# MODELING OF THE A320 LANDING GEAR DRAG DURING THEIR EXTENSION AND RETRACTION

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# Motivation

Various activities towards sustainable aviation with ambitious goals: 75% less $CO_2$ emissions, 90% less $NO_x$ emissions, 65% reduction of perceived noise emissions.

Short-term solutions:

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

DLR's "Low Noise Augmentation 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
- advisory system relies on a **high-quality flight performance model**

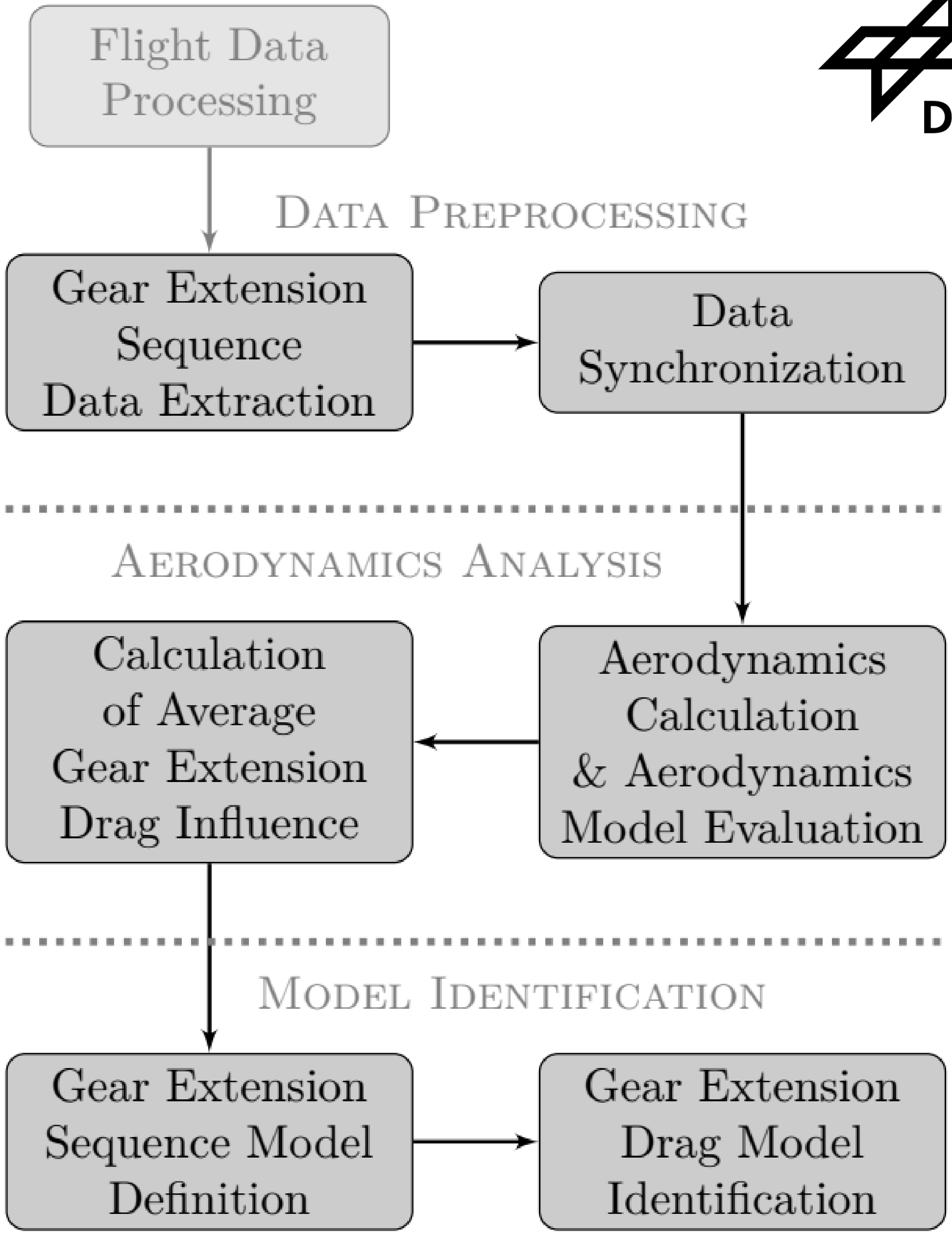

Fethi Abdelmoula and Marco Scholz. *LNAS - a pilot assistance system for low-noise approaches with minimal fuel consumption*. Belo Horizonte, Brazil, September 09th - 14th 2018. 31st Congress of the International Council of the Aeronautical Sciences (ICAS). https://www.icas.org/ICAS_ARCHIVE/ICAS2018/data/papers/ICAS2018_0096_paper.pdf

➔ Understanding the flight performance variations and the error that is potentially made by neglecting or improperly modelling transitions was desired

Credit: DLR

# Structure of the Talk

- Intro / Background / Motivation
- Getting suitable input data
  - Gear geometry and kinematics
  - Data from extension “maneuvers”
- Data analysis
  - Extraction of drag coefficient from data
  - Removal of non-gear contributions
  - Averaging / “denoising”
- Modelling the gear extension and drag evolution
  - Simplified extension sequence
  - Gear drag model and parameters
- Conclusions / Outlook



