Sensitivity Analysis for Takeoff and Landing Distance Parameters for Regional Air Mobility (RAM) Aircraft

07/30/2024

Gabino Martinez Rodriguez, Nathaniel J. Blaesser, Nicholas K. Borer
NASA Langley Research Center
Aeronautics Systems Analysis Branch

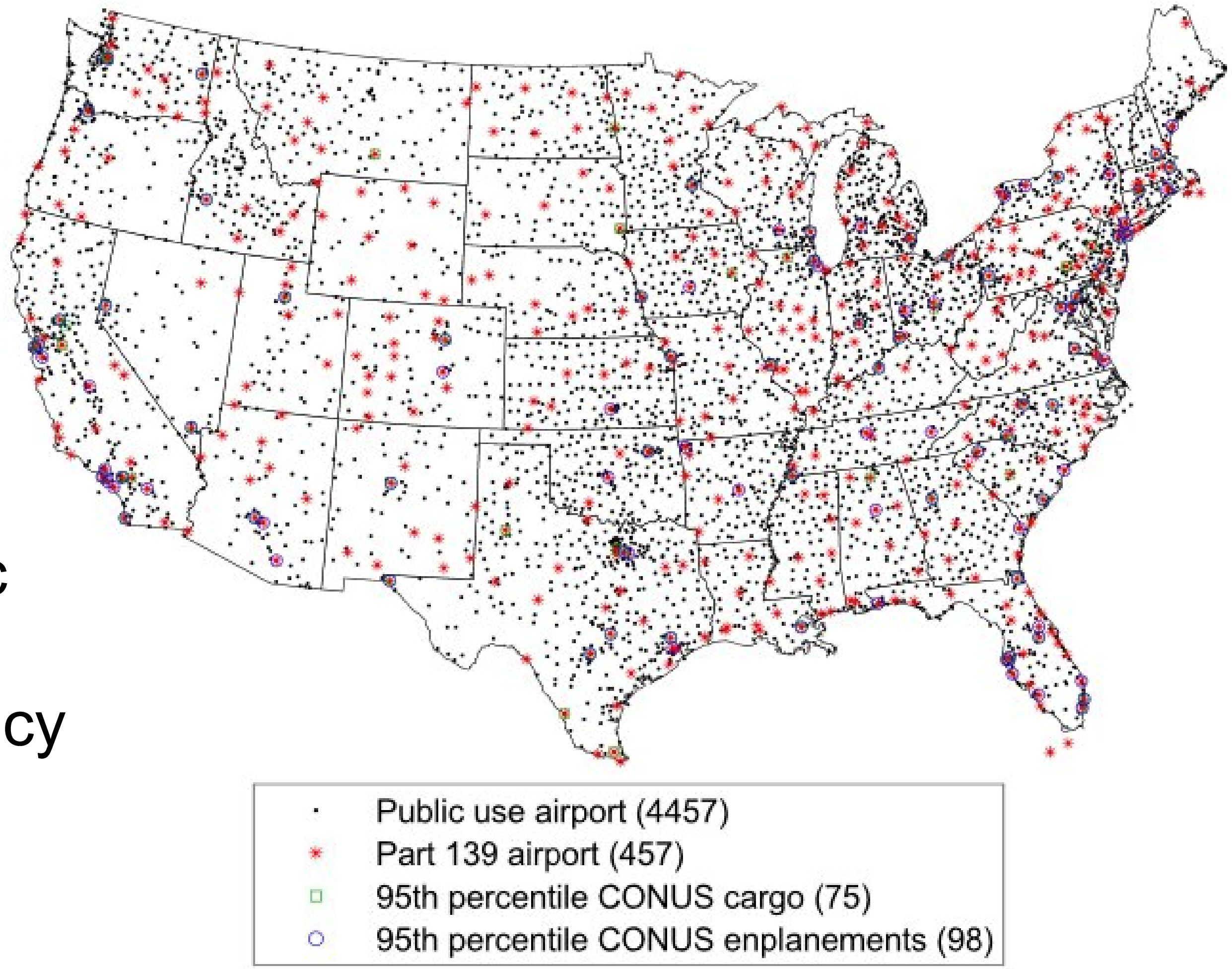
SACD
SYSTEMS ANALYSIS AND CONCEPTS DIRECTORATE

Introduction

- Wing sizing in conceptual design phase
  - Cruise wing sized for energy economy
  - Takeoff and landing (TOL) wing sized to generate enough lift to takeoff and land safely
  - Efficient design balances wing sizes
- High-lift systems
  - Used to alleviate the disparity in wing sizes
  - Traditional high lift devices (flaps, slats, etc.), distributed electric propulsion (DEP) or other technologies
  - Allow wing to be sized primarily for cruise
- Focus of research
  - Sensitivity of TOL distance to parameters of interest
  - TOL performance analysis is typically performed with high level parameters/ratios
  - Inadequate for aircraft designs with novel technologies/configurations
