Thrust Model Determination from Operational Flight Data Using a Smart Data Approach

Christoph Deiler

DLR - German Aerospace Center
Institute of Flight Systems
Department Flight Dynamics and Simulation
Braunschweig, Germany

Background

Sustainable aviation for EU “Flight Path 2050”:

- 75% less CO_2 emissions
- 90% less NO_x emissions
- 65% reduction of perceived noise emission

Short-term solutions:

- better aerodynamic performance and propulsion system efficiency
- further optimization of aircraft operations for emission reduction

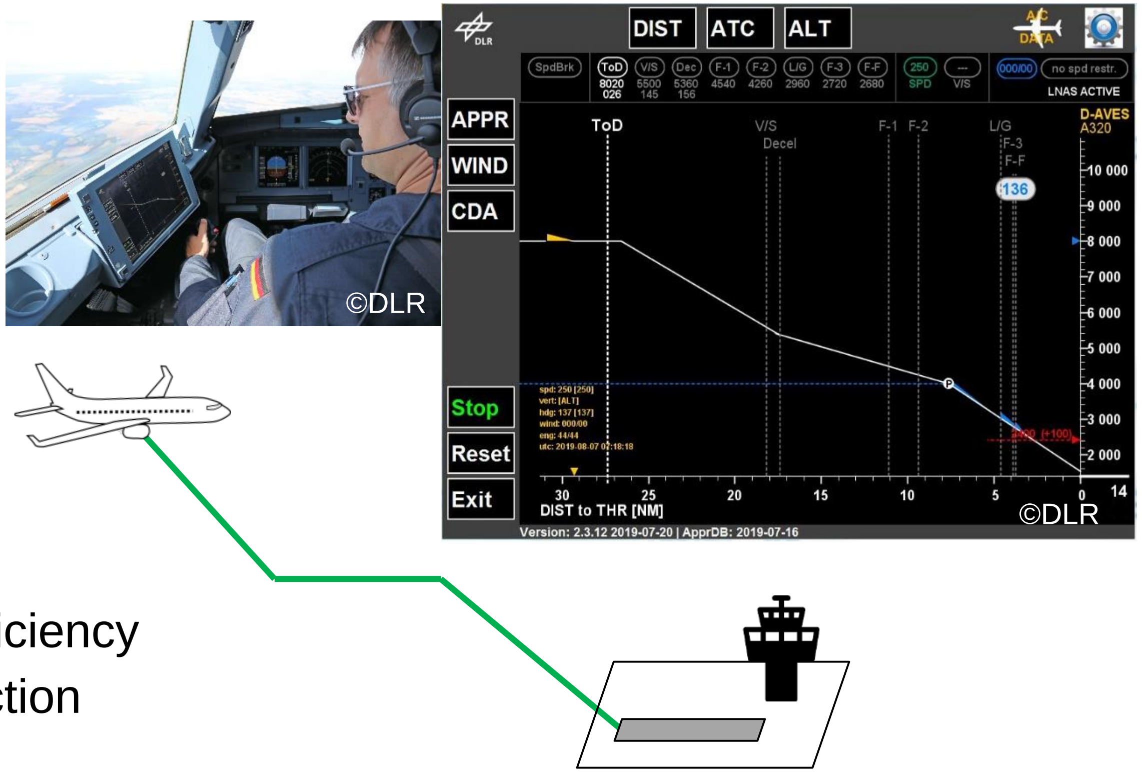
DLR’s “Low Noise Approach System” (LNAS) targets this goal:

- low power descent and approach by optimized energy management
- up to 25% fuel reduction and noise reduction up to 5 dB(A)
- advisory system based on a **high-quality flight performance model**

→Application of LNAS on airline fleets for wide field tests

→Airbus A320neo in SESAR Very Large Demonstration (VLD2) ALBATROSS

funding from the SESAR Joint Undertaking under the European Union’s Horizon 2020 research and innovation programme under grant agreement No 101017678



Fethi Abdelmoula and Marco Scholz. *LNAS - a pilot assistance system for low-noise approaches with minimal fuel consumption*. Belo Horizonte, Brazil, September 09th - 14th 2018. 31st Congress of the International Council of the Aeronautical Sciences (ICAS). https://www.icas.org/ICAS_ARCHIVE/ICAS2018/data/papers/ICAS2018_0096_paper.pdf

