Improved Safety and Capability via Direct Computation of Takeoff and Landing Performance Data

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Introduction

Traditional approach: performance data as section in flight manual
• Graphical / tabular data in document format
• Conservative meta-model of underlying physics-based model
• Time / cost to produce and maintain for OEM
• Artificial performance penalty for operator
• Inadequate margin in corners of envelope?

Alternative approach: performance as direct software model
• Flight planning from first-principles, physics-based model
• On-board and off-board solutions to meet operational requirements
• No excess conservatism / artificial penalty, use inherent capability of the airplane
• Never inadequate margin in corners of envelope

Objective: Quantify available improvement with direct-physics model and identify path to implementation
Scheduled performance

• Operators use performance data to plan max weight for every takeoff & landing
  • “Scheduled” performance
  • Done in accordance with applicable regulations

• Traditional: charts and tables
  • Forces simplifications from physics model
  • Human readable data
  • Intended as conservative approximation
  • Charts and tables digitized to automate usage
  • Paper treated as truth source for mitigation

Sample flight manual chart: Boeing 727-200
Analysis

• Evaluate impact of traditional approach on scheduled performance
• Two distinct approaches to developing flight-manual model
• Focus on takeoff and landing performance data
• Multiple operational scenarios for real-world operations
• Develop benchmark based on reverse-engineered physics model

Model Basis: C-130H

• Publicly available data
• Generic transport performance
• Familiar
Traditional approach

- Performance charts created from an approved, flight-test aero and propulsion model
- Additional charts with corrections for non-baseline conditions
- Conservatism in curve-fits and approximations
- Goal: ensure safe results at all expected conditions
- No industry standard
- Tribal knowledge of OEM and cert authority
Anatomy of a flight manual chart

- First-principles, physics-based model executed at baseline and variant conditions
- Charts constructed as a baseline plus corrections
- Does not perfectly reflect physics-based, flight-test expansion model
- Data scatter
- Conservative fairings used to make flight manual chart
Modeling corrections

• Corrections vary according to effects modeled

  • Baseline-only approach
    • Models correction at conditions of baseline chart only – no interactions
  • Full approach
    • Models correction at baseline plus all preceding corrections – captures interactions
  • Difference can be significant
Differing conservatism

- Corrections vary with curve-fit philosophy
  - One approach: capture 100% of data
    - Conservative envelope - never non-conservative
    - Punitive
  - Alternate approach: apply “engineering judgment”
    - Arbitrarily assume some points unlikely operationally
    - Less rigorous: conservative fit based on some % data
    - More rigorous: exclude outliers case-by-case
    - Arbitrary but less punitive

- No industry standard
- Approach varies according to company, program, cert authority

- Because engineering judgment is arbitrary, 100% fits applied in this study
- Results therefore “most conservative”
Balanced field length (BFL)

Critical takeoff distance is greater of balanced and unbalanced field length

Red curves incorporate baseline conditions for corrections only – no interaction of corrections

Black curves incorporate baseline plus all preceding corrections – capture interactions
Basis charts - *takeoff*

- Greater of balanced and unbalanced
- Red curves incorporate baseline conditions for corrections only – no interaction of corrections
- Black curves incorporate baseline plus all preceding corrections – capture interactions
Landing field length over 50 feet

Basis charts - landing

- Landing distance includes air distance from 50 ft to touchdown and ground distance from touchdown to stop
- Red curves incorporate baseline conditions for corrections only – no interaction of corrections
- Black curves incorporate baseline plus all preceding corrections – capture interactions
Operational considerations – all flight manual runs – takeoff

- Baseline-only corrections full corrections clearly differ
- What is effect operationally?
- As first pass, re-use the points used to make the flight manual charts
- Compare flight manual to physics
- Understand this is not necessarily realistic – treats extreme conditions as equally likely to occur as benign conditions in middle

Cumulative probability distribution for error in the flight manual-model for takeoff distance

**Base Corrections**: 162 ft at 50%, 611 ft at 80%
**Full Corrections**: 487 ft at 50%, 1,020 ft at 80%

Base non-conservative for 20% of cases
Operational considerations – all flight manual runs – landing

- Similar trend
- Smaller errors
- Greater error with full set
- Non-conservative results for about 20% of base set

Cumulative probability distribution for error in the flight manual-model for landing distance

Base Corrections: 75 ft at 50%, 240 ft at 80%
Full Corrections: 344 ft at 50%, 776 ft at 80%
Base non-conservative for 19% of cases
Capturing operational realism

- Reasonable to assume that conditions in the middle of the envelope occur more frequently than points at extremes
- In absence of real data, two hypothetical distributions fabricated
- Monte Carlo analyses (50,000 pts) applied to compare flight manual with first-principles
Operational scenario #1

Cumulative probability distribution for error in the flight-manual models

Base Corrections: 144 ft at 50%, 315 ft at 80%
Full Corrections: 329 ft at 50%, 573 ft at 80%
Base non-conservative for 5% of cases

Base Corrections: 66 ft at 50%, 131 ft at 80%
Full Corrections: 120 ft at 50%, 319 ft at 80%
Base non-conservative for 1% of cases
Operational scenario #2

Base Corrections: 78 ft at 50%, 163 ft at 80%
Full Corrections: 160 ft at 50%, 302 ft at 80%
Base non-conservative for 3% of cases

Cumulative probability distribution for error in the flight-manual models

Base Corrections: 30 ft at 50%, 73 ft at 80%
Full Corrections: 53 ft at 50%, 164 ft at 80%
Base non-conservative for 1-2% of cases

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Summary of distance penalty

• All scenarios show significant increase in takeoff and landing distance
Available operational weight increase with DTOLD

- Determined impact to takeoff and landing weight
- Converted distance errors to weight errors based on average feet of field length per pound of weight using all flight-manual runs
- All scenarios show significant increase in available takeoff and landing payload capability available if direct model used instead of conventional flight manual
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Summary of excess conservatism determined from different data sets
Barriers to implementation

- Regulatory regime
  - Differing guidance from FAA/EASA for EFB software and computerized AFMs
  - Primary vs. advisory
  - Embedded vs. EFB

- Reluctance of some OEMs and customers to move to first-principles data/models
  - Already popular in airline community
  - Practically unheard of in military and general aviation communities

- Reluctance of OEMs to release first-principles data/models

- Standards
  - SCAP – traditional channel for delivery of performance data to airline operators
  - Precedents set by early adopters of direct solutions
Conclusions

• Two significant shortcomings of traditional, paper-based flight manuals and electronic equivalents
  • Results in conservatism that diminishes the available performance of the aircraft
    • Reduces max weight for operation at a given airfield
    • Forces procedures that maximize performance capability (i.e., fewer reduced-power takeoffs)
  • Certain methods for traditional flight manuals routinely produce non-conservative results
    • Exposure will vary with operator
    • Exacerbated when “engineering judgment” results in curves that account for less than 100% of the data.
    • Procedures for constructing flight-manual not standardized
    • “Off-the-radar” to certification authorities?
Conclusions

• Traditional, paper-based manuals (and electronic equivalents) are an anachronism
  • Chart are provided in document-style format, but translated into tables for use in software
  • Actual charts rarely used, but required for on-board reference for flight crews
• Direct, first-principles models offer greater safety and capability with no physical change to airplane
  • Eliminate cost of developing traditional flight manual for OEM
  • Provide full capability with sufficient margin for operators

• Regulatory framework evolving
  • Airlines already utilizing these models
  • Military and general aviation seemingly unaware

• Disruptive technology in segments where not already adopted
  • Increases capability and efficiency of legacy platforms
  • Competitive discriminator for new platforms