Flight Test Evaluation of C-130H Aircraft Performance with NP2000 Propellers

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Introduction

• Flight tested a C-130H to determine impact of new 8-bladed NP2000 propellers on aircraft performance
• Used modern instrumentation and test techniques
• Assessed effects on all phases of flight:
  – Takeoff, climb, cruise, descent, landing
Background – NP2000

- Eight-blade propeller system by Hamilton Sundstrand
- Composite blades with graphite epoxy spar and Kevlar cover
- Modular hydraulic control system to control pitch angle
- In service with U.S. Navy E-2 fleet

Projected benefits:
- Increased thrust at equivalent engine torque
- Reduced vibration
- Less far-field noise
- Improved reliability and maintainability
Motivation

- New York Air Guard operates ski-equipped LC-130H aircraft from snow-covered surfaces
- During a ski-takeoff, skis “hang up” at approximately 60 knots
- Jet-Assisted Takeoff (JATO) bottles augment acceleration
- Cost of JATO bottles expected to become prohibitive

Increased thrust from the NP2000 proposed as cost-effective means of providing the necessary increase in thrust required for ski operations
Test Objective

• Quantify effect of new propeller on aircraft performance
  – The propeller changes:
    • Minimum control speeds
    • Airfield performance (takeoff and landing)
    • Airborne performance (climb, acceleration, cruise, deceleration, and descent)
  – Devised a suitable test plan to quantify the changes for all affected phases of flight
Approach: Performance Modeling

Modeling airplane performance requires models of thrust and drag

**During flight test:**
- Drag can never be measured directly
- Thrust can only be measured at static conditions

Assumed a traditional flight test approach:
- Use in-flight thrust model with a predicted propeller map
- Convert engine torque (measured) to net propeller thrust
- Airplane drag derived from computed thrust and measured flight conditions
- The drag model is a byproduct of the in-flight thrust model
Flight Test

- Test aircraft: C-130H from the Wyoming Air National Guard with T56-A-15 engines and NP2000 propellers
- Included an Electronic Propeller Control System (EPCS) that replaced the existing mechanical propeller control unit
- Remainder of the propulsion system (power section, reduction gearbox, propeller brake, safety coupling, etc.) identical to baseline C-130H configuration
- Tests conducted by 418th flight test squadron at Edwards Air Force Base from June 2010 to February 2011
Flight Test Plan

• Thrust stand
  • Measurements installed torque and net thrust statically
  • Calibrate engine and propeller measurements
• Airborne performance
  • Stabilized cruise test points (range performance)
  • Segmented climbs and descents
  • Level accelerations and decelerations
• Airfield performance testing
  • Takeoff
  • Rejected takeoff
  • Landing
Thrust Stand Testing

- Only condition where thrust directly measurable
- Collected data for ground idle, flight idle, maximum power, and intermediate power settings
- Quantified engine performance (torque versus turbine inlet temp)
- Evaluated available propeller models (thrust at static condition)
Cruise Testing

- A cruise test point consists of trimmed flight at stabilized speed and altitude, with engines thermodynamically stabilized
- Flown across envelope at a range of speeds/altitudes
- Validated predicted vs. measured engine parameters
- Determined drag
- Characterized range performance
Cruise Testing – Thrust Validation

• Used engine torque as input to engine deck to compute blade angle, net thrust, fuel flow for all four engines
• Compared computed to test measured values
• Excellent correlation

• Blade angle provided an independent indication/verification of engine torque and propeller thrust (sample shown here - all cruise test points for engine #1)
Cruise Range Performance

- Cruise range performance characterized by *specific range* (SR)
- SR = nautical miles per pound fuel
- Specific range test data indicated similar or slightly improved over baseline model
Climb and Descent Testing

- Climb and descent performance is characterized by *excess power*
- Excess power = margin of thrust minus drag available for the airplane to climb and/or accelerate at some given airspeed and weight
- Quantified via two types of tests:
  - (1) sawtooth climb (and sawtooth descent)
  - (2) level acceleration (and level deceleration)
- Data obtained from these tests quantify specific excess power characteristics of the aircraft at fixed power settings
Sawtooth Climb

