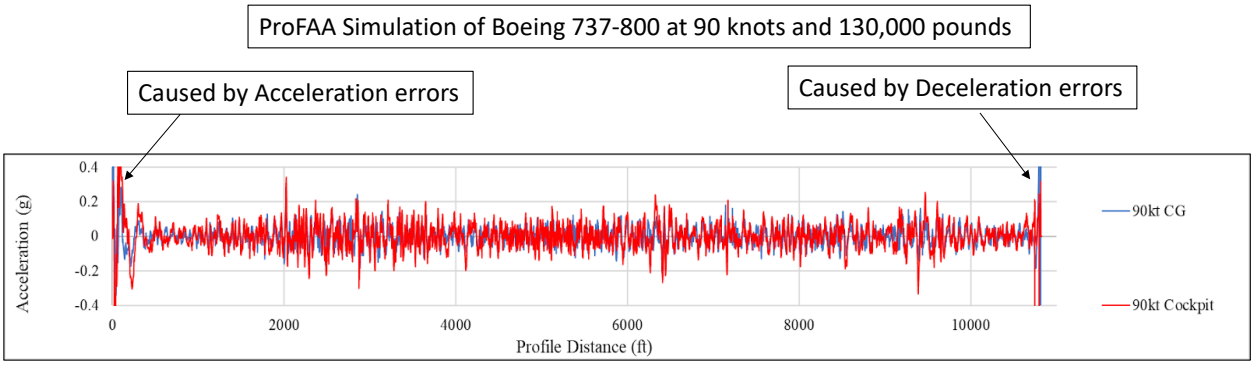


Figure E-7. Inertial Profiler Acceleration and Deceleration Errors

Figure E-8 is another example comparing an inertial profiler to true profile simulation results. Here, a ProFAA comparison of a Boeing 737-800 response at 130,000 pounds during a 90-knot constant speed taxi on Runway 12-30 at Miami International Airport. It shows a direct comparison using high-speed inertial (relative) data and SurPRO (true mean sea level [MSL]) data. The responses at the CP and CG are very similar. MIA Runway 12-30 did not have any significant rough areas. There were no areas that contained acceleration or deceleration errors.

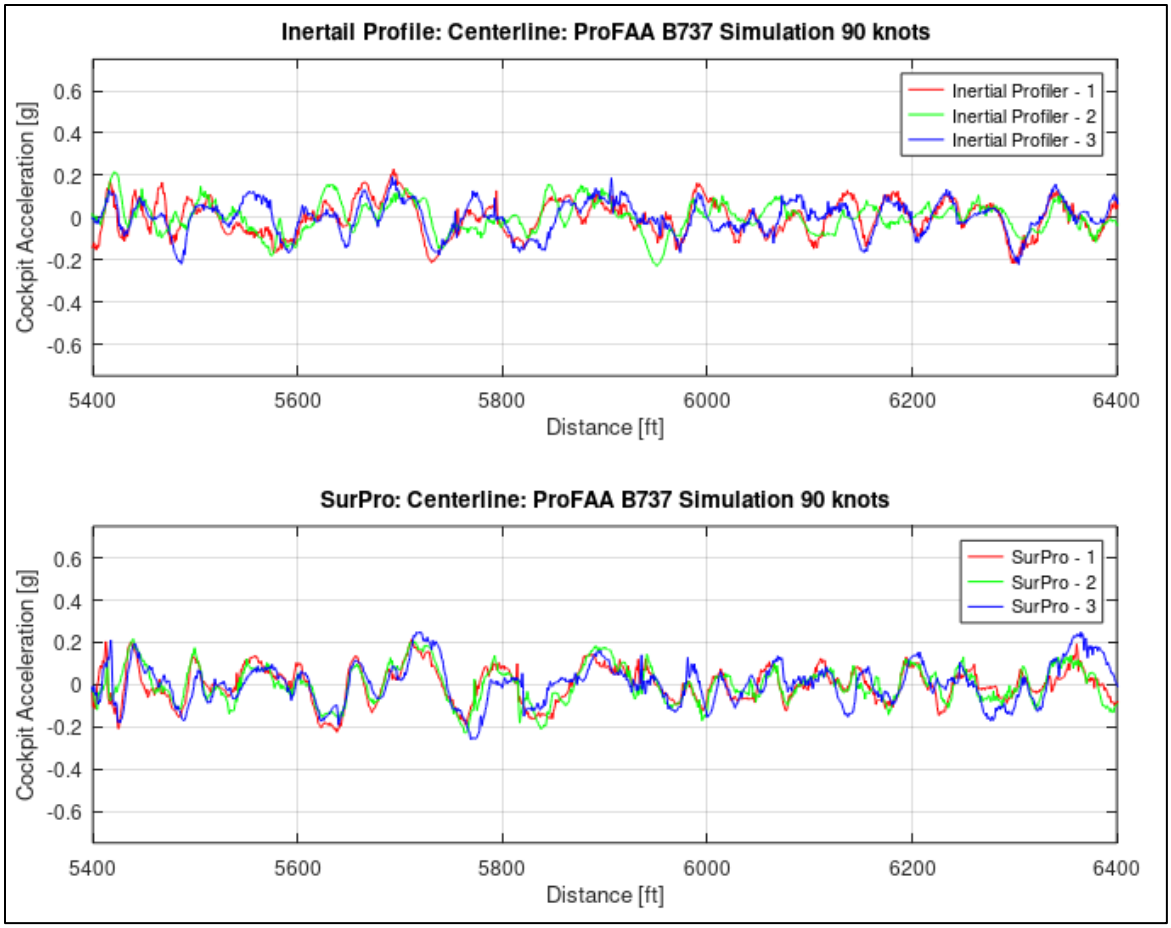


Figure E-8. ProFAA Simulated Response Comparing Inertial to SurPRO Profiles

The analyses conducted on the two runways (Wright-Patterson AFB and MIA) show that, for relatively smooth pavements, the predicted results for a Boeing 737-800 are very similar, concluding that either profiling device would have produced similar results. There is a need, however, to conduct similar comparisons for several runways and taxiways that have a significant bump event(s).