    - RAM aircraft

Motivation

- Regional Air Mobility (RAM)
  - Seeks to connect large network of underused public airports
  - Using shorter range aircraft with alternate forms of energy (electric)
- Electric RAM Aircraft
  - Range constrained due to low specific energy of current battery technology
  - Paramount to optimize energy efficiency for battery-powered aircraft
  - DEP allows wing area to be reduced while still being able to TOL

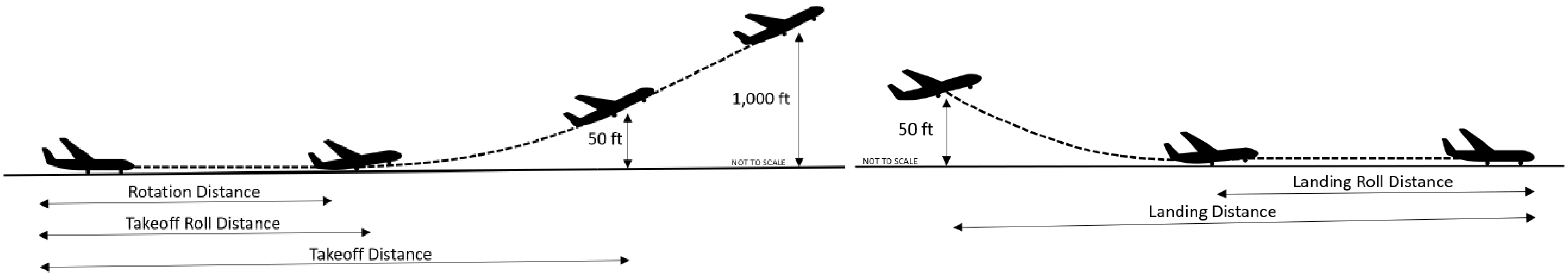


TOL Model

- Flight Optimization System (FLOPS)
  - Legacy aircraft sizing and synthesis tool
  - Six primary analysis modules
  - One of them is for TOL calculations
- Required data for FLOPS TOL module
  - Abundance of options and inputs required
  - C_L at specific angles of attack (lift curve)
  - C_D at specific C_L (drag polar)
  - Thrust at a range of power codes and forward velocities (engine deck)
- Aircraft model
  - RAM-like vehicle based on the Cessna 402C
  - Fully electric propulsion system