Challenges for Performance Model Determination

Available information for A320neo:

- flight data recorded on pilots' EFBs during operational flights with A320neo
- basic understanding of A320neo modifications
- a-priori knowledge about A320-232 aerodynamics based on DLR's ATRA

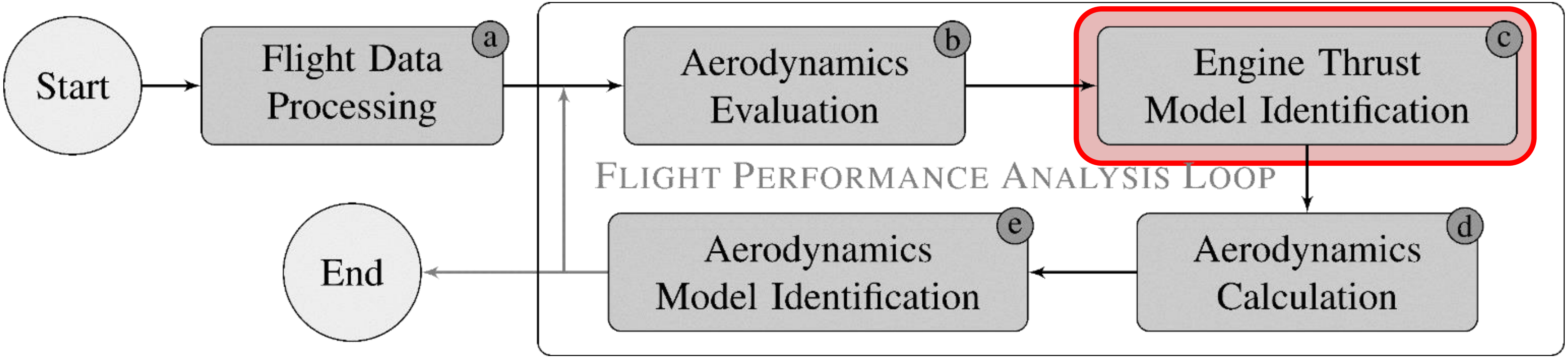
https://airbus-h.assetsadobe2.com/is/image/content/dam/channel-specific/website-/products-and-services/aircraft/header/aircraft-families/commercial-aircraft-stage_A320neo.jpg?wid=1920&fit=fit,1&qlt=85,0 (download 2021/Sep/01)

Typical "Big Data Problem":

- omnipresent and numerous ways of treatment
- desired:
  → solution with minimal effort and useful result (for LNAS)
- required:
  → aircraft performance model with separated aerodynamics and engines
  → reliable model outputs outside the given flight data envelope
- unstructured artificial intelligence methods are not a smart way to solve this problem

→ Fundamental engineering knowledge included in problem solution: **Smart Data Approach**

Data Evaluation Process for Flight Performance Model Determination

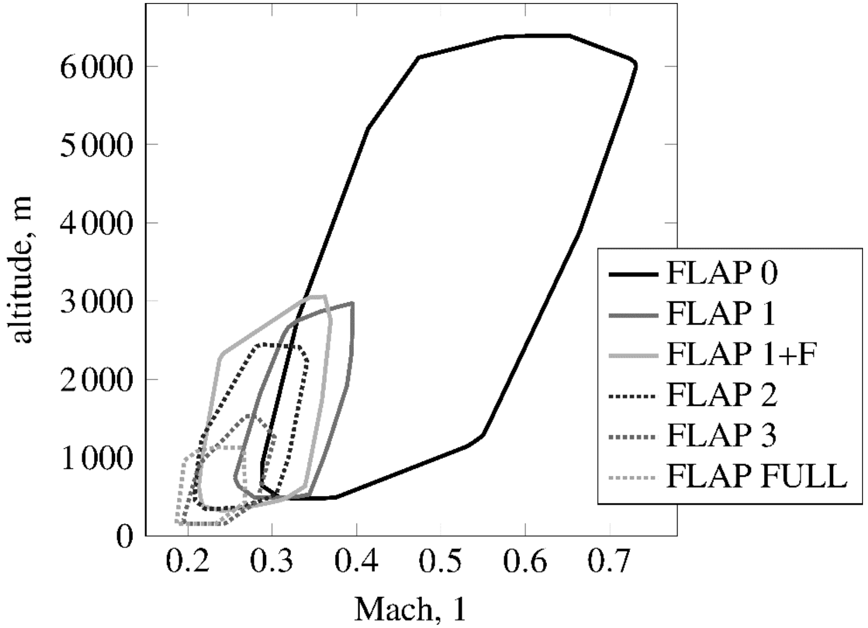


- Engineering knowledge included in all modules to reduce computational effort and enhance evaluation
- Fundamental assumption:
  large data base with sufficient variation of specific parameters → **decorrelation of aerodynamics and thrust**
- Focus on block c) within this work
  → further information about process will presumably be given at EuroGNC 2022
- Overall process design for execution on state-of-the-art desktop computer