Aircraft Characteristics

The majority of aircraft simulations conducted in this study were for the Boeing 737-800. The primary reasons were that this aircraft has now been added to the ProFAA aircraft database and that the pilot simulator tests (PSTs) included the Boeing 737-800. However, it is known that different aircraft types will response differently over the same profile. The parameters that have the most influence on aircraft response is

- Weight (primarily Type 3 roughness)
- Gear spacing (primarily Type 3 roughness)
- Rigid-body vibration natural frequencies (Type 3 roughness)

- Suspension characteristics (primarily Type 2 and Type 3 roughness)
- Tire size and tire pressure (primarily Type 1 roughness)
- The speed of bump encounter (Type 1, Type 2, and Type 3 roughness)

Consequently, there is a need for an adequate cross section of aircraft types that can be simulated in the upgraded ProFAA software. The three-step screening process will identify roughness that impact all types of aircraft. Step 3 will determine the response on a particular aircraft type.

Impact of Landing Gear Strut Servicing on Aircraft Response

It is not always the runway that impacts ride quality. Landing gear strut servicing can impact an aircraft's response to airport pavement roughness as well. Figure E-9 is an illustration of a typical landing gear pneumatic load-stroke curve. Notice that most of the available strut stroke is used up and only a few inches remain when the aircraft is at its static weight on the pavement. Most of the available strut stroke is designed to absorb the energy of landing impact. During taxi and takeoff the strut operates in and around the non-linear knee of the curve. If a strut has an underserviced pre-charge pressure, the static spring constant can change dramatically. The stiffer spring will also have less stroke remaining to absorb pavement roughness. Improper strut and tire servicing can be a consideration in the Step 3 pavement evaluation procedure.

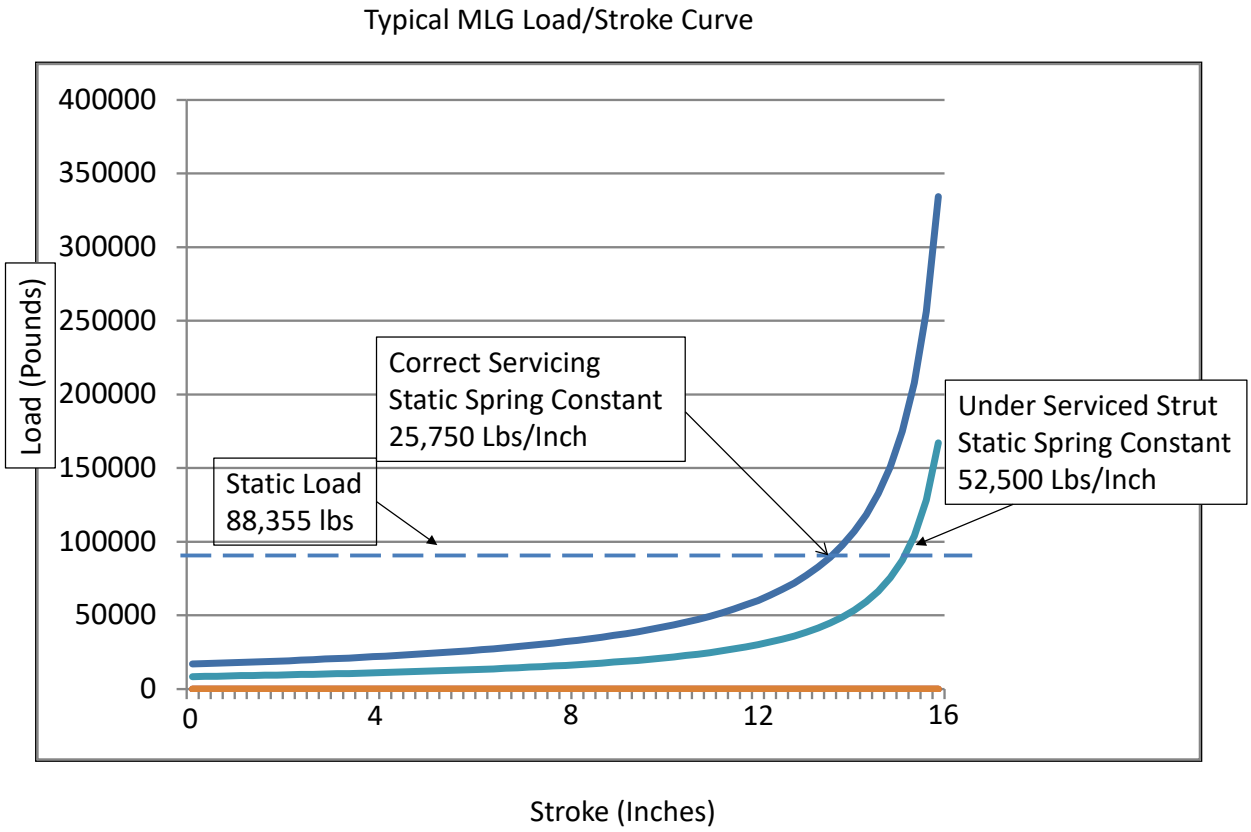


Figure E-9. Typical Landing Gear