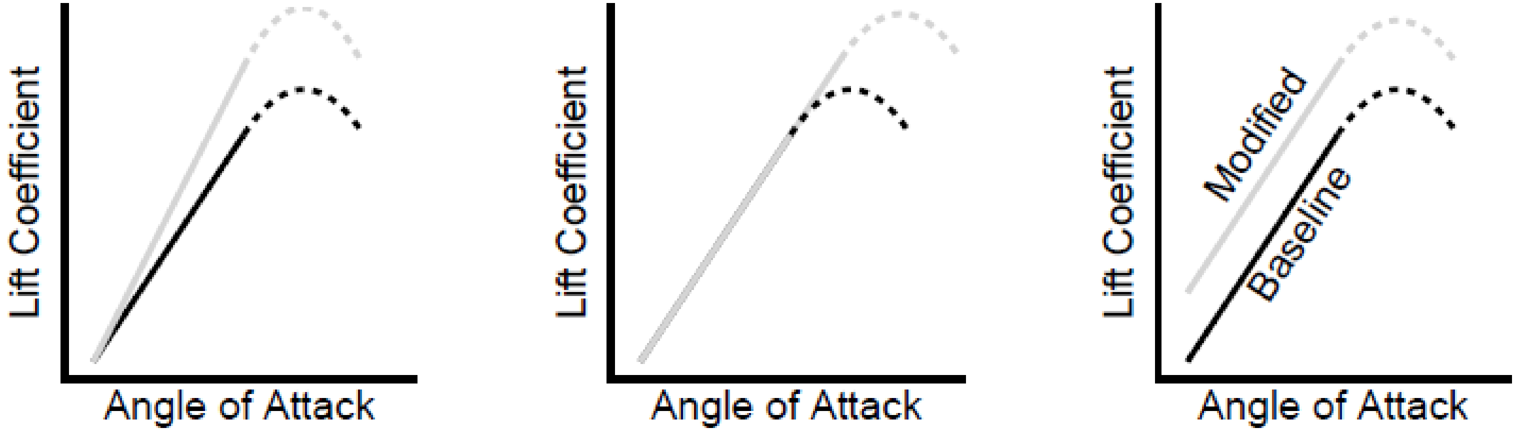
TOL Simulation

- TOL distances
  - Measured from 50 ft obstacle clearance
  - Standard sea level conditions
  - Approach at 130% stall speed
  - Application of brakes occurs four seconds after touchdown



Aerodynamic Parameters of Interest

- Lift curve
  - Three aerodynamic parameters are sufficient to build the lift curve
    - Lift-curve slope
    - Maximum angle of attack
    - Lift coefficient at zero degrees angle of attack
  - These three parameters can be varied to account for different types of high-lift systems



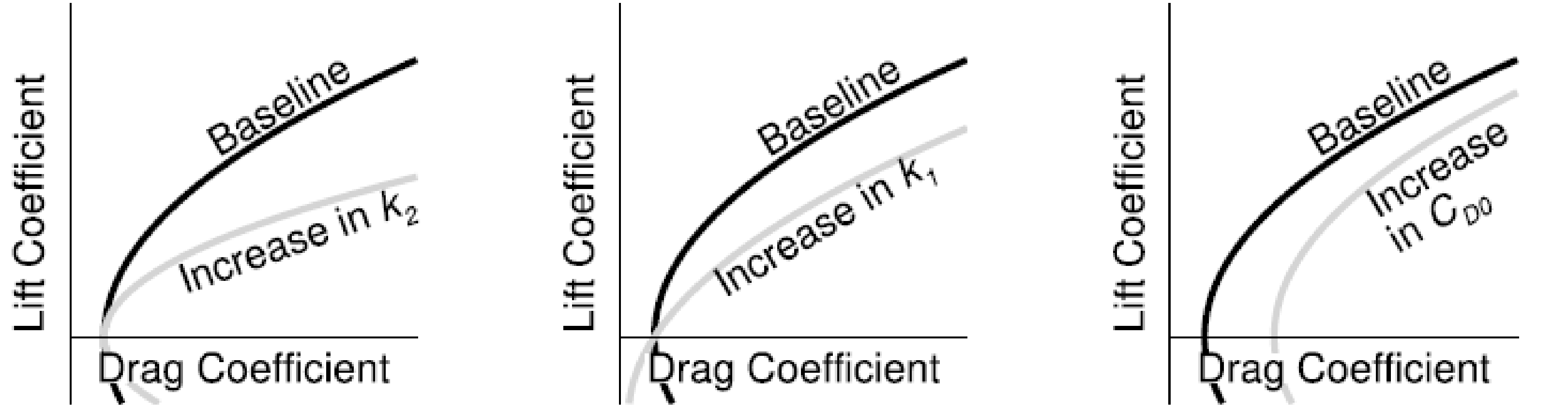
(a) Scaling factor on lift curve slope.

(b) Offset/delay in maximum angle of attack.

(c) Offset in lift coefficient for all angles of attack.

Aerodynamic Parameters of Interest Cont.

