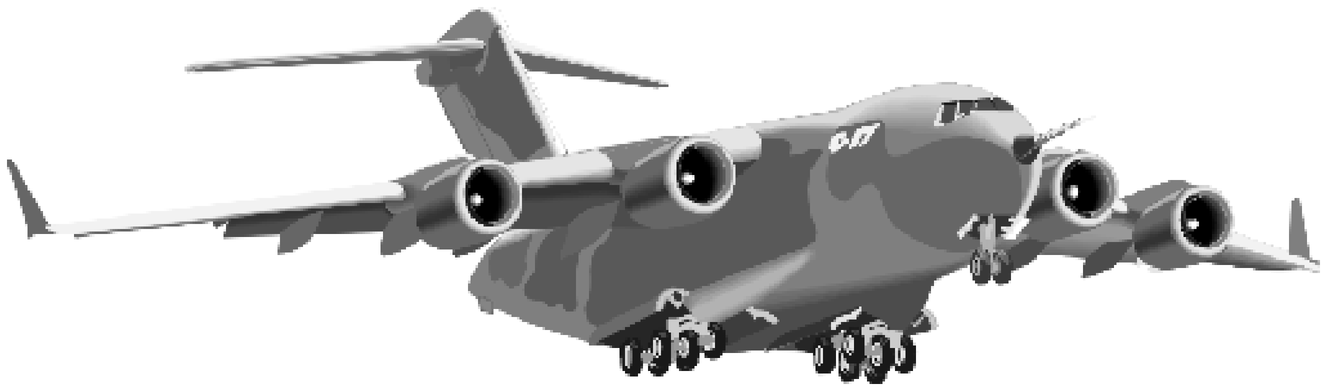
WATERWAYS EXPERIMENT STATION

C-17 Runway Roughness Model for Semi-prepared Airfields



By

Don R. Alexander

Presentation Outline

- Background
- Objective
- Approach
- Model Implementation
- Model Overview
- Model Validation
- Model Data Requirements
- Conclusions
- Recommendations

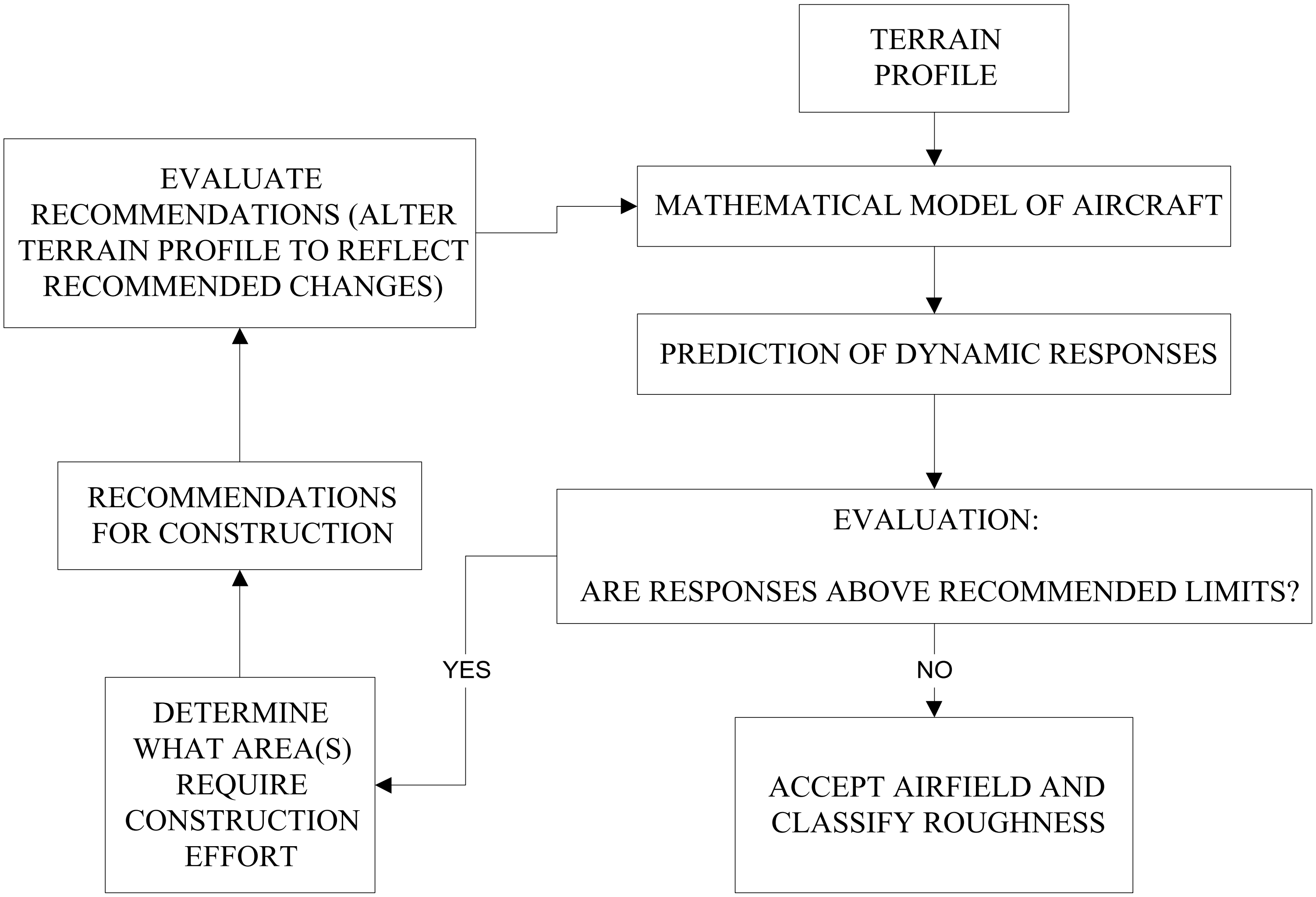
Background

- C-17 was designed to operate on semi-prepared airstrips
- Semi-prepared airstrips are generally rougher than paved runways
- Rougher airstrips generate larger impact forces during landing, takeoff, and taxi operations

Objective

- **The objective of this investigation was to develop a runway roughness model capable of evaluating the surface condition of a semi-prepared runway and categorizing it in terms of its relative roughness. The severity level was to be categorized as GREEN, YELLOW, or RED condition.**

C-17 SMOOTHNESS CRITERIA



Objectives were accomplished by:

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- **Collecting surface profile data at six C-17 flight test sites categorized as semi-prepared runways**
- **Developing a numerical model for the prediction of the C-17 ground response**
- **Implementing this numerical model with a user-friendly interface for the use of airfield pavement engineers, airfield managers, or aircraft support personnel**

Approach

- **Need to model C-17 ground operations as close to the real aircraft as possible**
- **Need to account for short and long wavelengths bumps and dips**
- **Using roughness indexes to evaluate the overall shape of the runway might miss critical areas on the runway**
- **For the reasons above, it was decided to use the TAXIG/C-17A numerical simulation software to predict the actual aircraft performance on ground operations**
- **TAXIG/C17A Reference Manuals 1,2, and 3. Doc. Ref. No. 961013-009, Eglin, AFB, Florida**

Model Overview

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- **Model considers:**
  - **Airframe rigid and flexible modes**
  - **Weight**
  - **Thrust**
  - **Drag**
  - **Breaking and rolling Forces**
  - **Aerodynamic controls**
  - **Landing gear geometry**
  - **Surface profile**