Operational Flight Data Base

Knowledge-based data selection:

- height above ground > 50 ft or barometric altitude > 500 ft
- true airspeed above 130 kts
- fixed flap/slat configuration
- gear not moving



number of aircraft	3
number of flights	844
number of data points	55 479 606

data envelope	min	max
baro altitude	500 ft	20 964 ft
Mach	0.1866	0.7311
weight	48.57 t	73.44 t

flap/slat configuration	data points
FLAP 0	43 056 406
FLAP 1	1 914 563
FLAP 1+F	1 547 312
FLAP 2	4 514 991
FLAP 3	1 069 383
FLAP FULL	3 376 951

Engine Thrust Characteristics

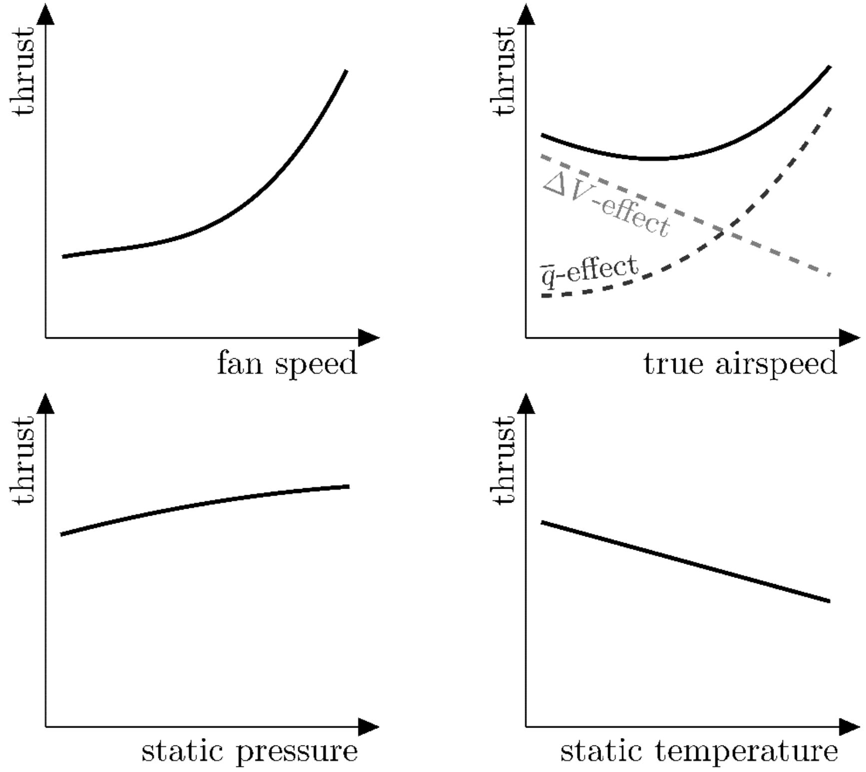
anti-ice status	data points	
	all	sym. conditions
off	55 367 617	53 143 789
engine on / wing off	111 989	111 685
engine & wing on	0	0

Required thrust calculation for symmetric thrust conditions:

- total req. thrust in aero. system: $T_{\text{tot,x,a}} = m_{\text{AC}} \cdot g \cdot n_{\text{x,a}} + C_D \cdot \bar{q} \cdot S.$
- transfer to body-fixed system: $T_{\text{tot,x}} = \dfrac{T_{\text{tot,x,a}}}{\cos(\alpha) \cdot \cos(\beta)}$
- required thrust per engine: $T_{\text{req}} = 0.5 \cdot \dfrac{T_{\text{tot,x}}}{\cos(\sigma) \cdot \cos(\varepsilon_{xy})}$
- regressor definition:
  - engine fan speed N_1
  - Mach number Ma
  - barometric altitude H
  - temperature offset