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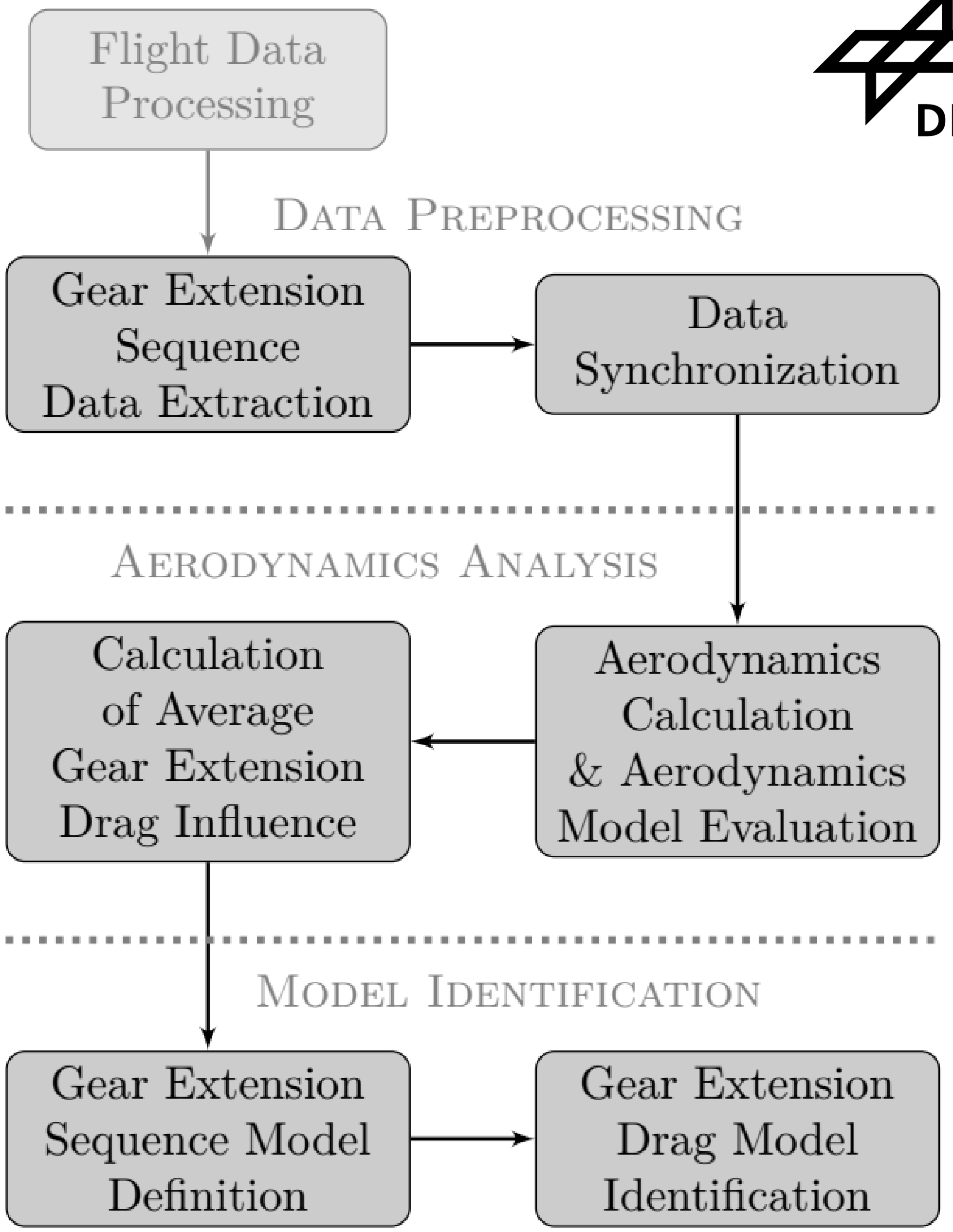

# Gear Geometry and Kinematics

- Available data from the A320ceo “ATRA” from DLR
- Gear identical/similar to the available operational data from A320neo

- Maintenance video(s)

# Gear Geometry and Kinematics

- Areas of interest for the main and nose gears marked in red
  → cf. series of snapshots with timing in the paper
- Gear doors are already partly opened at start of video
  ➔ time reference t = 0 s set to the moment at which the nose landing gear doors reached their fully opened position

# Gear Geometry and Kinematics

| time | nose gear event or state |
|---|---|
| 0.0 s | nose gear doors fully open |
| 1.37 s | nose gear starts moving |
| 1.61 s | nose gear starts resting |
| 1.77 s | nose gear starts moving again |
| 3.47 s | wheel out, covered with doors on side |
| 5.57 s | wheel out in freestream |
| 14.37 s | nose gear down and locked |
| 14.87 s | nose gear doors start closing |
| 16.27 s | nose gear doors closed |

| time | main gear event or state |
|---|---|
| 1.32 s | main gear doors fully open |
| 1.34 s | main gear starts moving |
| 1.47 s | main gear covering hole |
| 1.57 s | wheel exiting hole, legs out |
| 1.61 s | main gear starts resting |
| 1.87 s | main gear starts moving again |
| 2.51 s | first wheel out |
| 3.44 s | second wheel covering hole |
| 5.47 s | second wheel out |
| 14.57 s | main gear down and locked |
| 14.87 s | main gear doors start closing |
| 16.47 s | main gear doors closed |