- Drag polar
  - Defined as a second-order polynomial, $C_D = k_2 C_L^2 + k_1 C_L + C_{D_0}$
  - Three more parameters are required to build the drag polar
    - k_2 - parameter associated with lift induced drag
    - k_1 - parameter that appears due to asymmetry about the $C_L = 0$ axis
    - C_{D_0} - lift independent drag coefficient



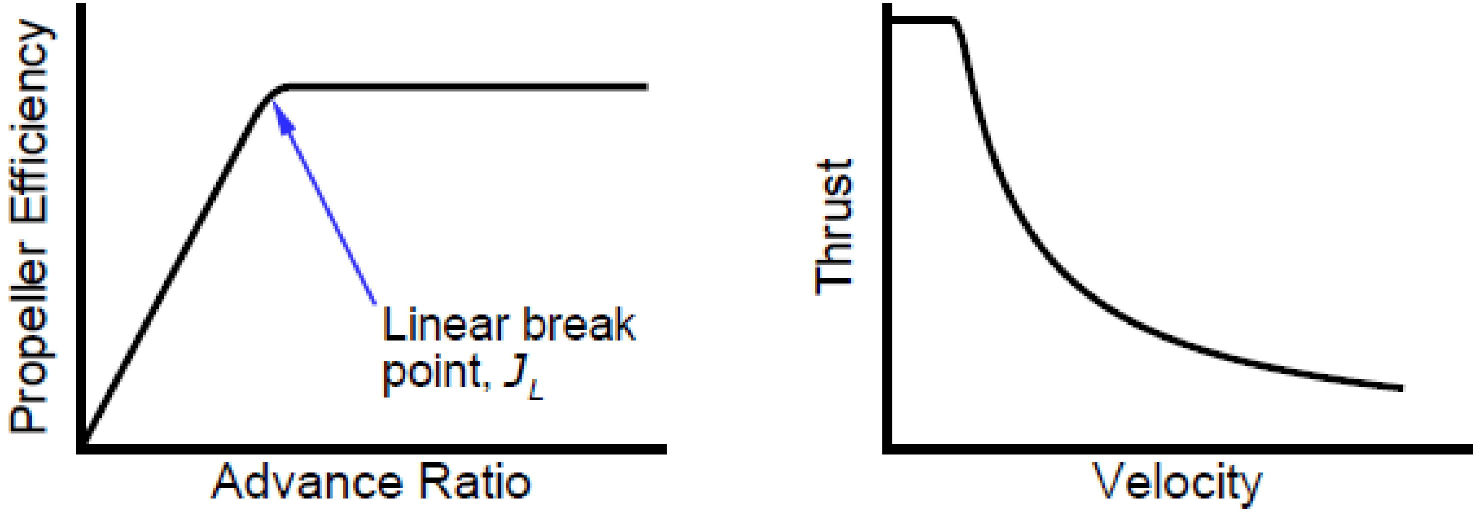
(a) Change in the non-linear term, k_2, in the drag equation.

(b) Change in the linear term, k_1, in the drag equation.

(c) Change in the zero-lift drag coefficient, C_{D0}.

Propulsive Parameters of Interest

- Engine deck
  - Electric motor with variable pitch propeller
  - Propeller efficiency model is simplified to a linear and constant section
  - Results in additional parameters for the propulsion model
    - Maximum motor power
    - Static thrust coefficient
    - Maximum propeller efficiency



(a) Notional propeller efficiency. (b) Notional thrust profile.

Other Parameters of Interest

- FLOPS TOL module parameters of interest
  - Wing Incidence
  - Rolling friction coefficient
  - Braking friction coefficient (landing specific)
  - Approach angle (landing specific)
  - Sink rate at touchdown (landing specific)
- Some parameters are indirectly set by the parameters of interest
  - Maximum lift coefficient
  - Minimum drag coefficient