Aircraft Dynamic Model Layout

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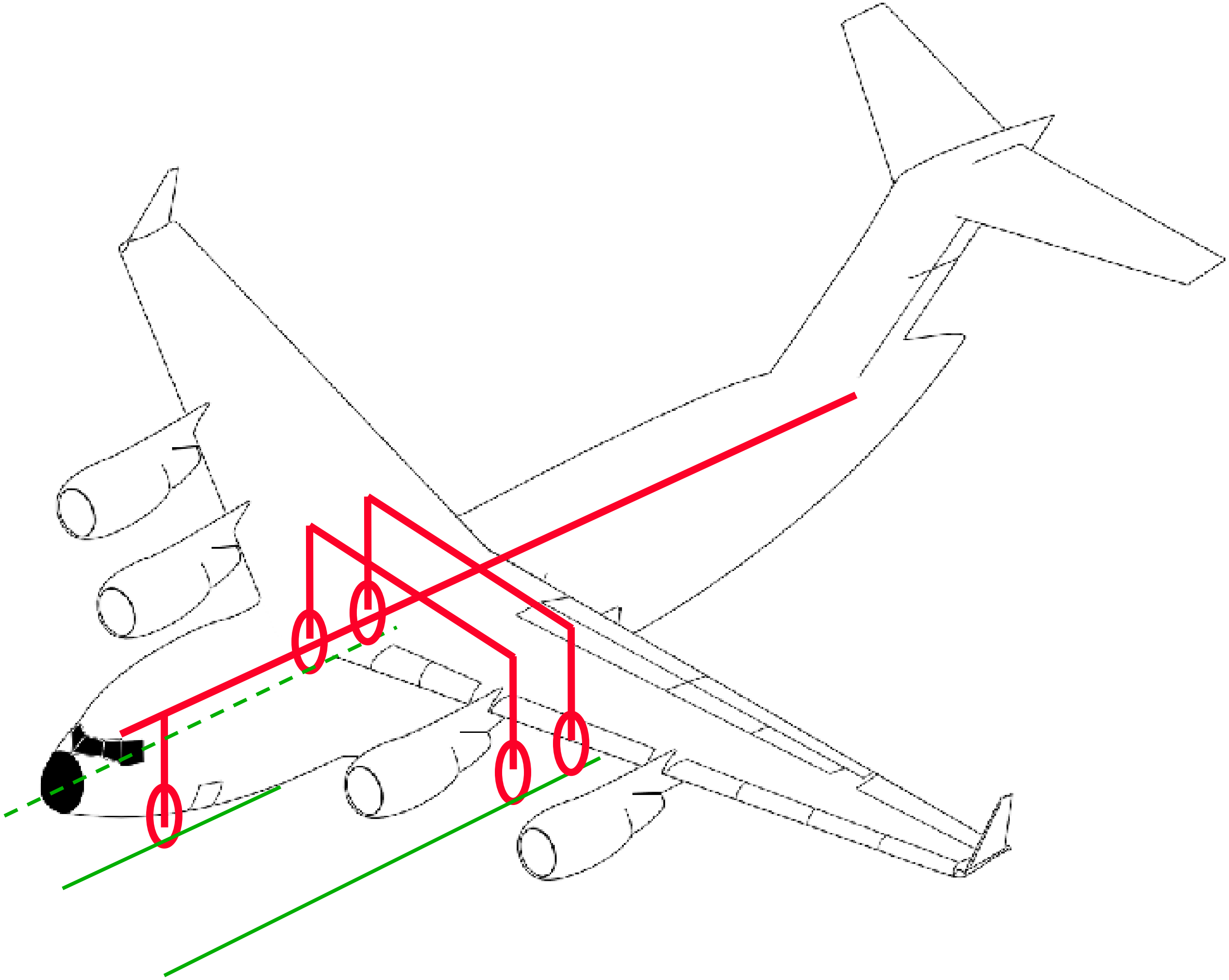
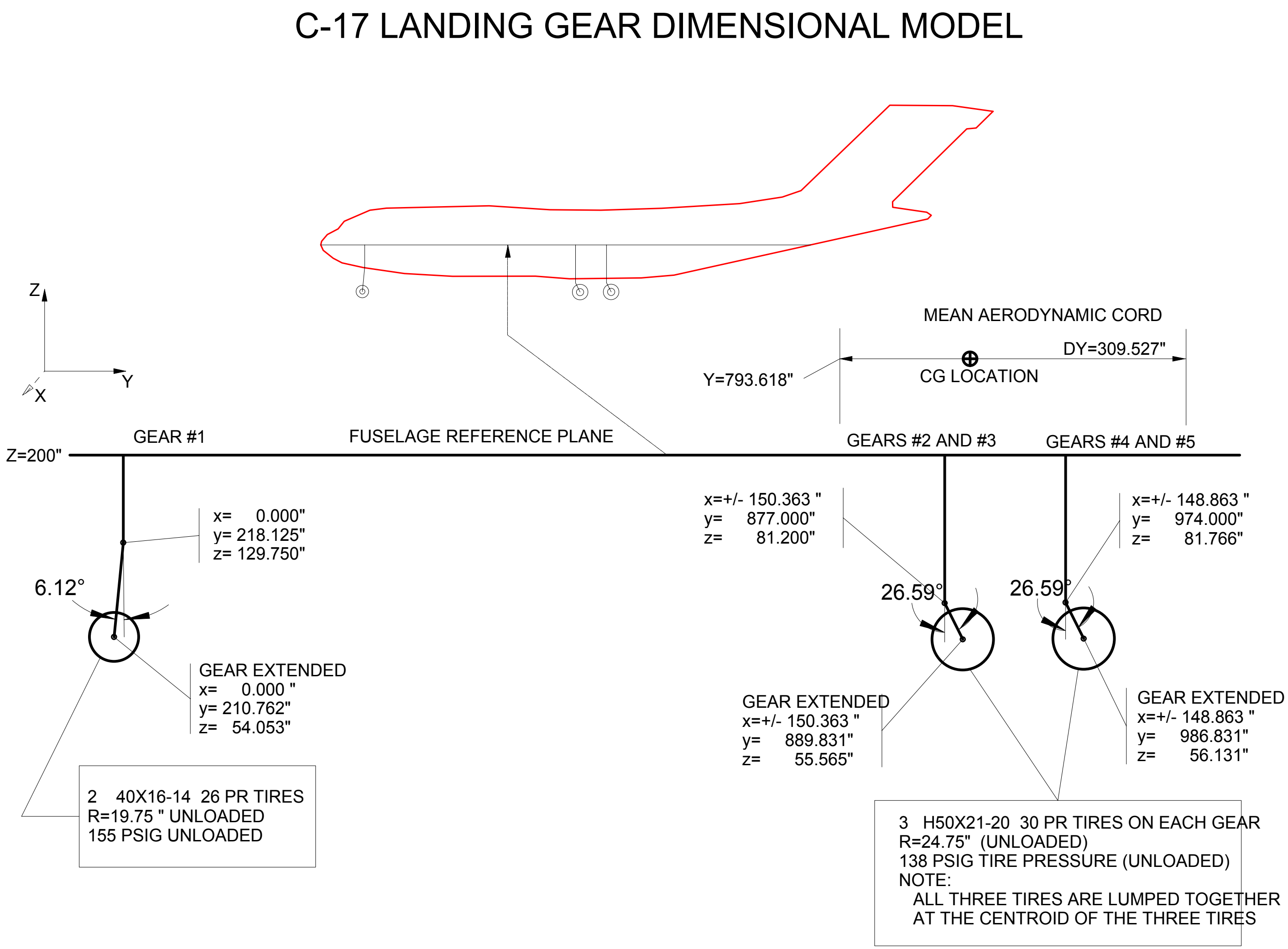


C-17 Dimensional Model



Model Assumptions

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- **Landing gear replaced by a point-load/runway surface interface and a mass and non-linear spring dynamic system**
- **Lateral and yaw motion are considered to be small and therefore disregarded**
- **Motion of the aircraft and landing gear is described by Newton's Second Law of Motion,** $\Sigma F = m*a$
- **Rectilinear particle motion is assumed (Taylor integration):**
  - $s=s_0 + v*t + 0.5*a*t^2$
  - $v = v_0 + a*t$
- **t == small time increment (typically: 0.0002-0.0005 sec)**
- **Runway is a non-yielding surface (rigid surface)**

Model Limitations

- Point-load nature of landing gear/runway surface interface
- Non-yield (rigid) runway surface
- Only one tire pressure is currently incorporated
- Straight aircraft movement on runway

Modeling Process

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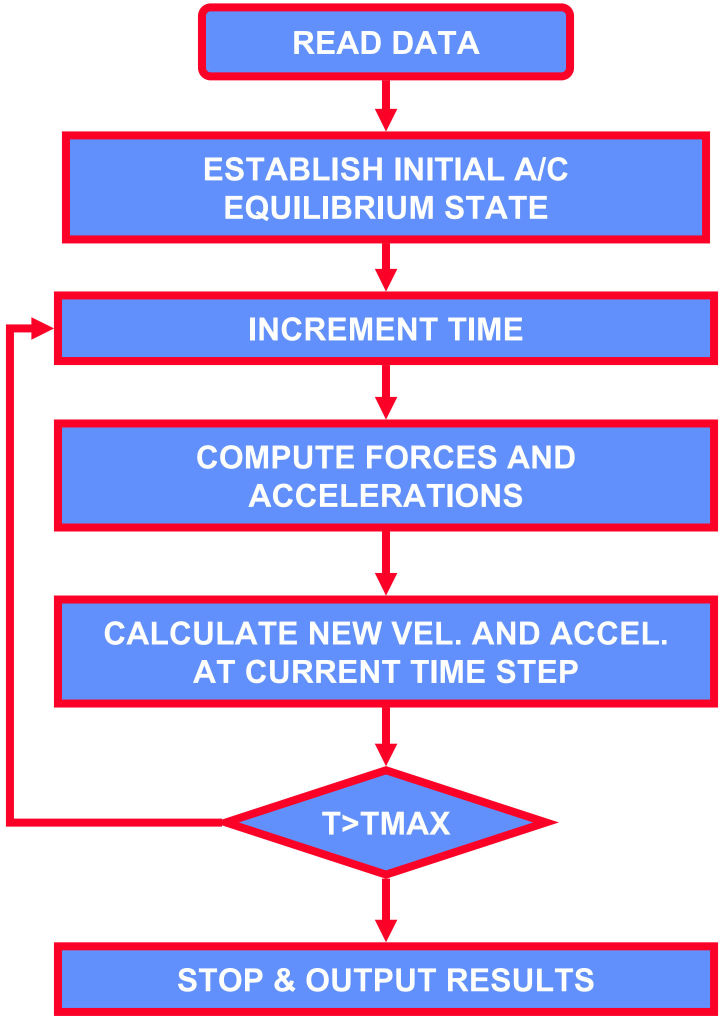

Model Validation

- Model has not yet been fully validated by an RQC test
- Program has been checked on a double bump test performed by McDonnell Douglas in June 1994 (MDC-93K7026 and MDC-95K7198)
- Initial comparisons have been performed on landing operations at Holland Landing Zone