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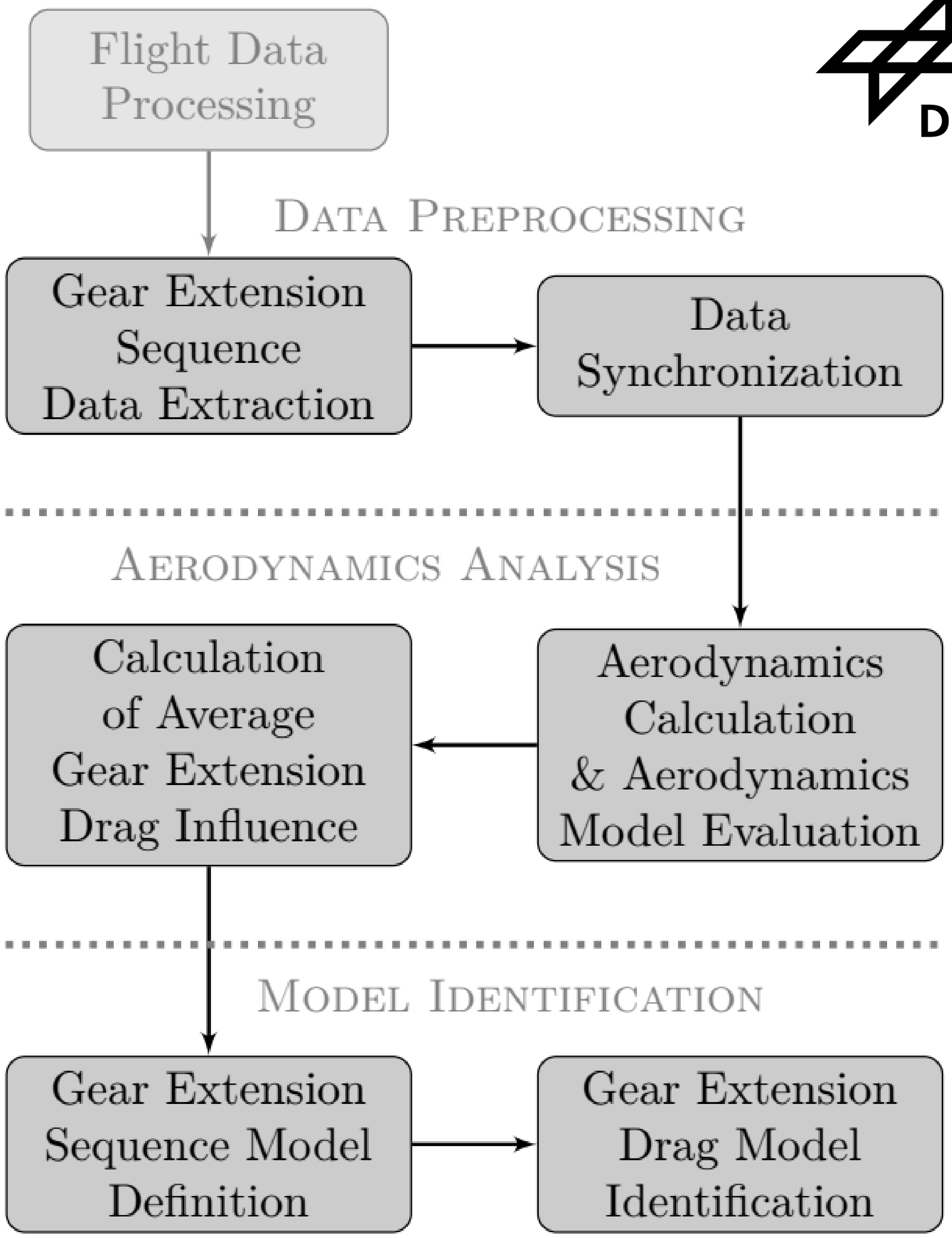
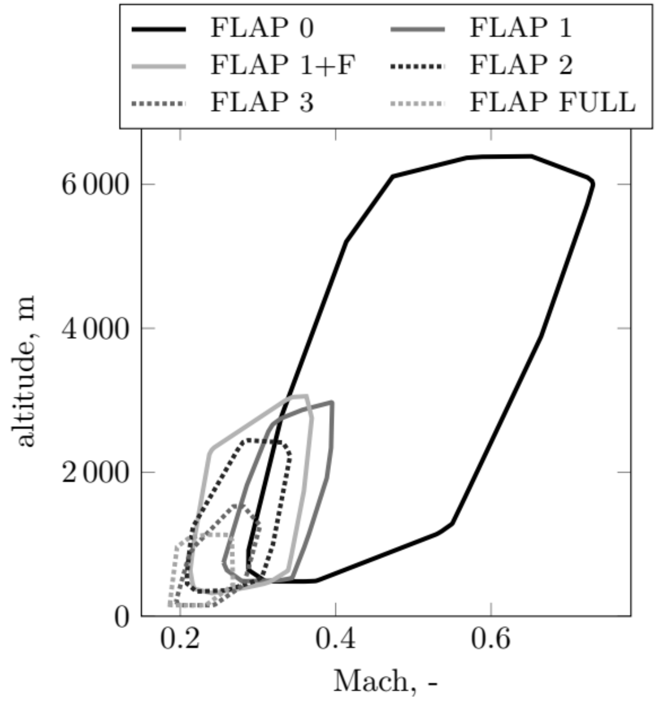