- Involve two climbs across a nominal test altitude on reciprocal headings perpendicular to the prevailing wind
- Minimize wind effects
- Climb initiated well below target altitude to allow speed and power to stabilize
- A thermodynamically stable engine allows better in-flight thrust calculation
Sawtooth Climb Results

- Test data generally indicate excess power improved for flaps up and flaps 50%
- Exception at 100% flaps
- Greatest turning of slipstream
- Possible slipstream effects
Level Accelerations

- Alternate method for determining the excess power
- More efficient than sawtooth climbs
- For a level acceleration, aircraft climbs at target power setting at initial speed until the target altitude is reached and aircraft transitions to a horizontal acceleration
- Initial climb at the target power setting stabilizes engine for in-flight thrust calculation
Level Acceleration Results

- Data agree with sawtooth climb results and indicate improved excess power
- Level accelerations provided more data (larger speed band) over much fewer test points than sawtooth climbs
- Unfortunately, no accelerations with 100% flaps data available to corroborate sawtooth climb results
Airfield Performance

• Takeoff and landing quantified by physical models that include:
  – Thrust (takeoff power, ground idle and flight idle)
  – Aerodynamics
  – Flight test constants and correlation factors, including transitions (engine failure recognition, brake application, etc.)

• Include effects of minimum control speeds
  – Tested as prerequisite to takeoff testing
  – Minimum control speeds increased as a consequence of increased thrust
  – Determines minimum lift-off speed \( (V_{MCA} - \text{min control speed in the air}) \)
  – Determines minimum go-speed \( (V_{MCG} - \text{minimum control speed on the ground}) \)
  – Critical field length for takeoff accounts for engine failure
4-Engine Takeoff

- Increase in net thrust resulted in increased low-speed acceleration (~20% at sea level/ISA and high/hot)
- Reduced 4-engine takeoff distances (both ground roll and distance to 50 feet)

4-Engine Distance to 50 feet:
Sea level, standard day, and 4,000’ PA, ISA+30°C
Normal Takeoff – Critical Field Length

- Mixed impact on CFL due to increase in $V_{MCG}$ and $V_{MCA}$
- Used MIL-STD-3013A rules
- Better at some conditions, worse at others
  - CFL slightly increased at conditions of weight, altitude, temperature where minimum control speeds govern takeoff
- Mitigation of increased minimum control speeds would help

![Graph showing Critical Field Length vs. Gross Weight for different conditions.](image URL)

**Critical Field Length:**
- Sea Level, Standard Day, and 4,000’ PA, ISA+30°C
- 54H60 Props (Solid Lines)
- NP2000 Props (Dashed Lines)
Landing

- Increase in net thrust at flight idle increased touchdown speed and increased air distance.
- Decreased reverse thrust at low speed increased ground roll.

**Graph:**
- **Gross Weight**
- **Landing Distance:**
  - Sea level, standard day
  - Flaps 100%
  - 4 Engines in Max Reverse
  - 3,000 PSI Brakes

**Lines:**
- 54H60 Props (Solid Lines)
- NP2000 Props (Dashed Lines)

**Graph Details:**
- Landing Distance from 50 ft
- Total Distance
- Ground Roll
Conclusions

- **Airborne performance:**
  - Greater climb and acceleration capability compared to the baseline model of the aircraft (exception at the 100%-flap)
  - Similar or slightly improved range performance compared to baseline

- **Airfield performance**
  - Reduced max-effort and 4-engine takeoff distances
  - Mixed picture for normal takeoff (critical field length)
    - Slightly increased at conditions of weight, altitude, temperature where minimum control speeds set takeoff speeds
    - Decreased at all other conditions
  - Mitigation of increased minimum control speeds would help
  - Increased landing distances due to changes to flight idle, ground idle and reverse thrust
    - Potential for improvement via adjustments to blade angle schedule
Questions?
Back-Up
Handling Qualities

• Limited sideslip testing performed
  – Indicated rudder force lightening
    • benefit to adding a sideslip indication system

• No stall testing performed
  – Tested in previous phase
  – Lockheed Martin reviewed data -
    • stall characteristics degraded
    • strong benefit to adding artificial stall warning