Double Bump Comparisons

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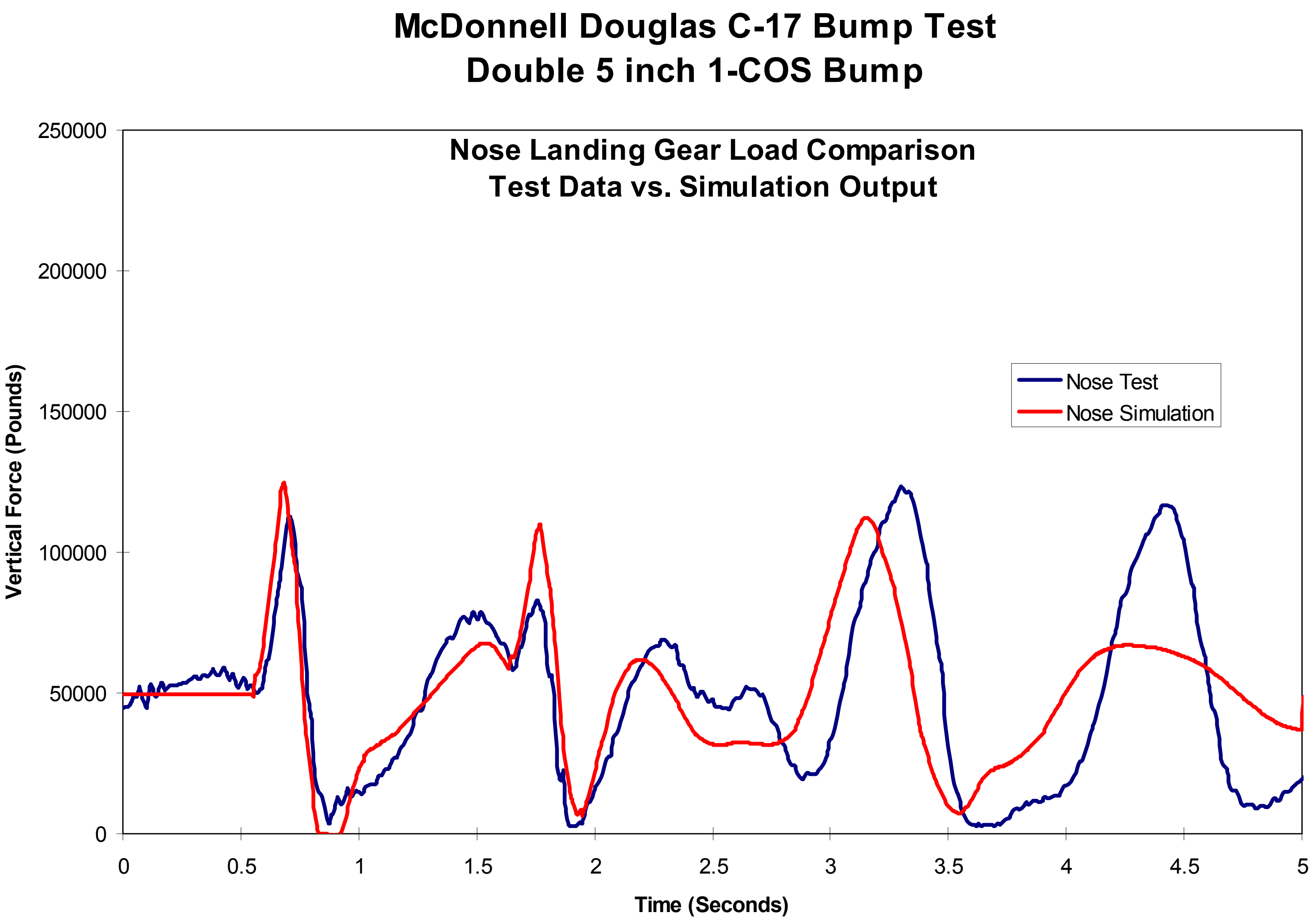
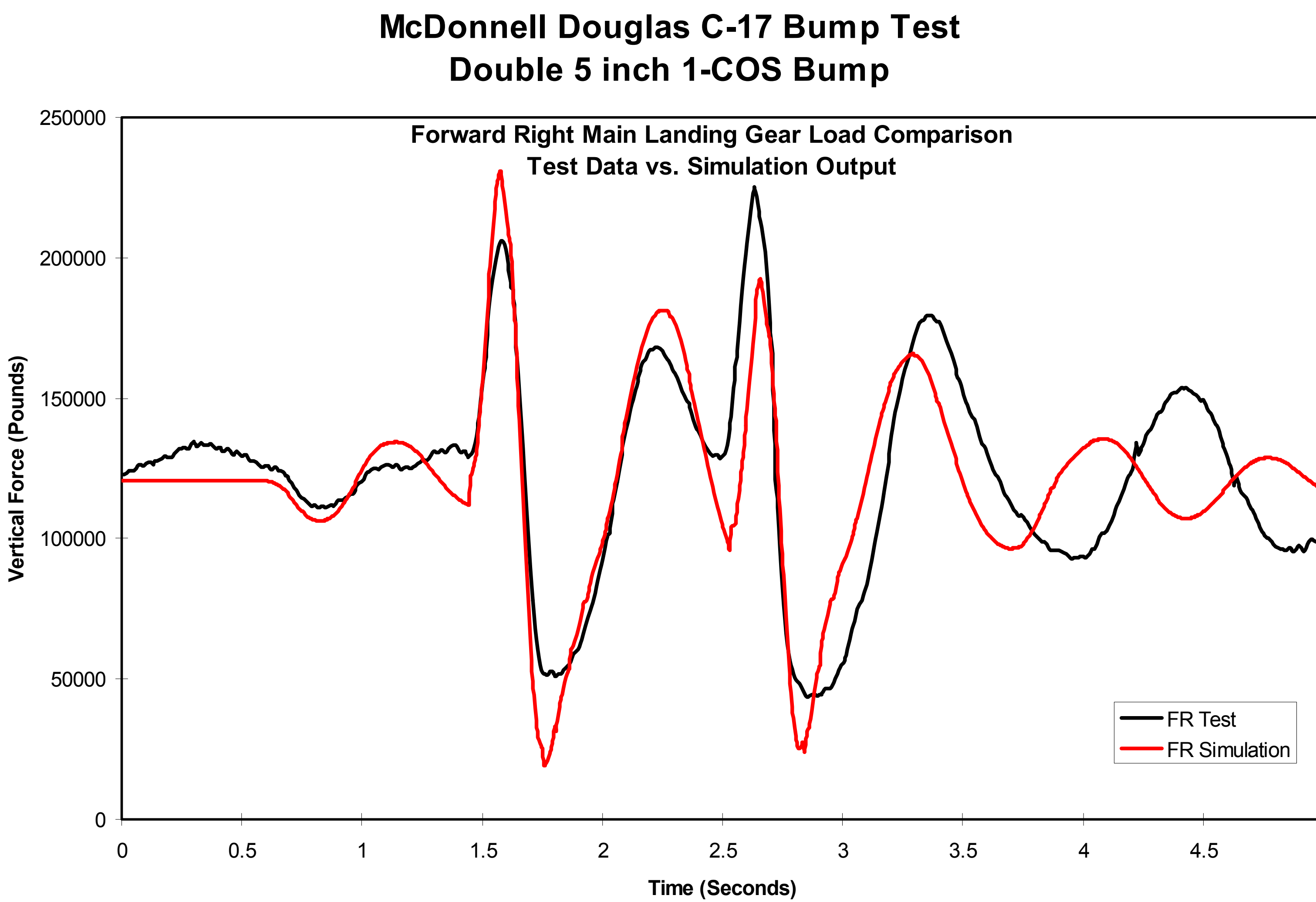
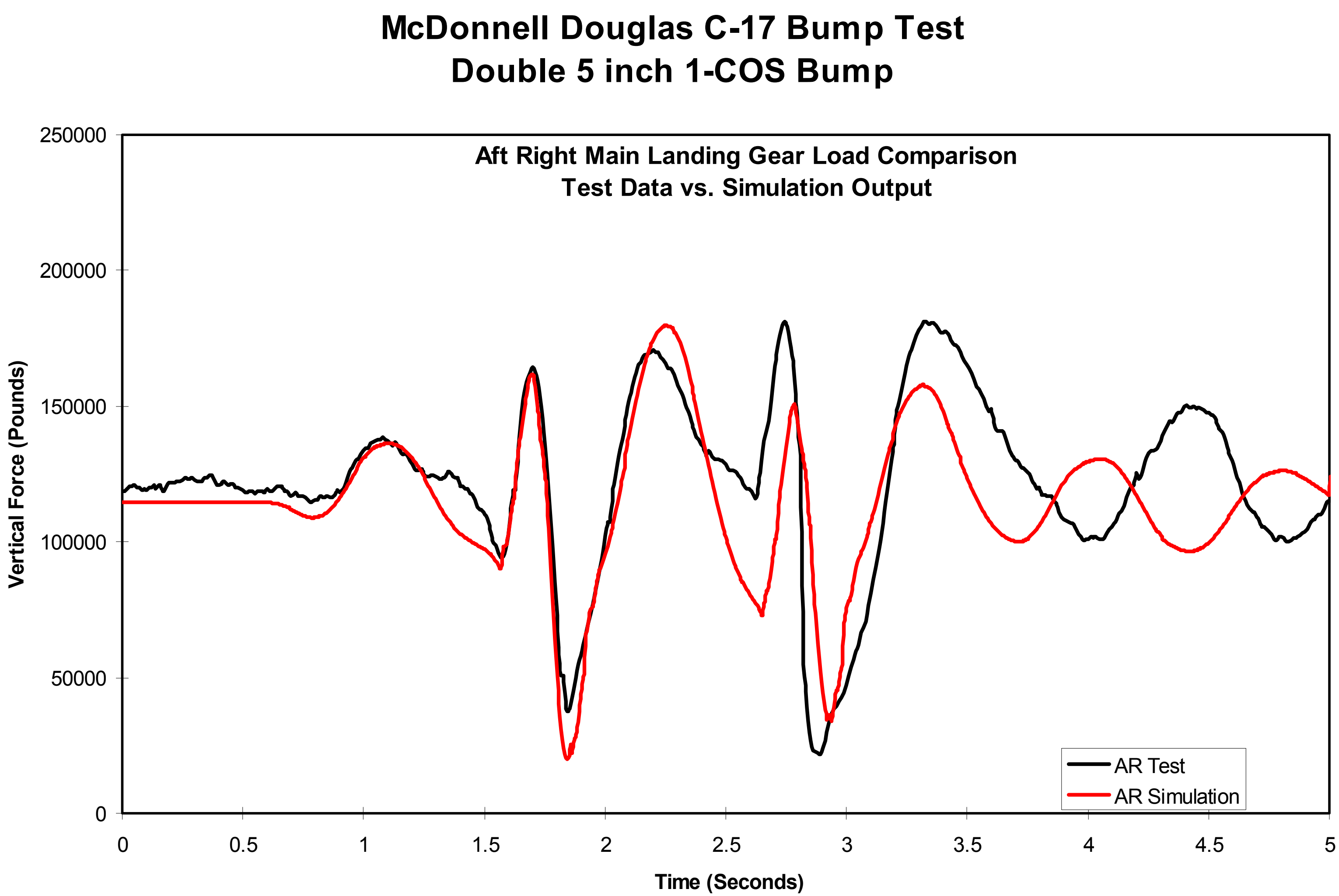