# Data from Extension Maneuvers

| | |
|---|---|
| number of aircraft | 3 |
| number of flights | 844 |

| data envelope | min | max |
|---|---|---|
| barometric altitude | 500 ft | 20 964 ft |
| Mach number | 0.1866 | 0.7311 |
| total weight | 48.57 t | 73.44 t |

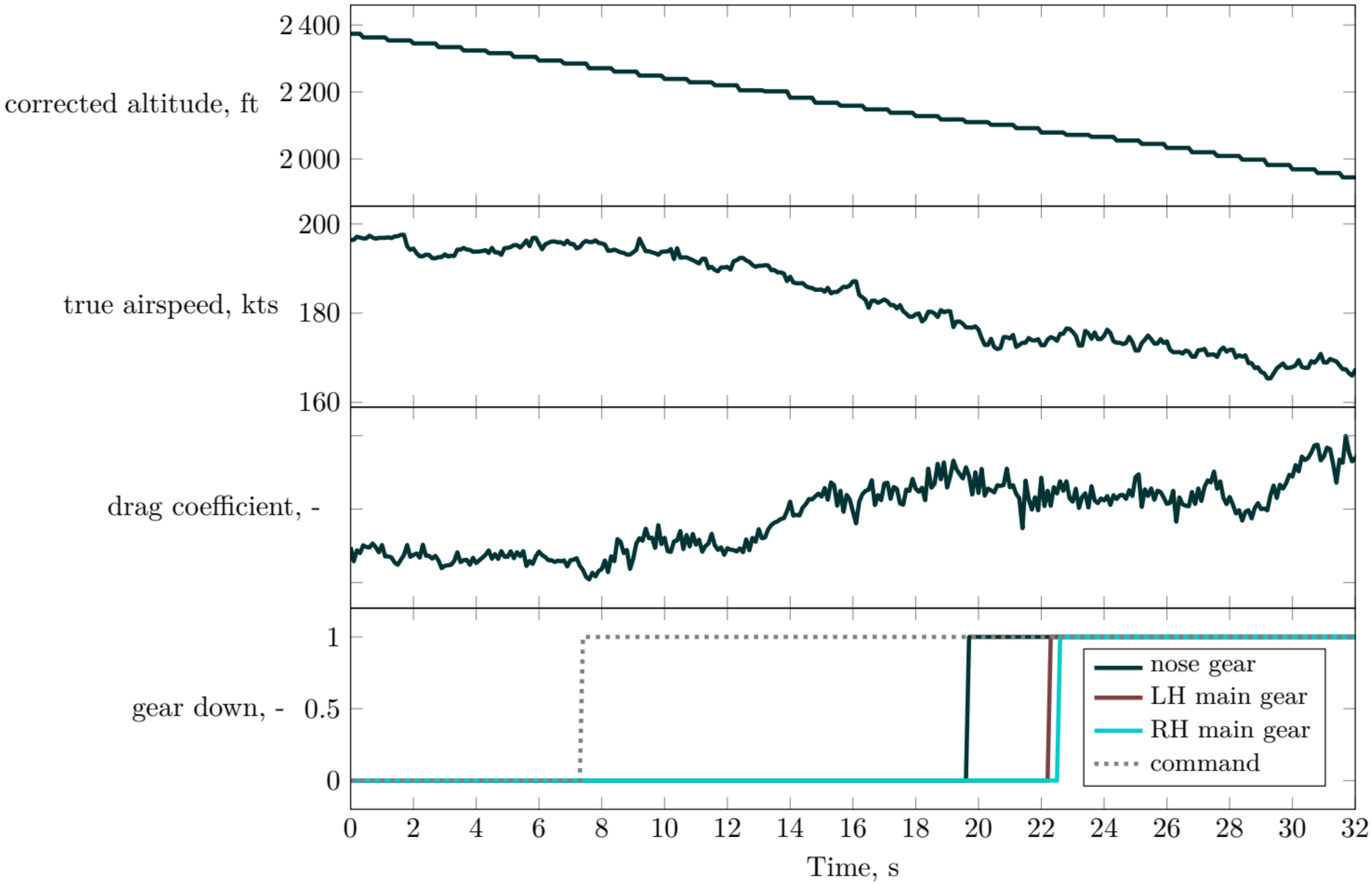



- Data recorded with LNAS EFB App during regular airline operations
- Subset of 844 flights from 3 aircraft considered
- **804 gear extension “maneuver” were deemed “clean and stable enough” and further analyzed**
- As expected, most extensions were performed in FLAP 2 configuration

| high lift configuration | number of time segments |
|---|---|
| FLAP 1 | 13 |
| FLAP 2 | 761 |
| FLAP 3 | 29 |
| FLAP FULL | 1 |

- Data from all configurations considered at once
- No high-lift configuration change during gear extension