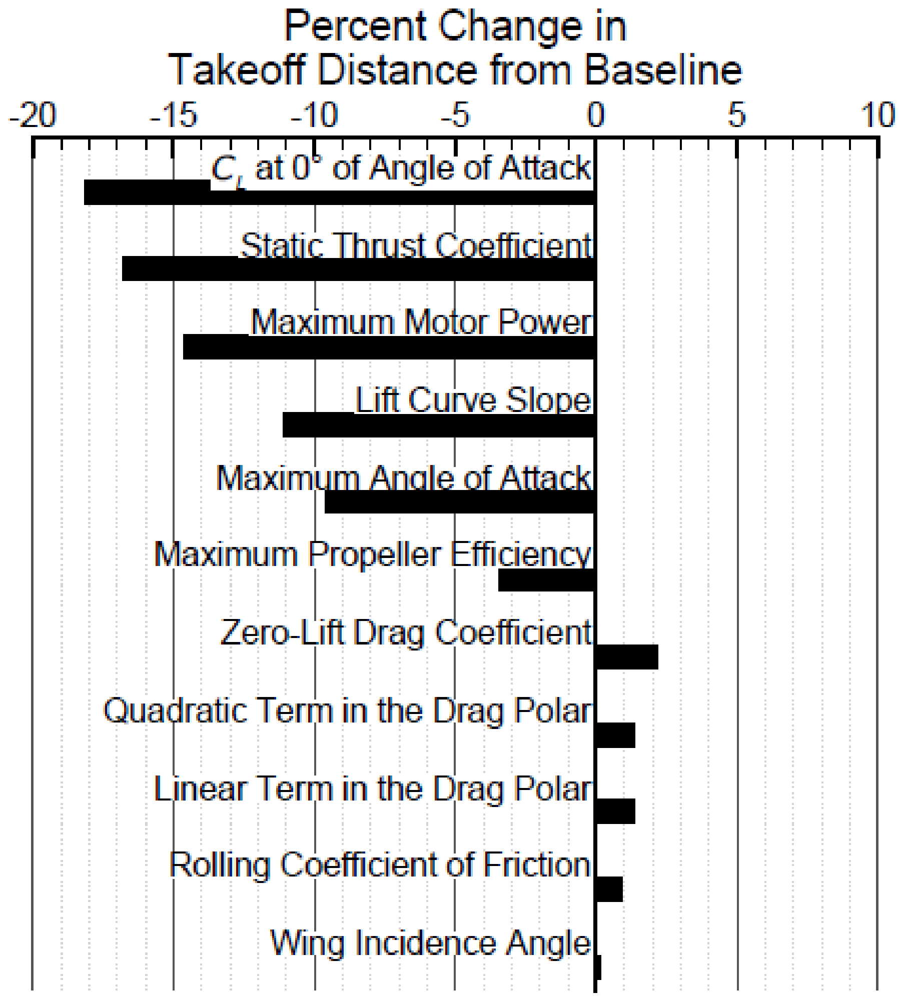
Sensitivity Analysis

- Latin Hypercube design of experiments
- Full quadratic response surface model fit to data
- Normalized with baseline TOL distances
- Sensitivity value is the percent change in TOL distance with a one percent change within the selected bounds of the parameter of interest

Parameter	Lower Bound	Upper Bound
Lift Curve Slope (per degree)	0.0658	0.0987
Maximum Angle of Attack (degree)	12	16
C_L at Zero Degree Angle of Attack	0.3	1
Quadratic Term in the Drag Polar	-20%	+20%
Linear Term in the Drag Polar	-20%	+20%
Zero-Lift Drag Coefficient	-20%	+20%
Maximum Motor Power (HP)	260	390
Static Thrust Coefficient	0.4	0.6
Maximum Propeller Efficiency	0.56	0.84
Rolling Coefficient of Friction	0.016	0.024
Braking Coefficient of Friction	0.288	0.432
Approach Angle (degree)	2	4
Sink Rate at Touchdown (ft/s)	2	6
Wing Incidence Angle (degree)	0	4