Double Bump Comparisons



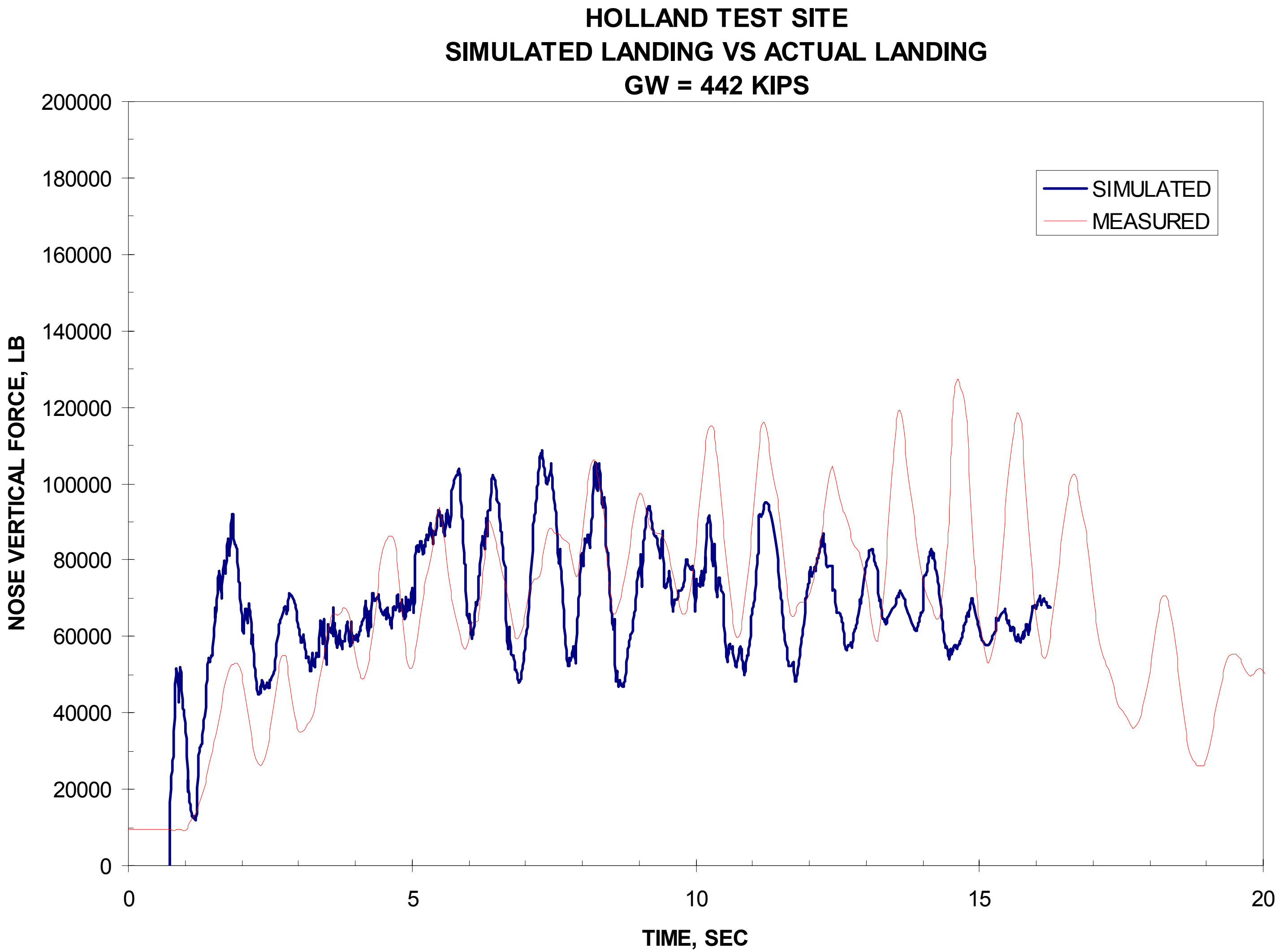
Double Bump Comparisons



Comparisons at Holland LZ

- **Hard surface with very little damage is well simulated by TAXIG/C-17A**
- **Good surface profile data collected**
- **Only landing simulations were performed**

Initial Comparisons at Holland LZ - Nose



Initial Comparisons at Holland LZ - Forward

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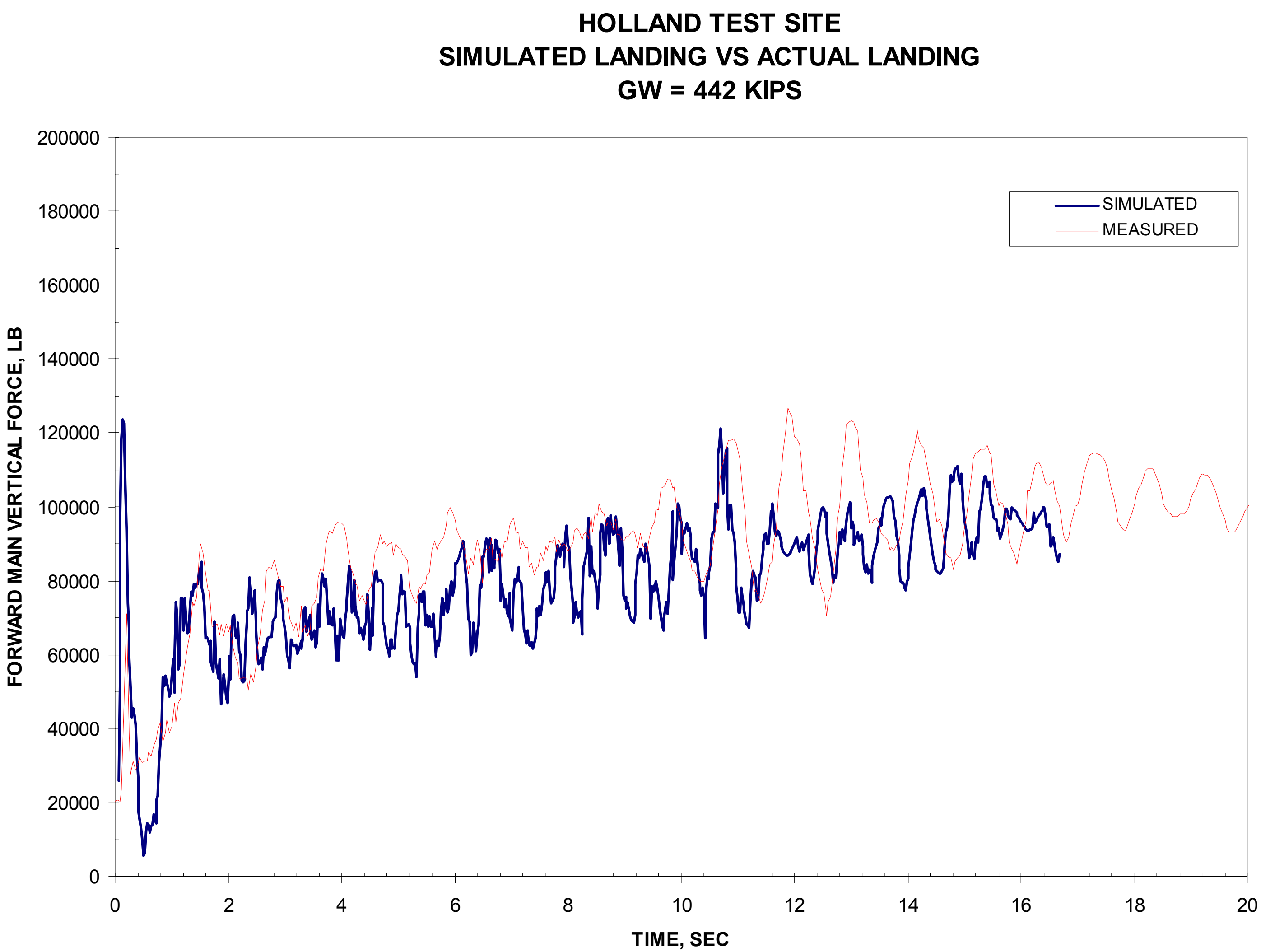

Initial Comparisons at Holland LZ - AFT

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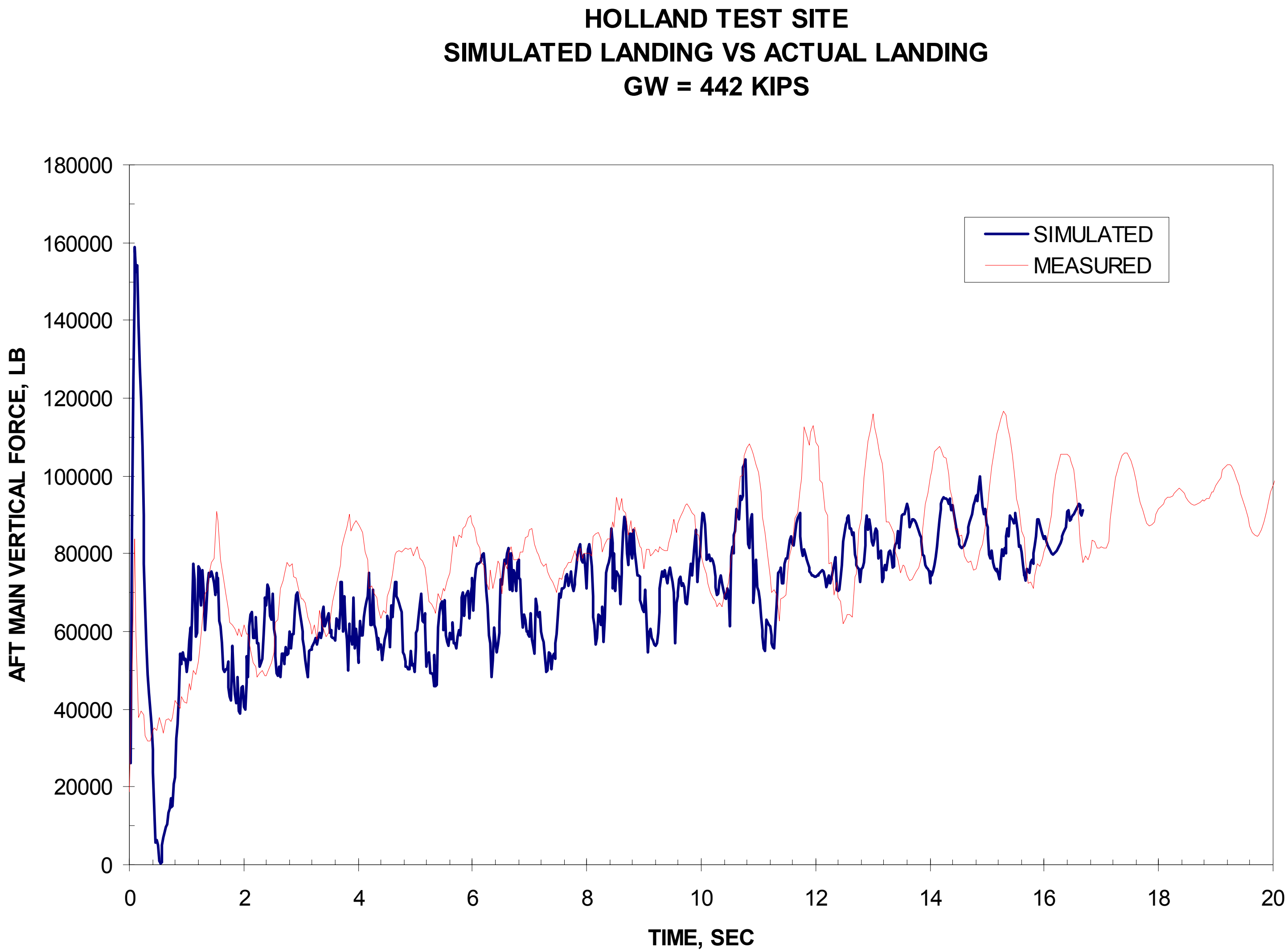