# Data from Extension Maneuvers - Example



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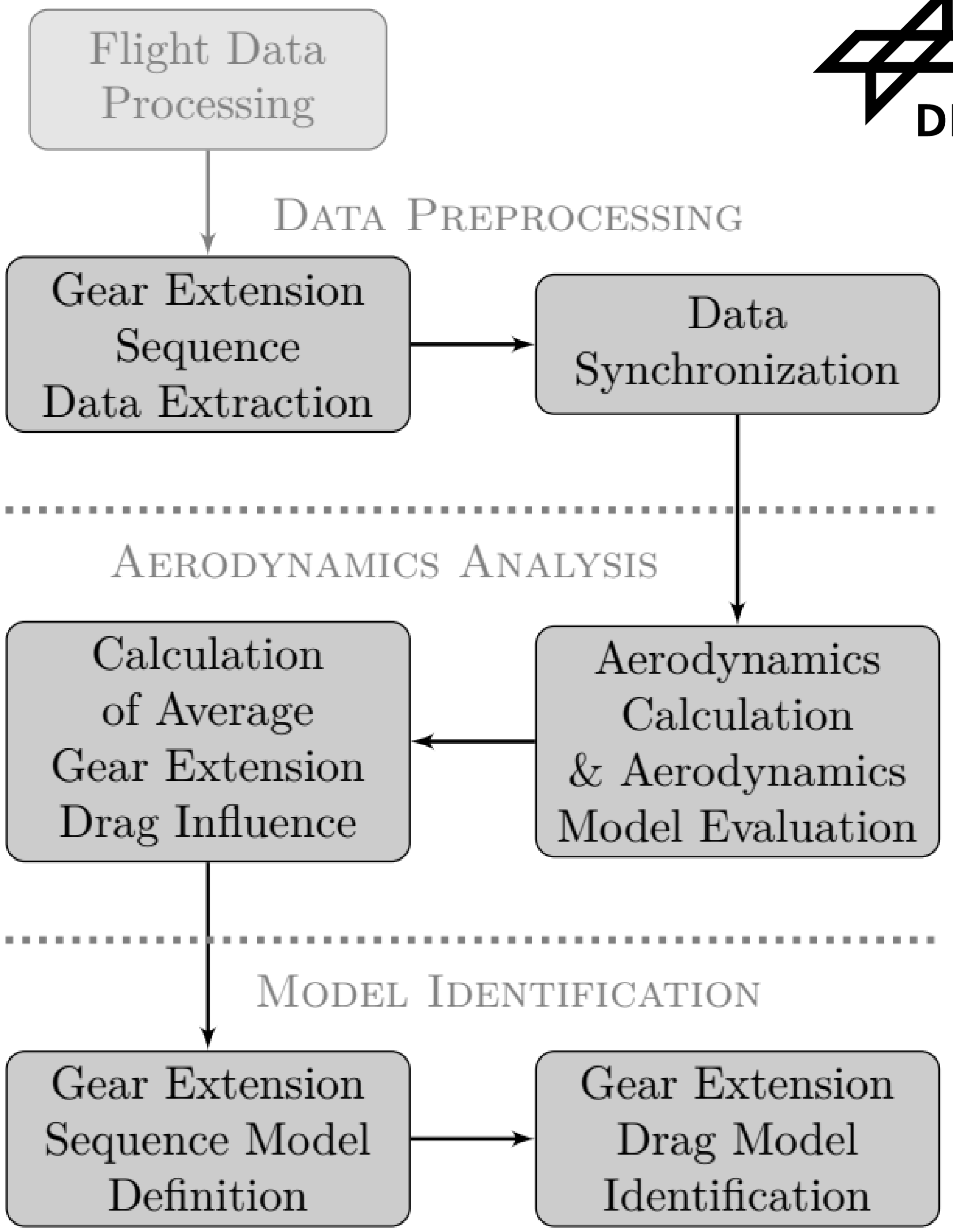

# Extraction of Drag Coefficient from Measurement

- No “drag coefficient” sensor, rather estimate based on accelerometer measurement, mass, air data measurements, and estimated thrust

$$C_{X,\text{meas}} = (m_{\text{AC}} \cdot a_{x,\text{CG}} - T_{\text{x}})/(\bar{q} \cdot S_{\text{Wing}})$$
$$C_{Y,\text{meas}} = (m_{\text{AC}} \cdot a_{y,\text{CG}} - T_{\text{y}})/(\bar{q} \cdot S_{\text{Wing}})$$
$$C_{Z,\text{meas}} = (m_{\text{AC}} \cdot a_{z,\text{CG}} - T_{\text{z}})/(\bar{q} \cdot S_{\text{Wing}})$$

Very good thrust model required

$$C_{D,\text{meas}} = -\, C_{X,\text{meas}}\ \cos(\alpha) - C_{Z,\text{meas}}\ \sin(\alpha)$$
$$C_{L,\text{meas}} = \quad C_{X,\text{meas}}\ \sin(\alpha) - C_{Z,\text{meas}}\ \cos(\alpha)$$