→ net thrust model function: $T_{\text{req}} \approx T_{\text{net}} = f(N_1, Ma, H).$

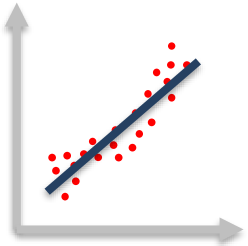
from aerodynamics model:
a-priori information or updated during process



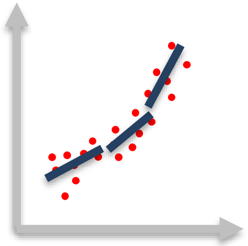
Different Modeling Approaches

- Linear Model:
  - most simplest approach
  - no capability to model the expected nonlinear thrust characteristics

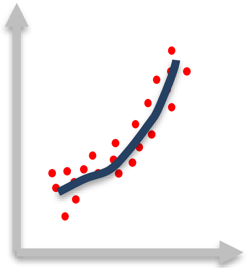
$$T_{\text{net}} = \theta_0 + \theta_1 \cdot N_1 + \theta_2 \cdot Ma + \theta_3 \cdot H$$



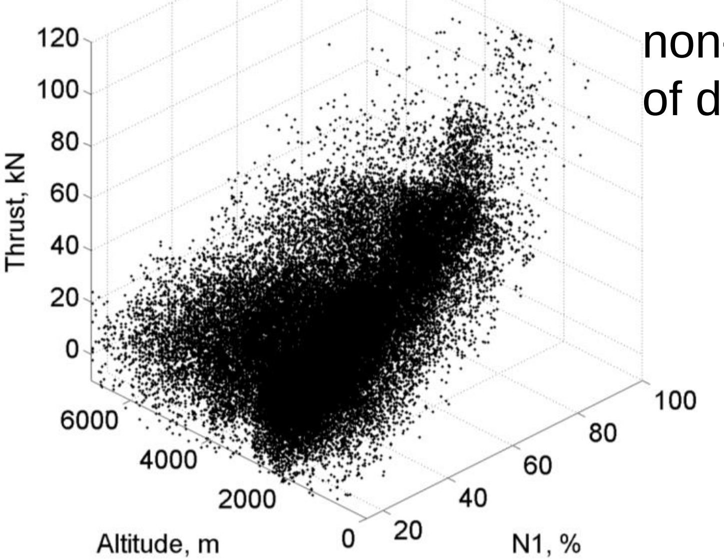
- Local-Linear Model:
  - better approximation of nonlinear thrust characteristics
  - model stitching problem between different linear models for continuous simulation



- Nonlinear Table:
  - full coverage of nonlinear thrust characteristics
  - large estimation problem with given big flight data set → ***data clustering*** to reduce problem size
  - gradient-based Gauss-Newton method to solve estimation problem
  - introduction of regularization for ***smooth and steady*** engine thrust representation by penalizing second-order derivatives in the table



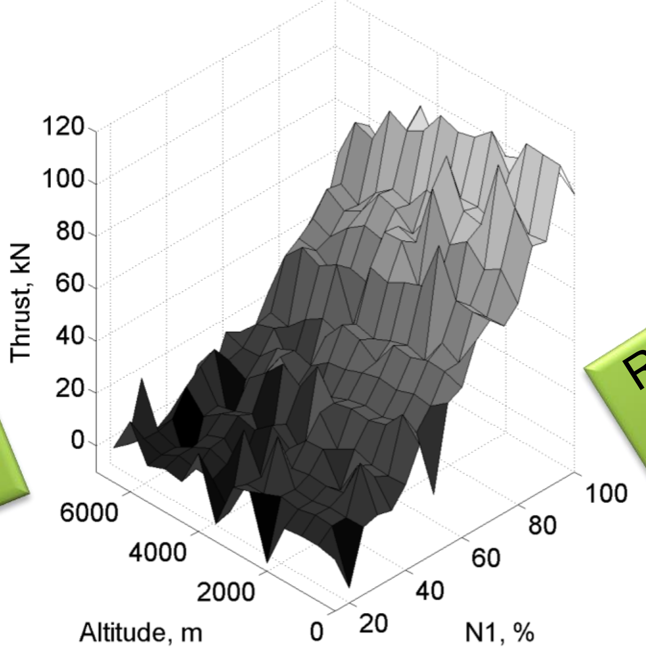
Generic Example on Challenges During Nonlinear Thrust Table Estimation
The Smart Approach to Solve the Problem with Engineering Knowledge