Runway Surface Roughness Criteria

- **Based on the ratio (R) of the maximum vertical forces (F_v) and the design load limit of the landing gears (DLL)**
  - **$R = (F_v/DLL)*100$**
  - **$F_v = f(Drag)$**
- **Severity levels are initially setup as:**
  - **GREEN: $0 < R < 80$**
  - **YELLOW: $80 <= R < 100$**
  - **RED: $R >= 100$**

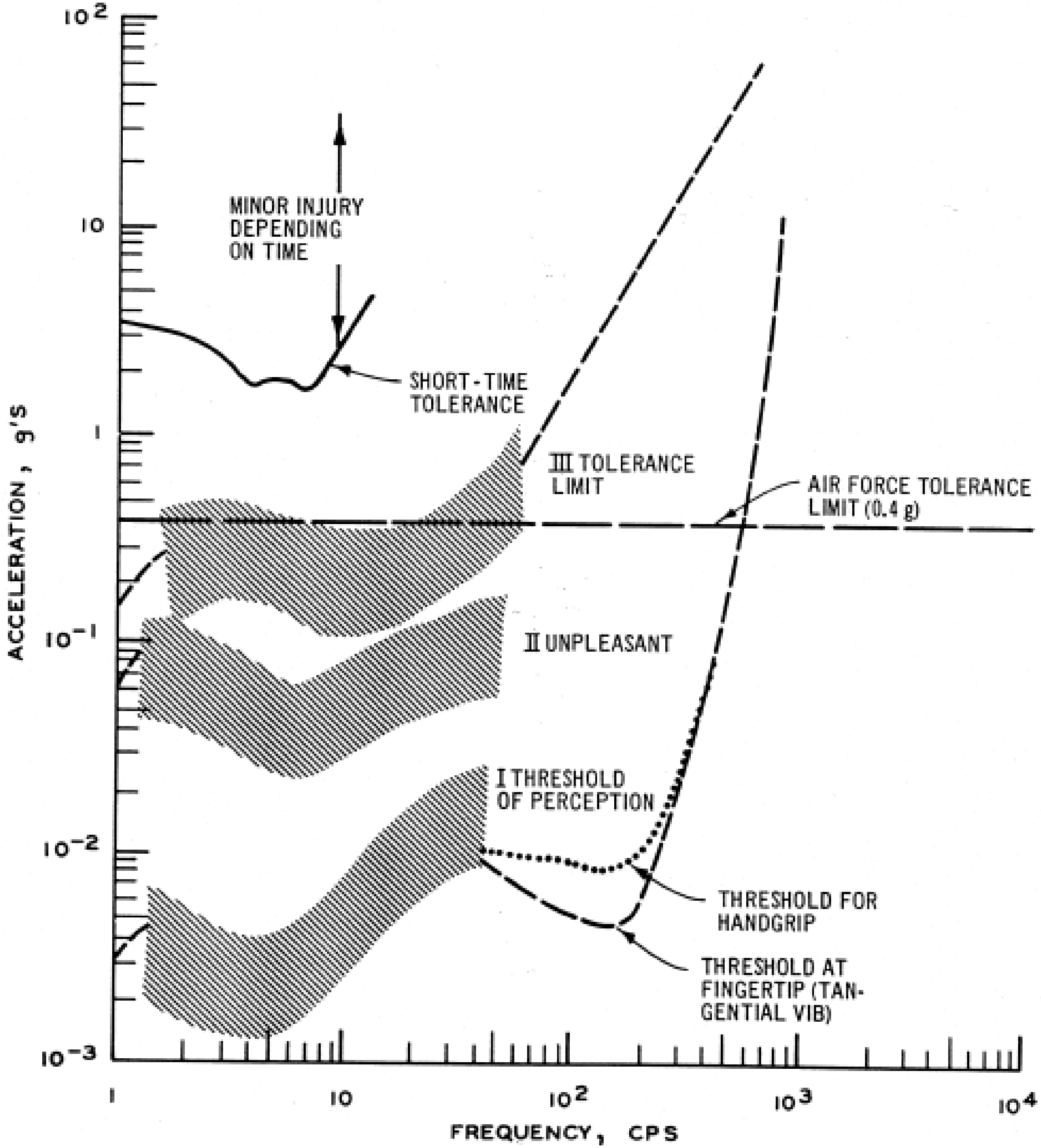
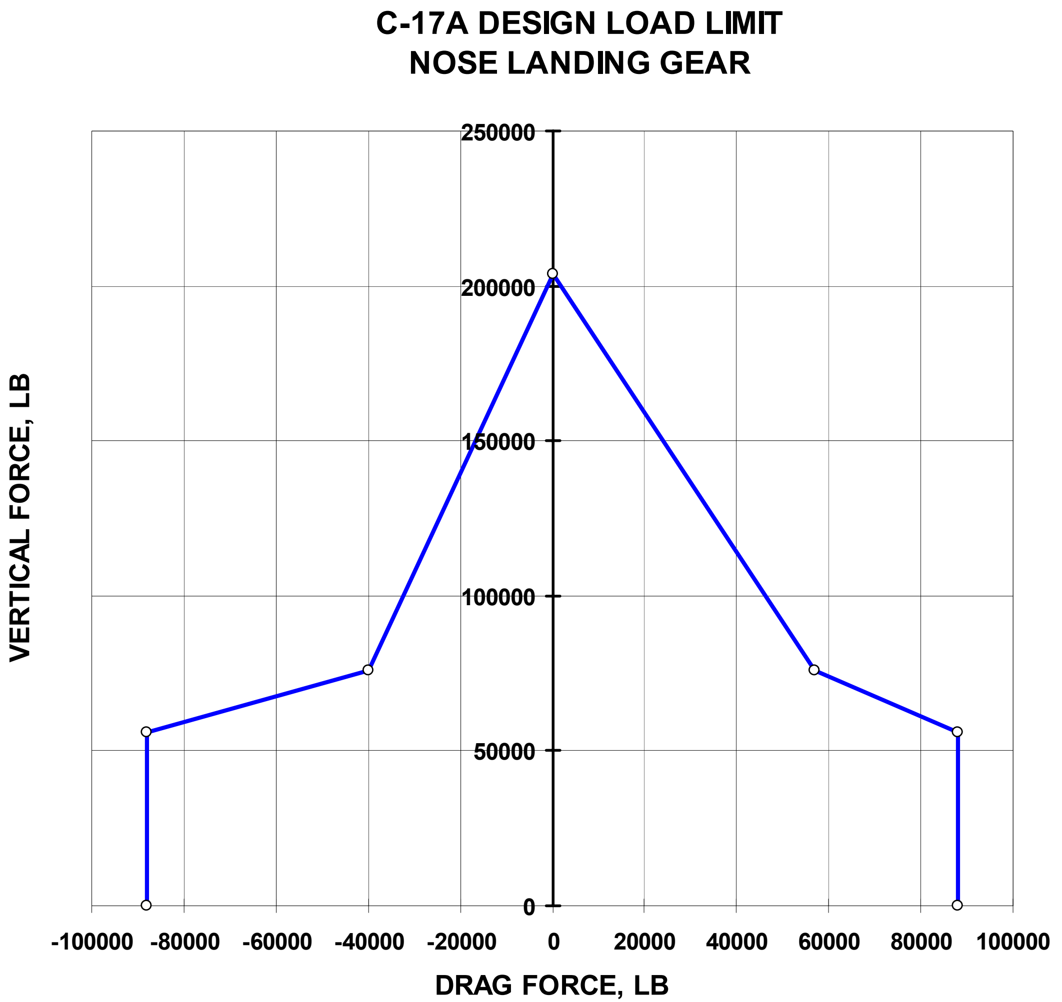
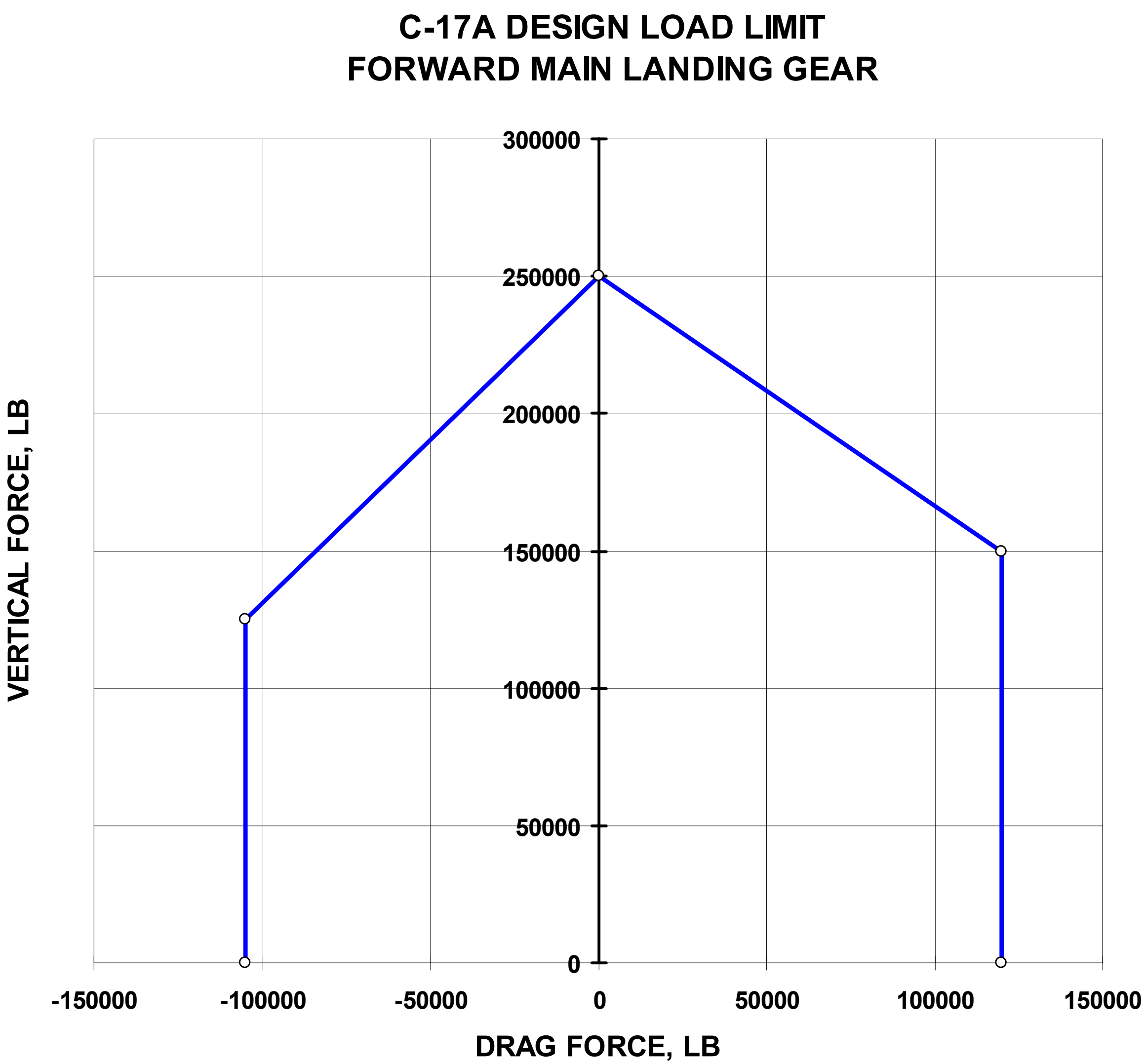