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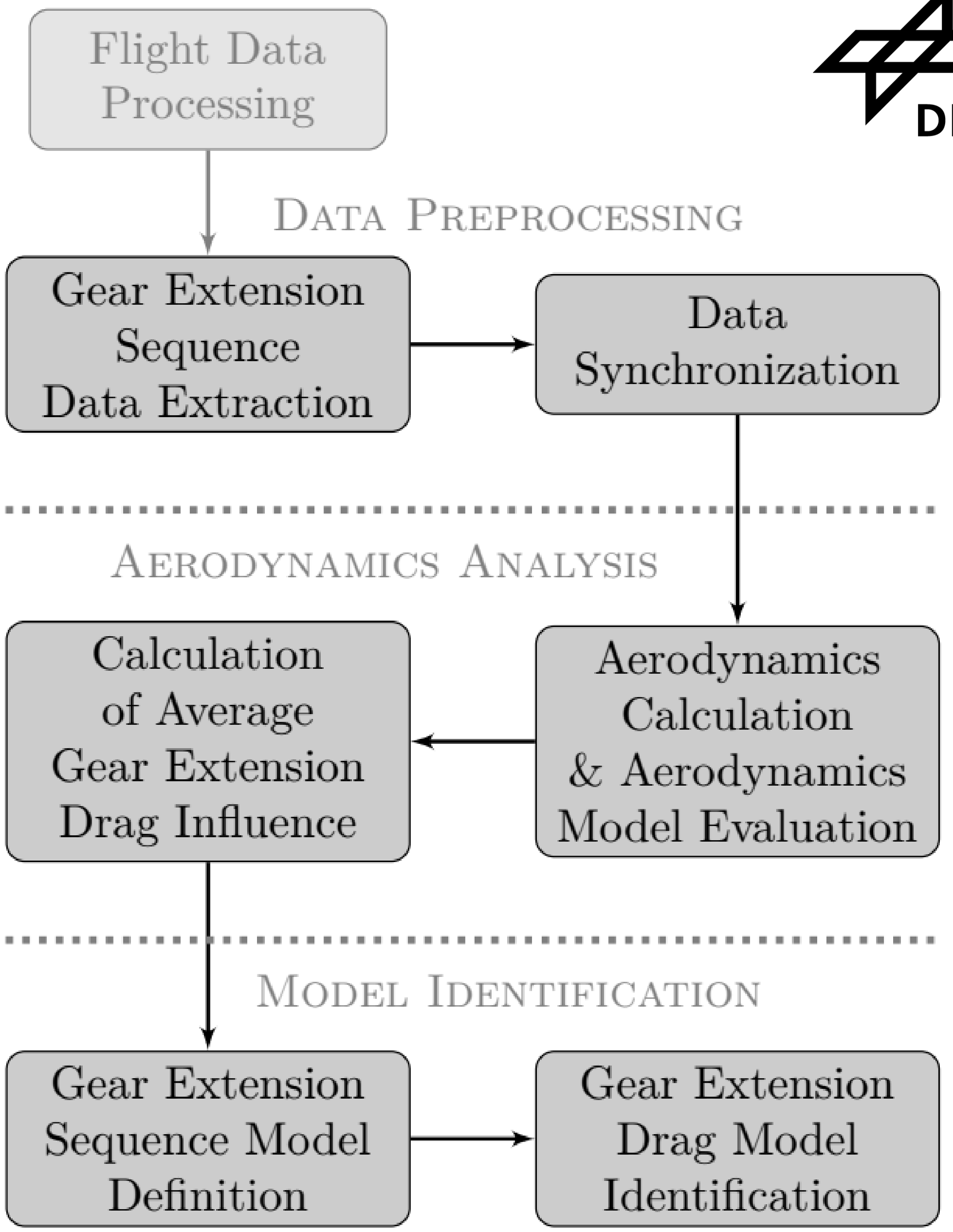
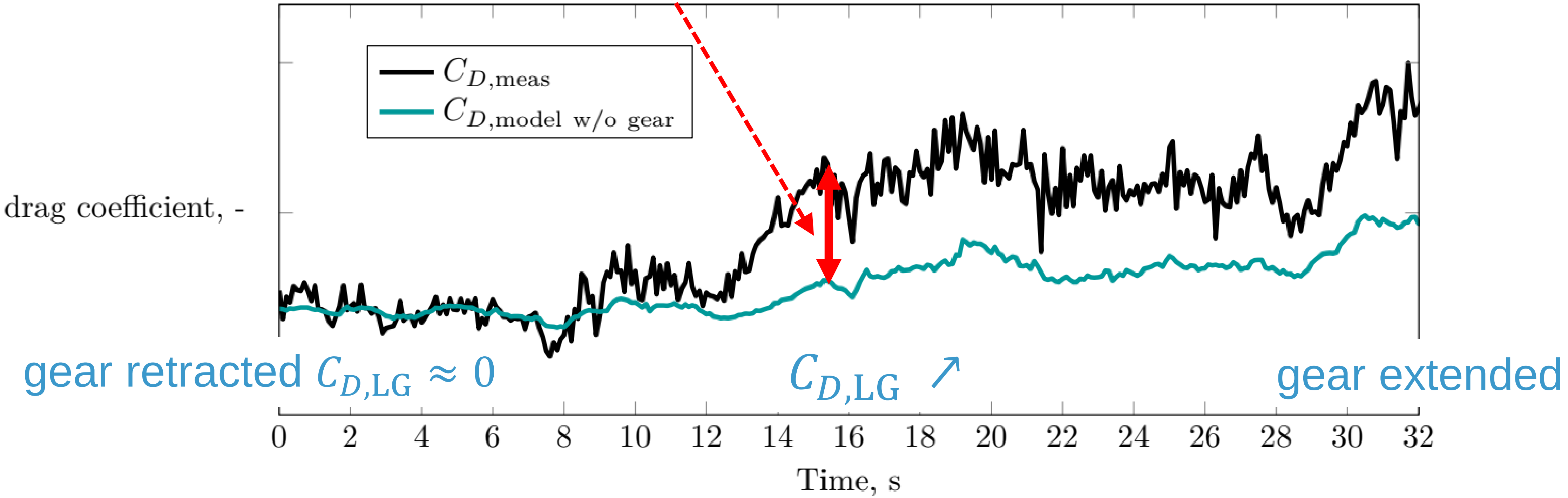