non-uniform distribution
of data across the envelop

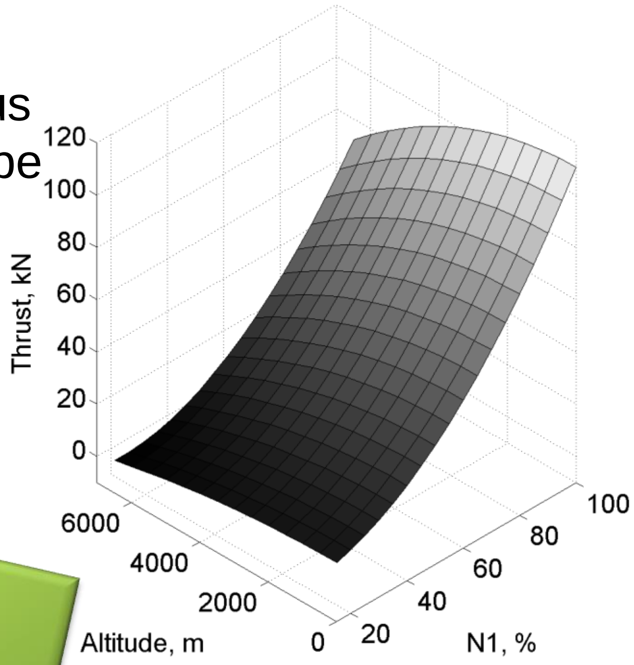
Data Clustering and
Table Estimation

thrust model with irrational
local discontinuities



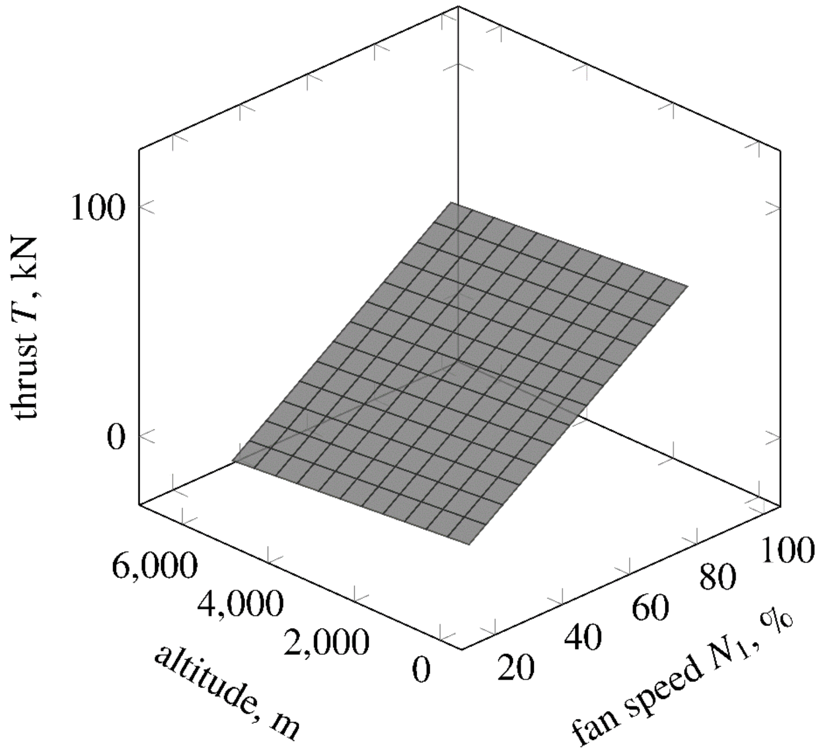
Regularization
of Optimization
Problem

thrust model
with continuous
nonlinear shape

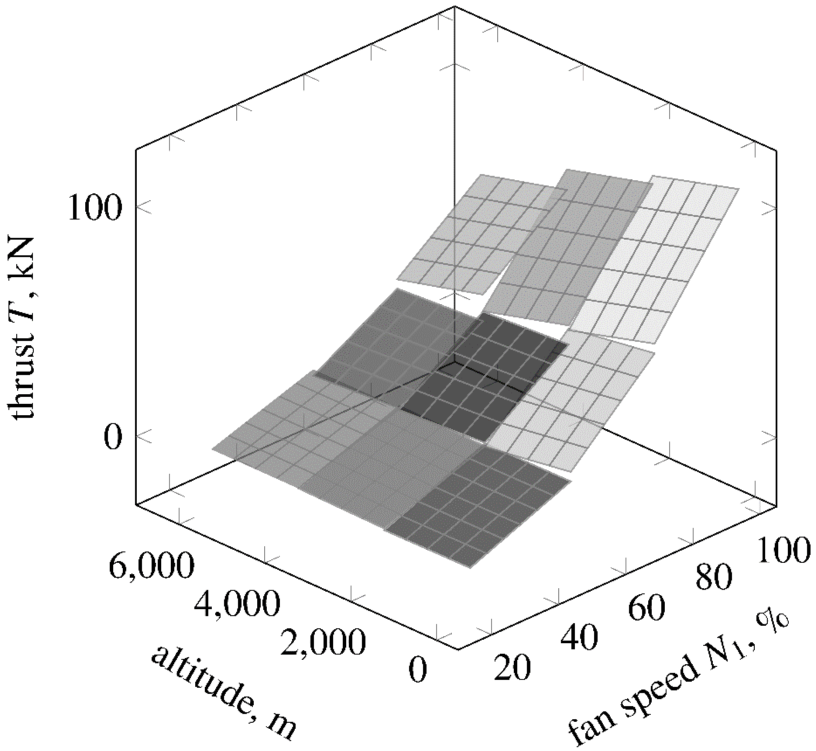


A Snapshot on the Engine Model Determination Results

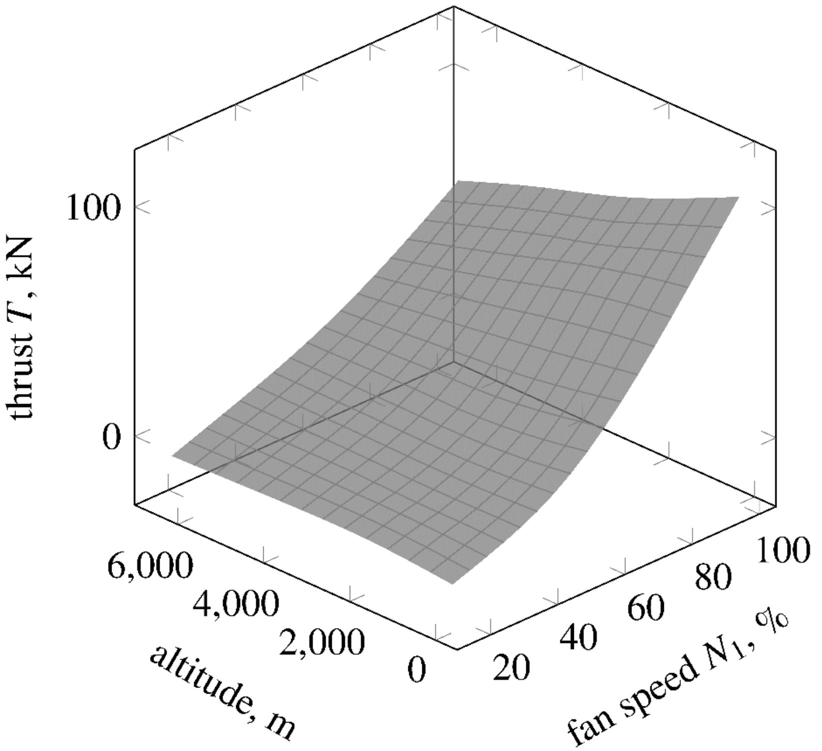
Model evaluations for example conditions at Mach = 0.4 (anti-ice off)



linear



local-linear



nonlinear table

DLR

Short Summary

- Background of work: flight performance model determination for **optimized aircraft operation** with **LNAS** during approach **with less emissions and noise**

- Big data problem solved by usage of fundamental engineering knowledge
  → smart data approach
  → thrust model determination part of a flight data evaluation process

- Evaluation of different thrust model structures
  → nonlinear thrust table best choice
  → table estimation process relatively fast even with large data base

- More detailed presentation on thrust model determination proposed for EuroGNC 2022!

Contact

Christoph Deiler

christoph.deiler@dlr.de

DLR - German Aerospace Center

Institute of Flight Systems

Department Flight Dynamics and Simulation

Braunschweig, Germany

DLR