Figure 27. Human tolerance criteria for exposure to vertical vibration (from Reference 5)

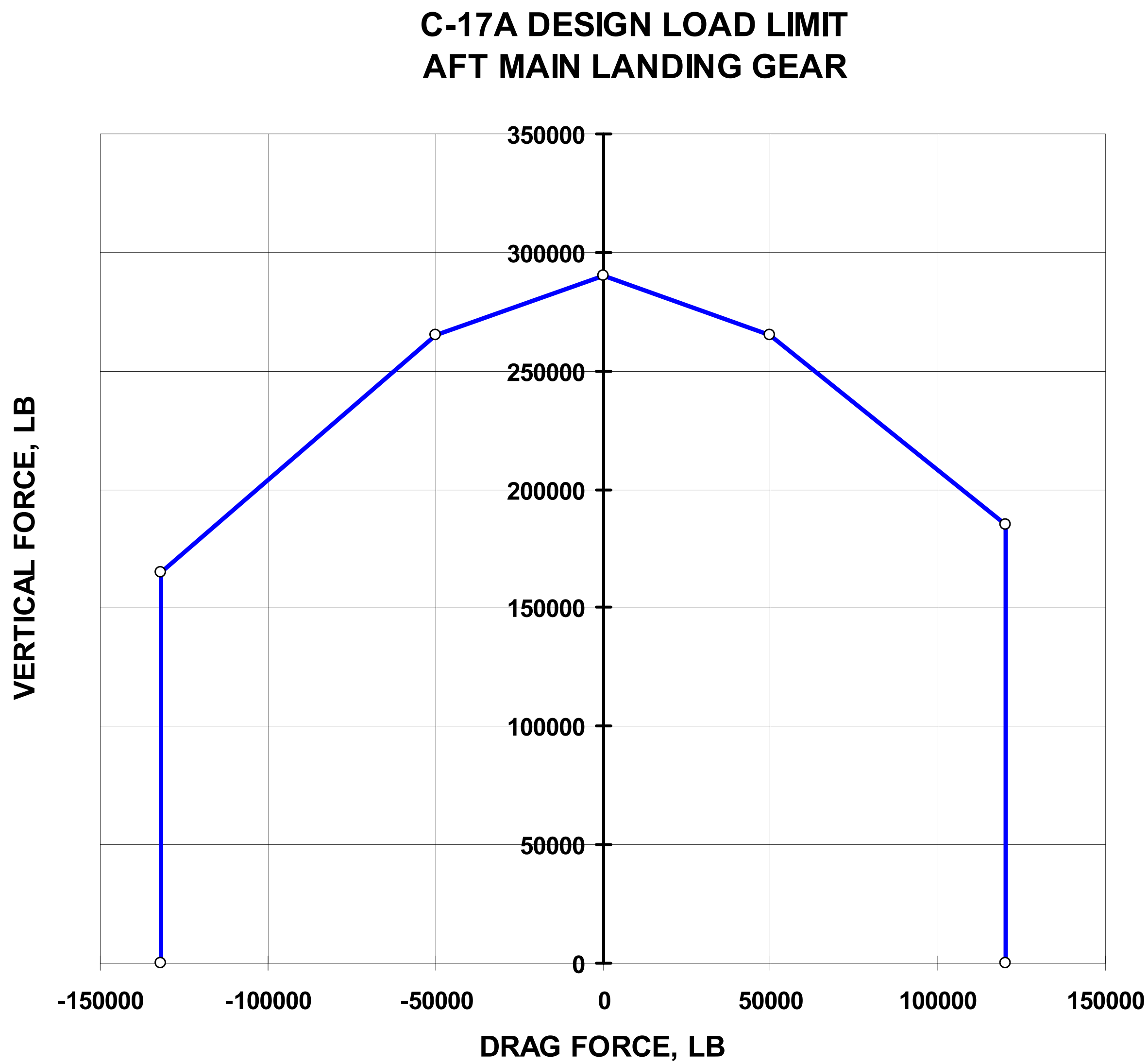
DLL Charts - Nose Gear



DLL Charts - Forward Main Gear



DLL Charts - Aft Main Gear



Data Requirements for Roughness Model

- Aircraft
  - Estimated operating weight
  - CG location
  - Angle of attack for landings
  - Landing speed
  - Braking and rolling coefficients
  - Usage of thrust reversal
  - Pitch and Roll moment of inertia
- Runway
  - Longitudinal surface profiles
  - Direction of aircraft ground operations
  - Profile offset point of landing or takeoff

C-17 Roughness Computer Program (C17ROUGH)

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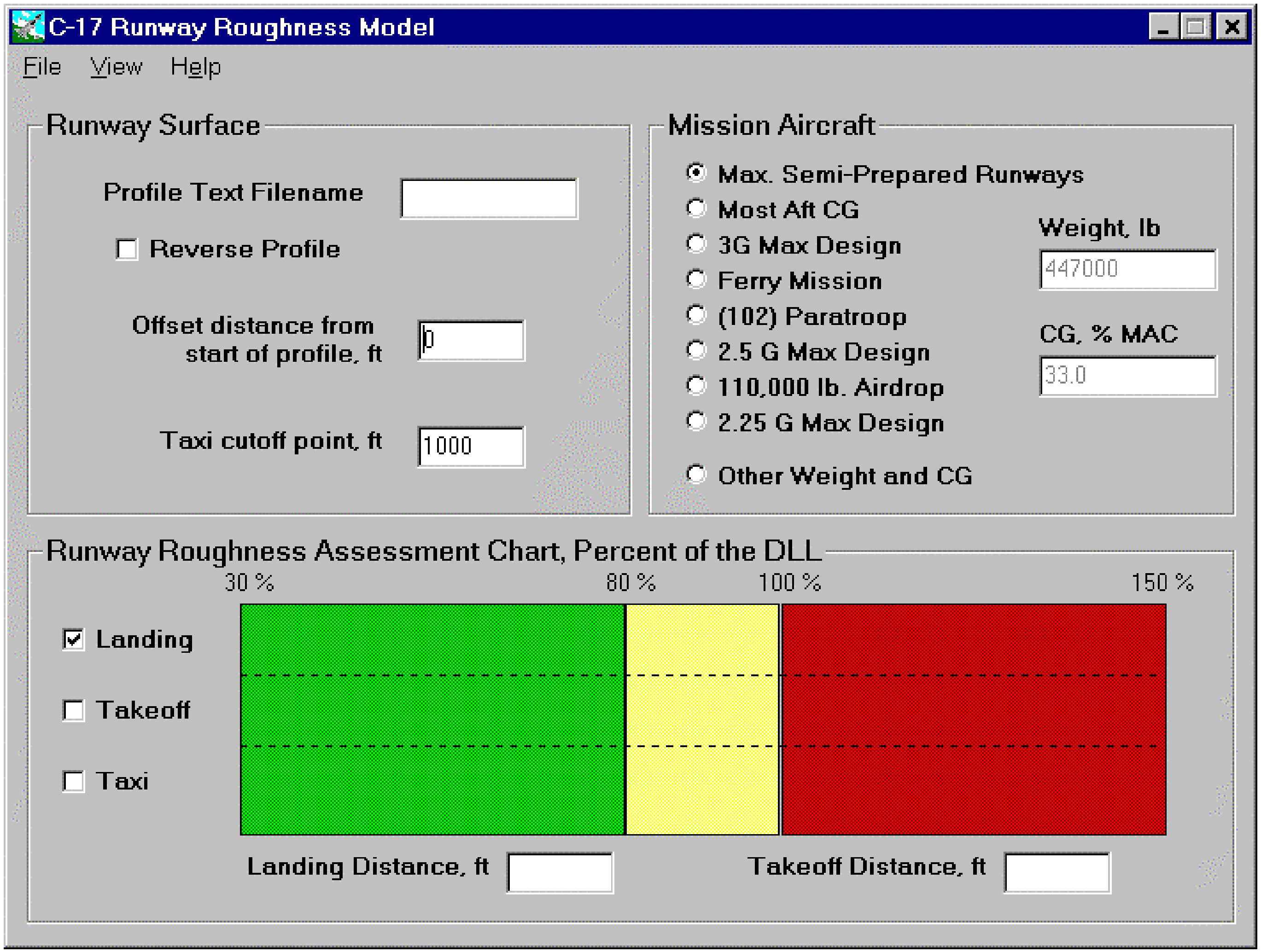