# Removal of Non-Gear Contributions

- Basic principle: $C_{D,\mathrm{LG}} = C_{D,\mathrm{meas}} - C_{D,\mathrm{model\ w/o\ gear}} + e_{C_D}$

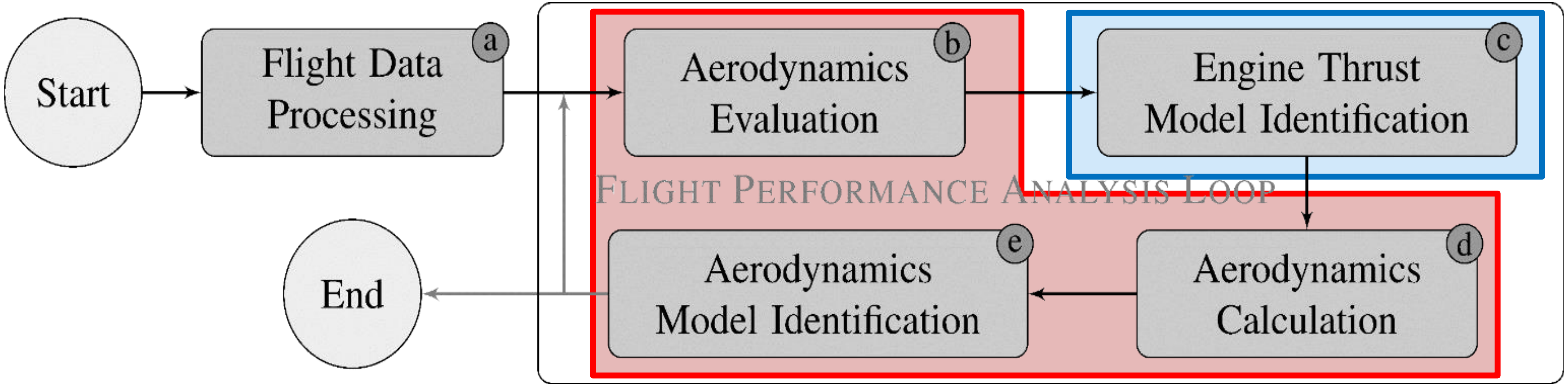



➔ A very good drag model for the gear-up configuration required

➔ The “measured” drag coefficient is rather “noisy/fluctuating”

# Prior Work Used

- Various activities performed and published recently focusing on improving the quality of the flight performance models, e.g.
  - Deiler, C., “Engine thrust model determination and analysis using a large operational flight database,” *CEAS Aeronautical Journal*, Vol. 14, No. 1, 2023, pp. 29–45. doi:10.1007/s13272-022-00625-y.
  - Deiler, C., “Aerodynamic model adjustment for an accurate flight performance representation using a large operational flight data base,” *CEAS Aeronautical Journal*, Vol. 14, No. 2, 2023, pp. 527–538. doi:10.1007/s13272-023-00659-w.