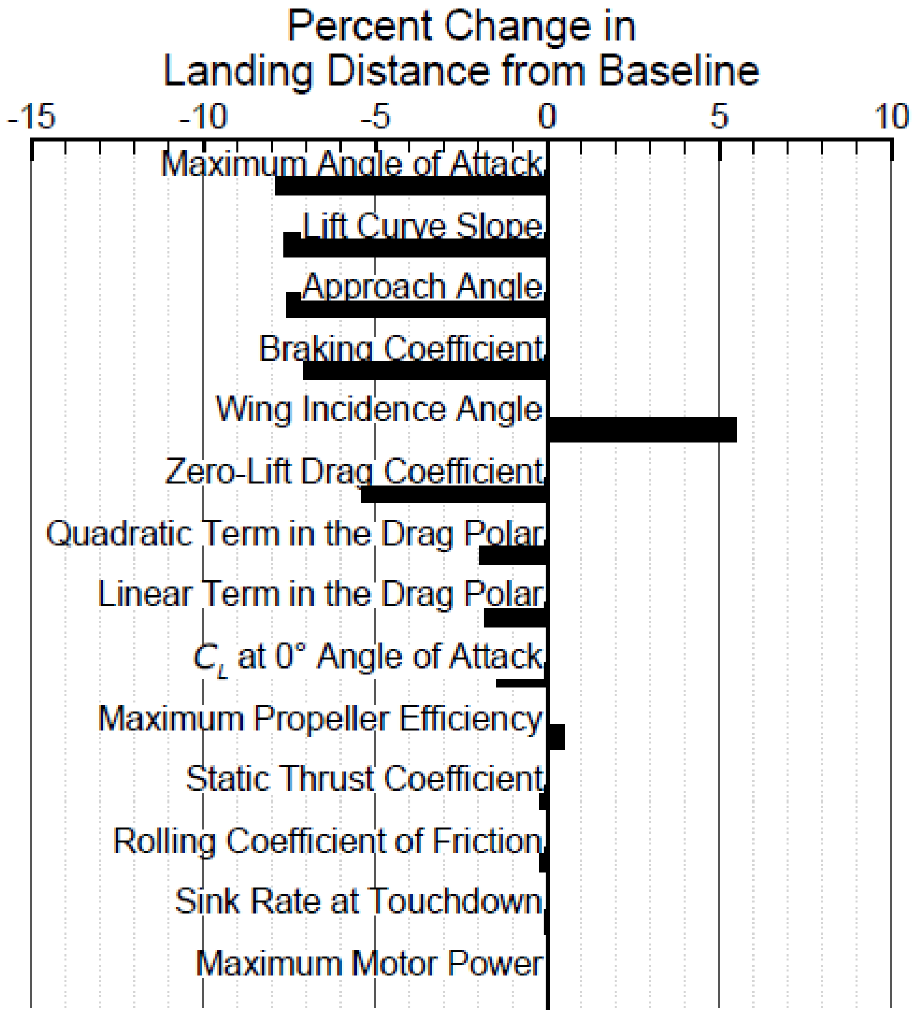
Takeoff Results

- Baseline model within one percent of takeoff distance compared to Cessna 402C
- Lift coefficient at zero-degree angle of attack
  - Shifts lift curve setting max lift coefficient
  - Other lift curve parameters set max lift coefficient
- Drag polar parameters
  - Moderately impactful due to small drag increments at low C_L
- Propulsion parameters
  - Highly impactful as vehicle must be accelerated to cue speeds



Landing Results

- Baseline model within half a percent of landing distance compared to Cessna 402C
- Propulsion parameters
  - Minimally impactful due to low use of propulsion system during landing
- Lift curve parameters
  - Highly impactful since they set maximum C_L
- Drag polar parameters
  - Moderately impactful due to small drag increments at low C_L
- FLOPS parameters
  - Contains highly and minimally impactful



Concluding Remarks

- Takeoff key takeaways
  - Most impactful parameters are those relating to propulsion and the lift curve
  - Drag polar parameters are moderately impactful but not near the level of the most impactful parameters
- Landing key takeaways
  - Lift-curve parameters are some of the most impactful
  - Among the most impactful as well were the approach angle, wing incidence, and braking coefficient
    - These parameters are often overlooked by many empirical approaches to estimate TOL performance.
  - The drag polar parameters were amongst the moderate impactful parameters

Thank You

- Questions?

- Thank you to the NASA Aeronautics Research Mission Directorate (ARMD) for funding this work
  - Transformative Aeronautic Concepts Program (TACP)
  - Convergent Aeronautics Solutions (CAS)
  - Aircraft as Energy Nodes (ÆNodes) Activity