C17ROUGH Options

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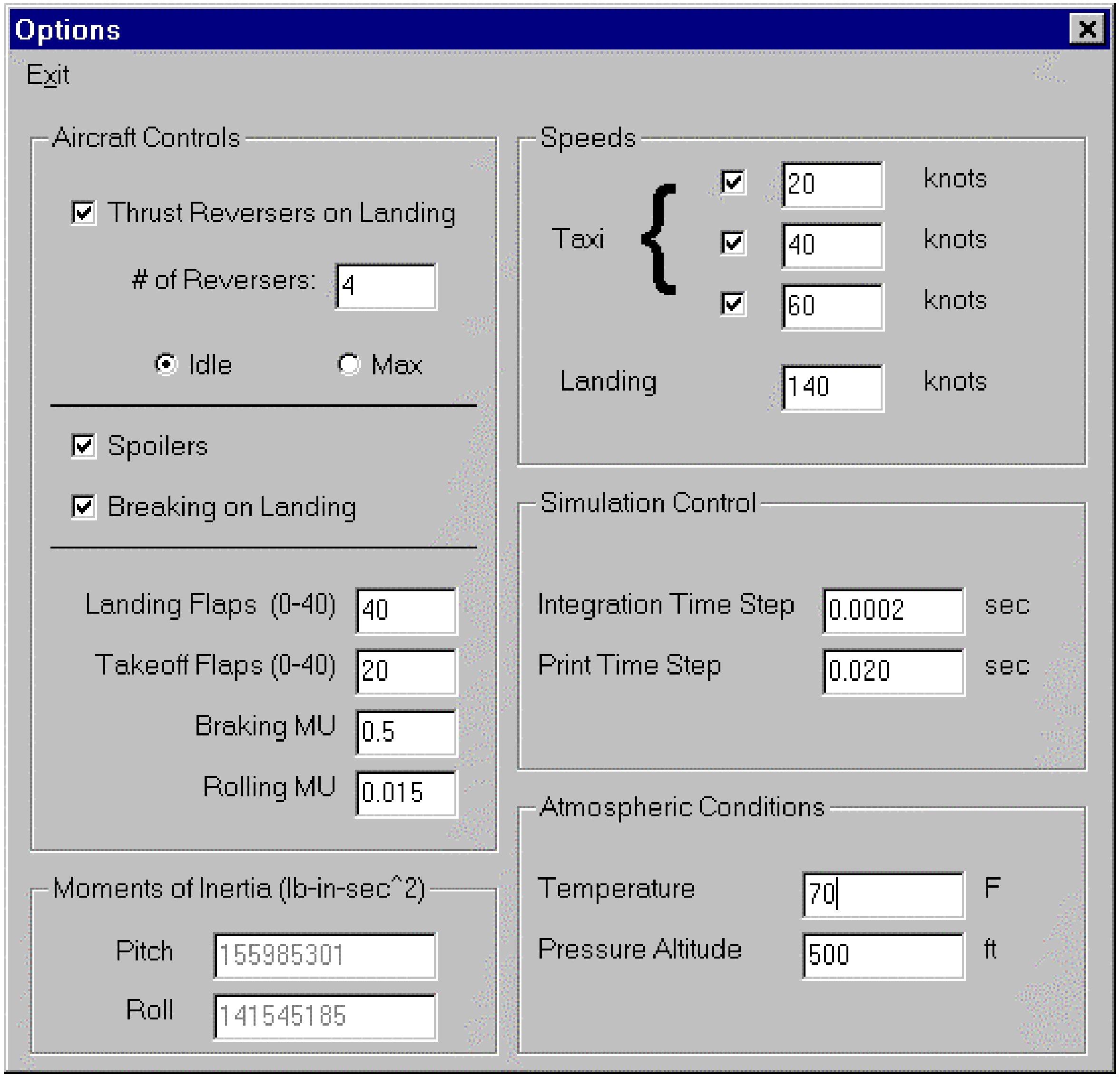

C17ROUGH Sample Output

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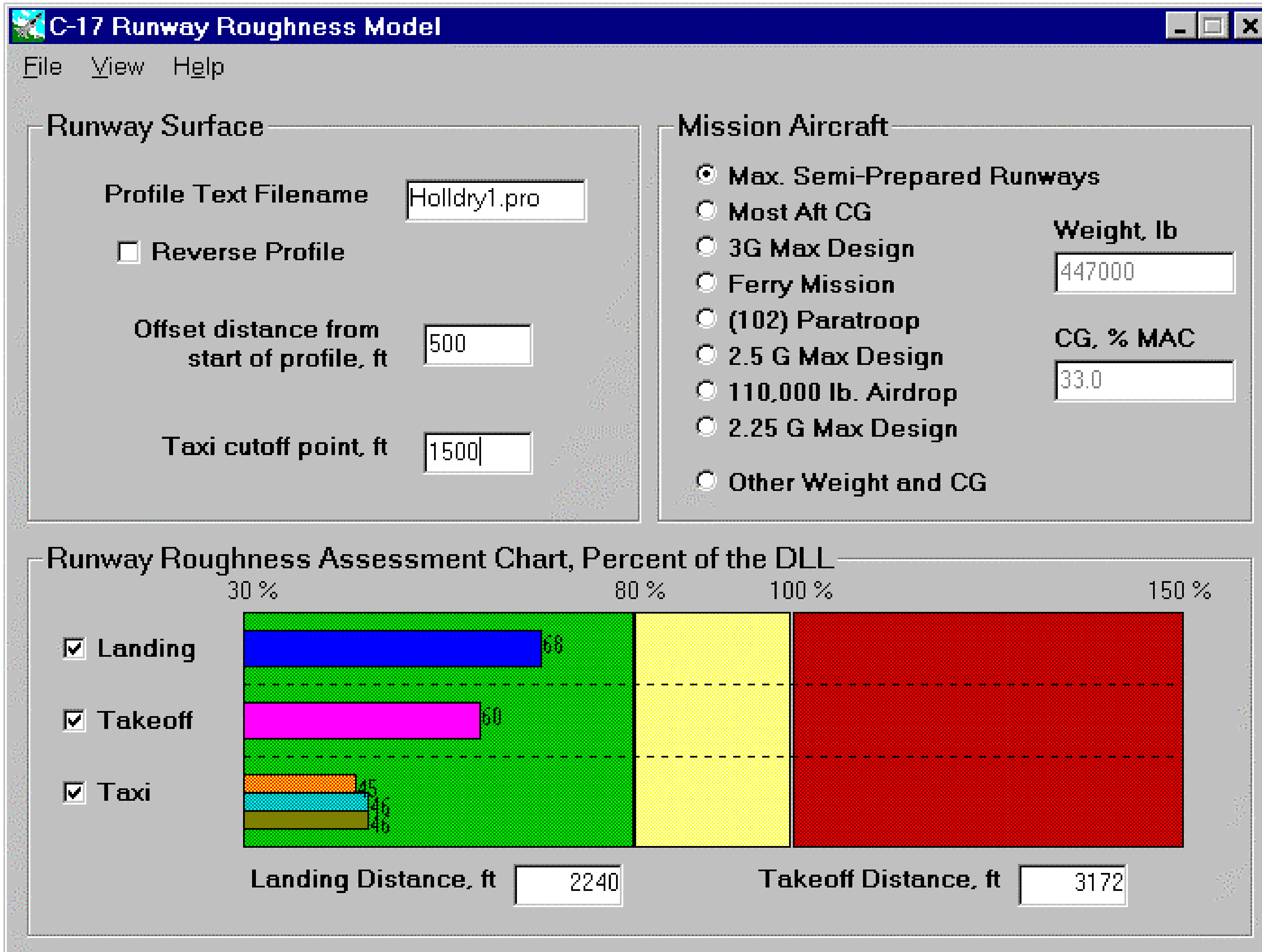
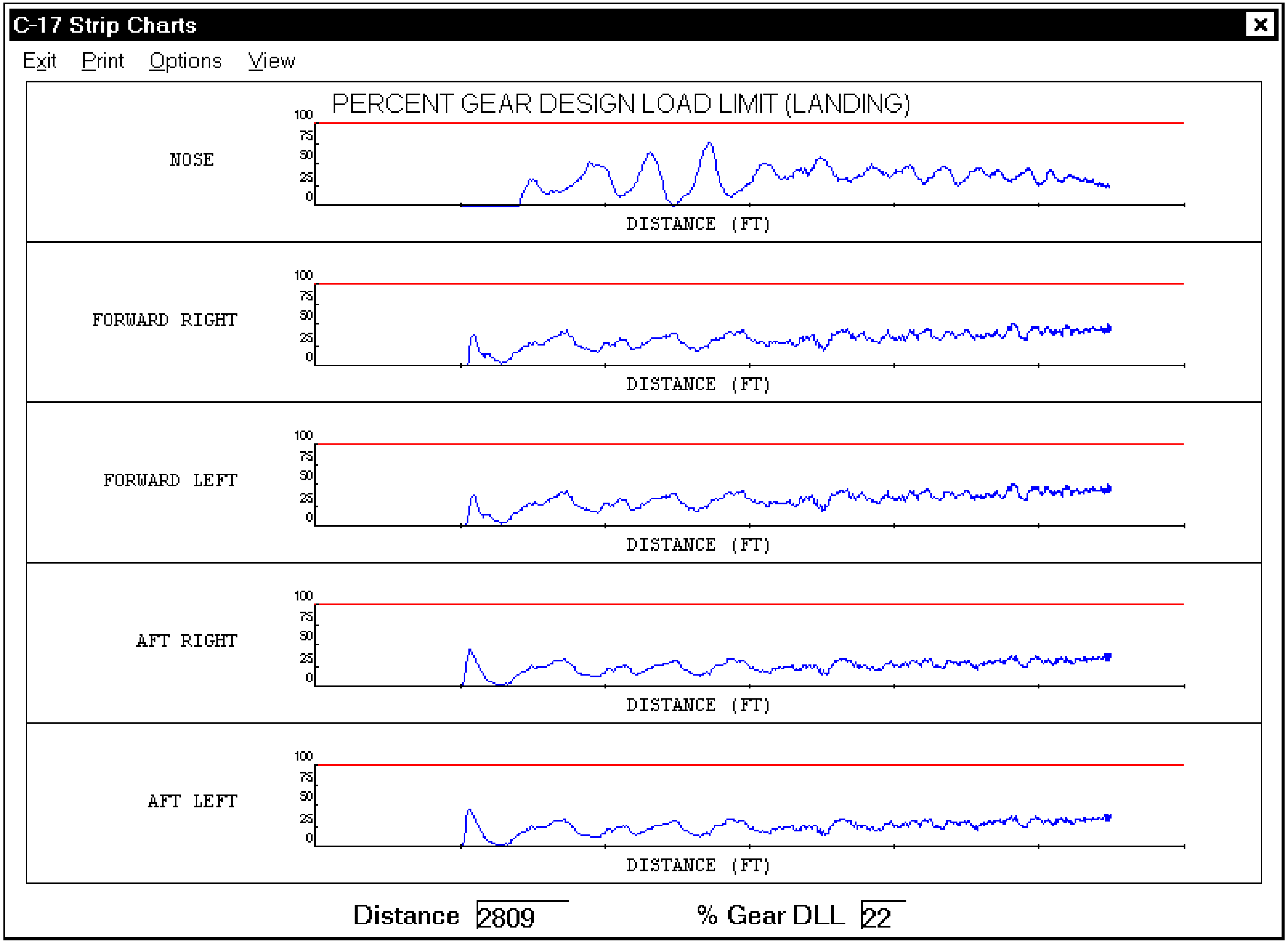


Sample Output Charts



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Sample Output Chart

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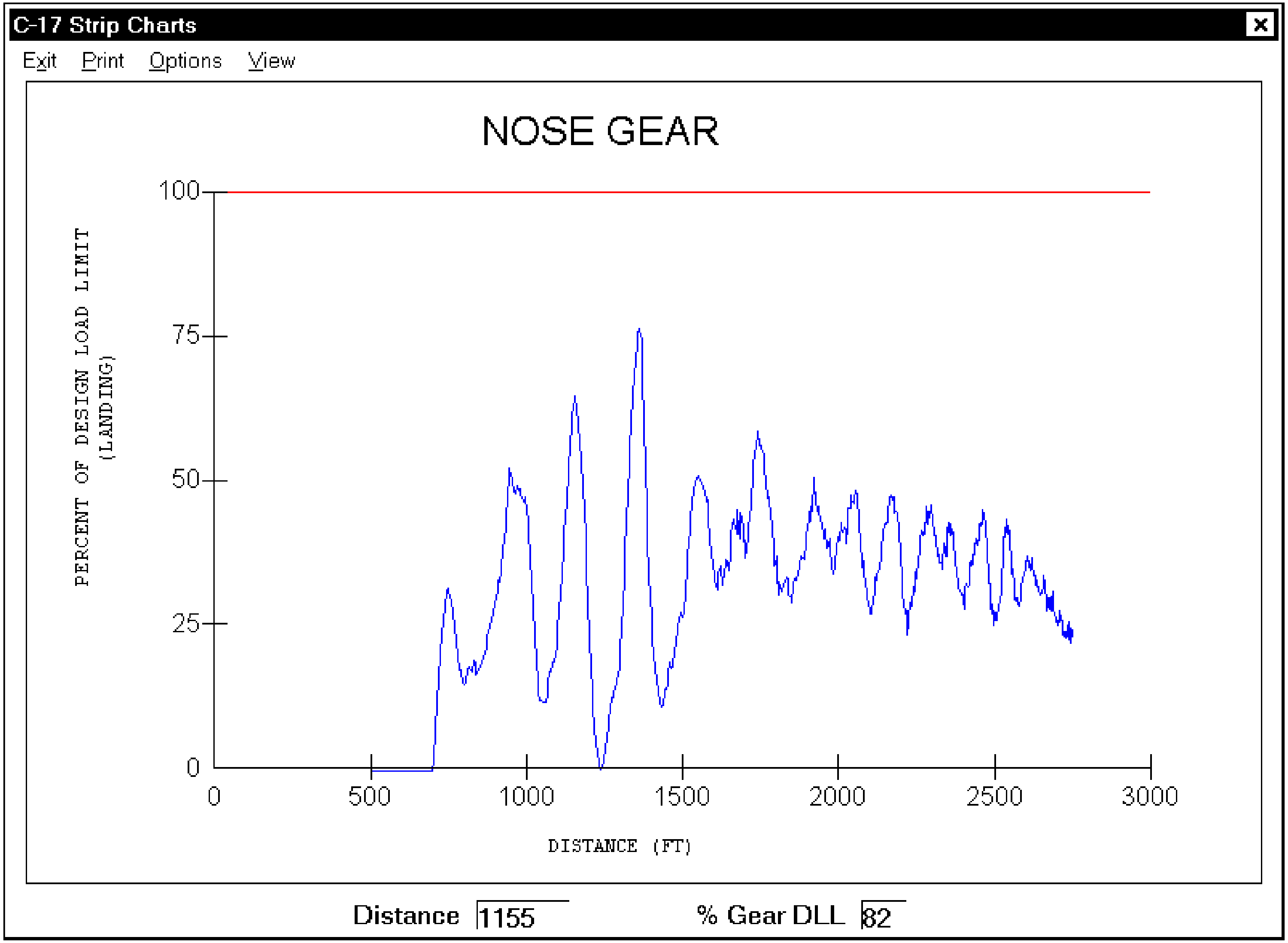
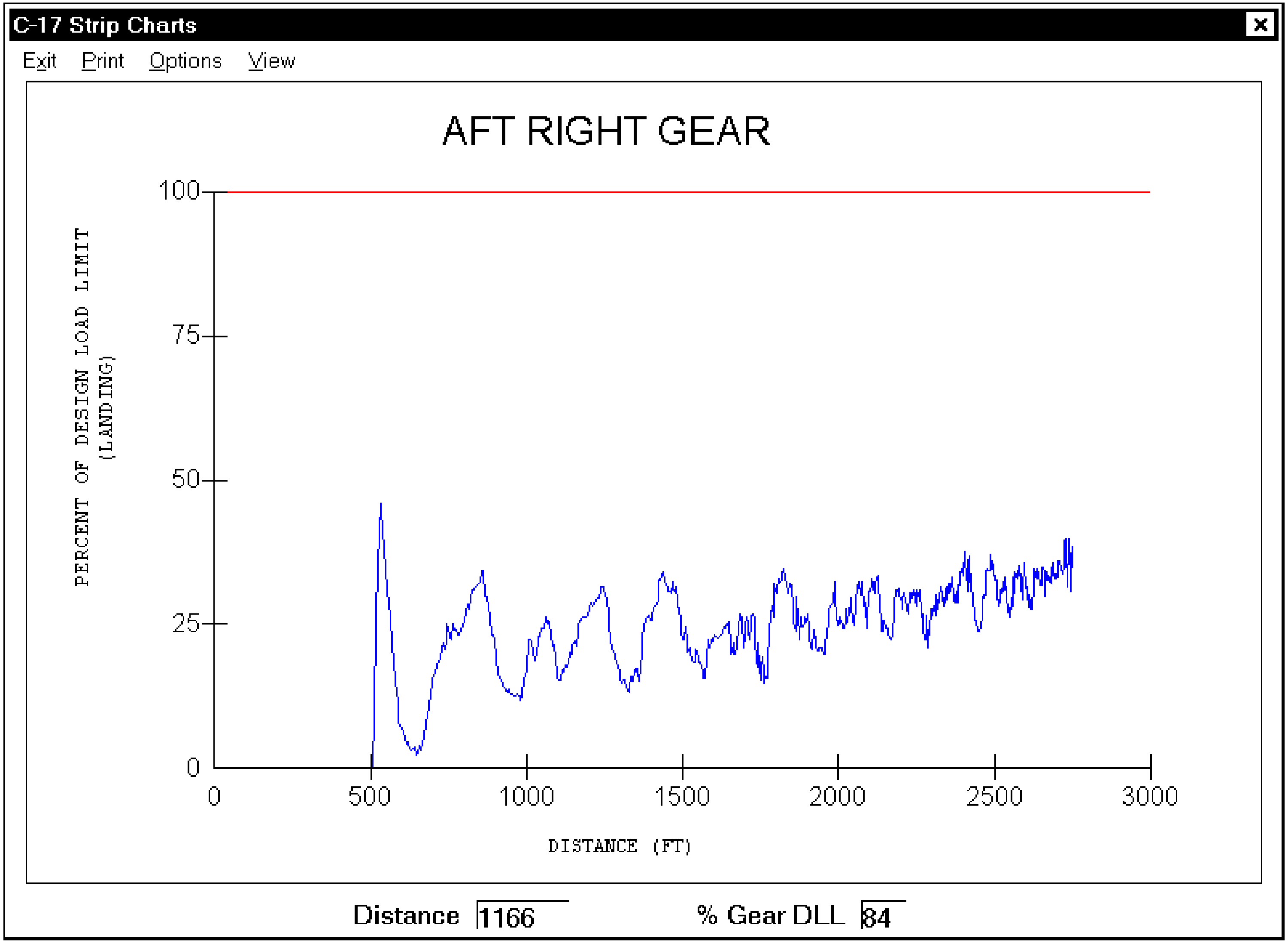


Sample Output Chart



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Conclusions

- A numerical model for the evaluation of semi-prepared runways for C-17 operations was developed (TAXIG/C-17A) and implemented with a user-friendly software interface (C17ROUGH)
- Initial comparisons between landing gear vertical forces measured during landing operations at Holland Landing Zone and the bump test performed by McDonnell Douglas are in good agreement with those predicted by the simulation software.

Recommendations

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- Incorporate the C-17 Runway Roughness Criteria for semi-prepared airfields in the ETL
- Perform an RQC validation test to properly validate TAXIG/C-17A
- Include tire pressure as a variable into the computer simulation. This will improve the prediction of forces on soft dirt runways.
- Add a tire model capable of accounting for short bumps and dips.
- Add a runway model in which the surface yields as the aircraft tire rolls on it. This will improve the prediction of forces on soft dirt runways.