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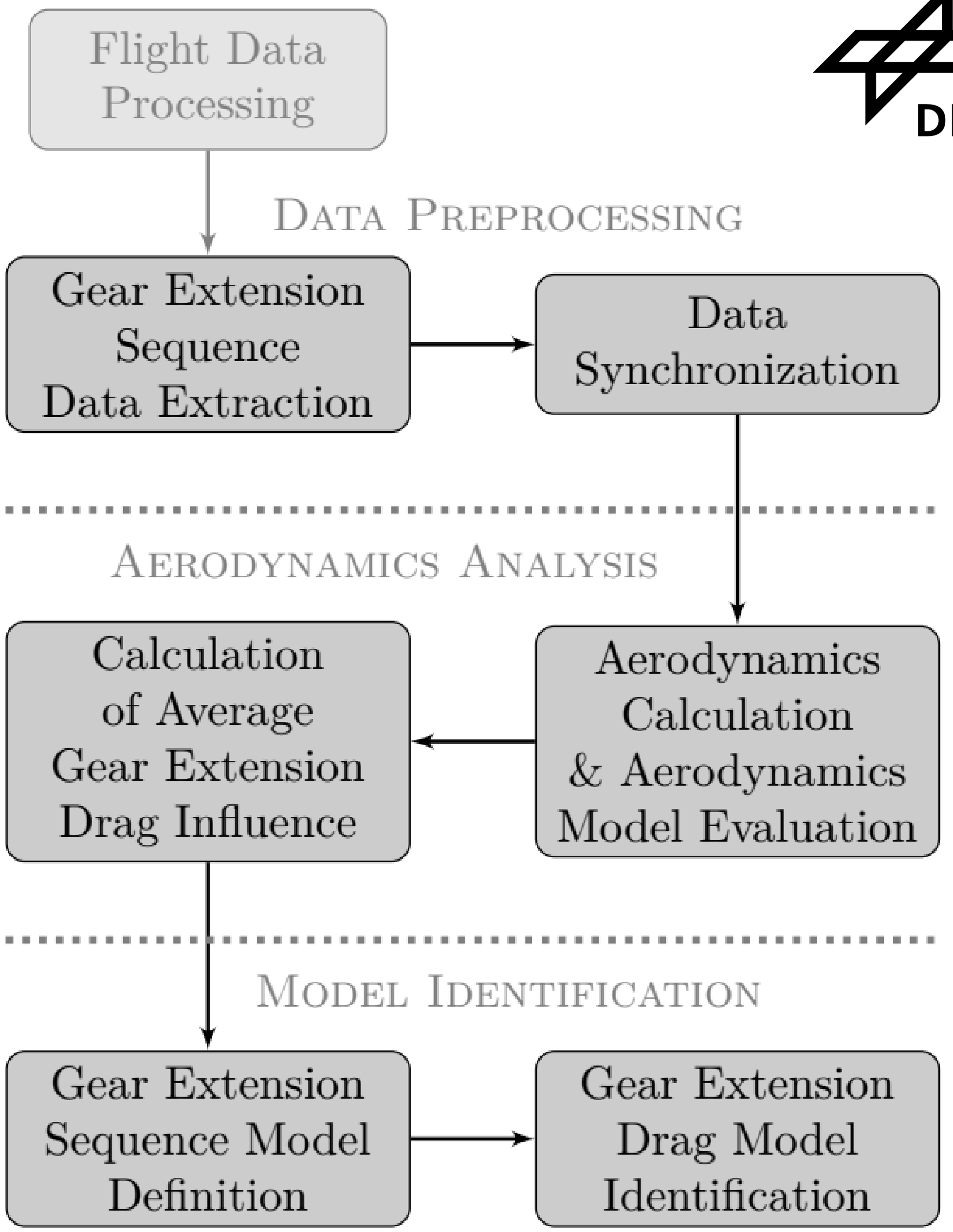
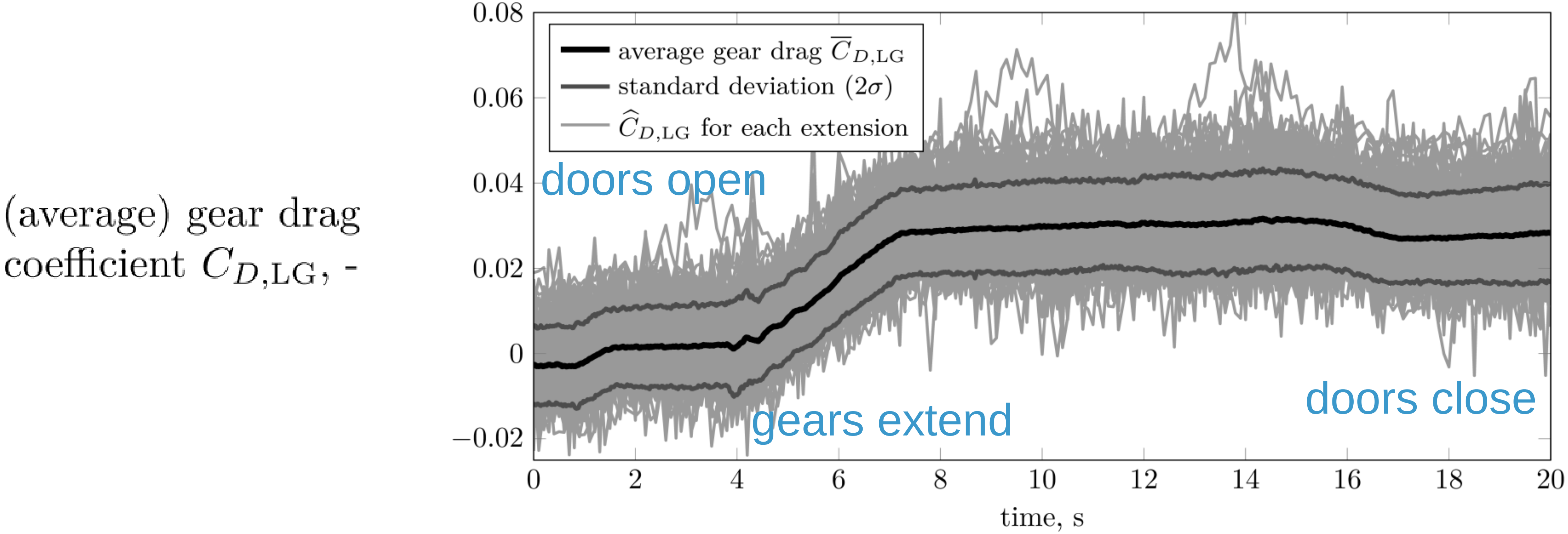


# Removal of Non-Gear Contributions

- Averaging after time-synchronization of the 804 gear extensions (t = 0 at gear lever down flag, but signal only recorded at 1 Hz ⇒ one second uncertainty which needs to be estimated and compensated)




➔ Fluctuations not directly correlated with the progress of the extension seem to cancel each other nicely by averaging on many independent extensions

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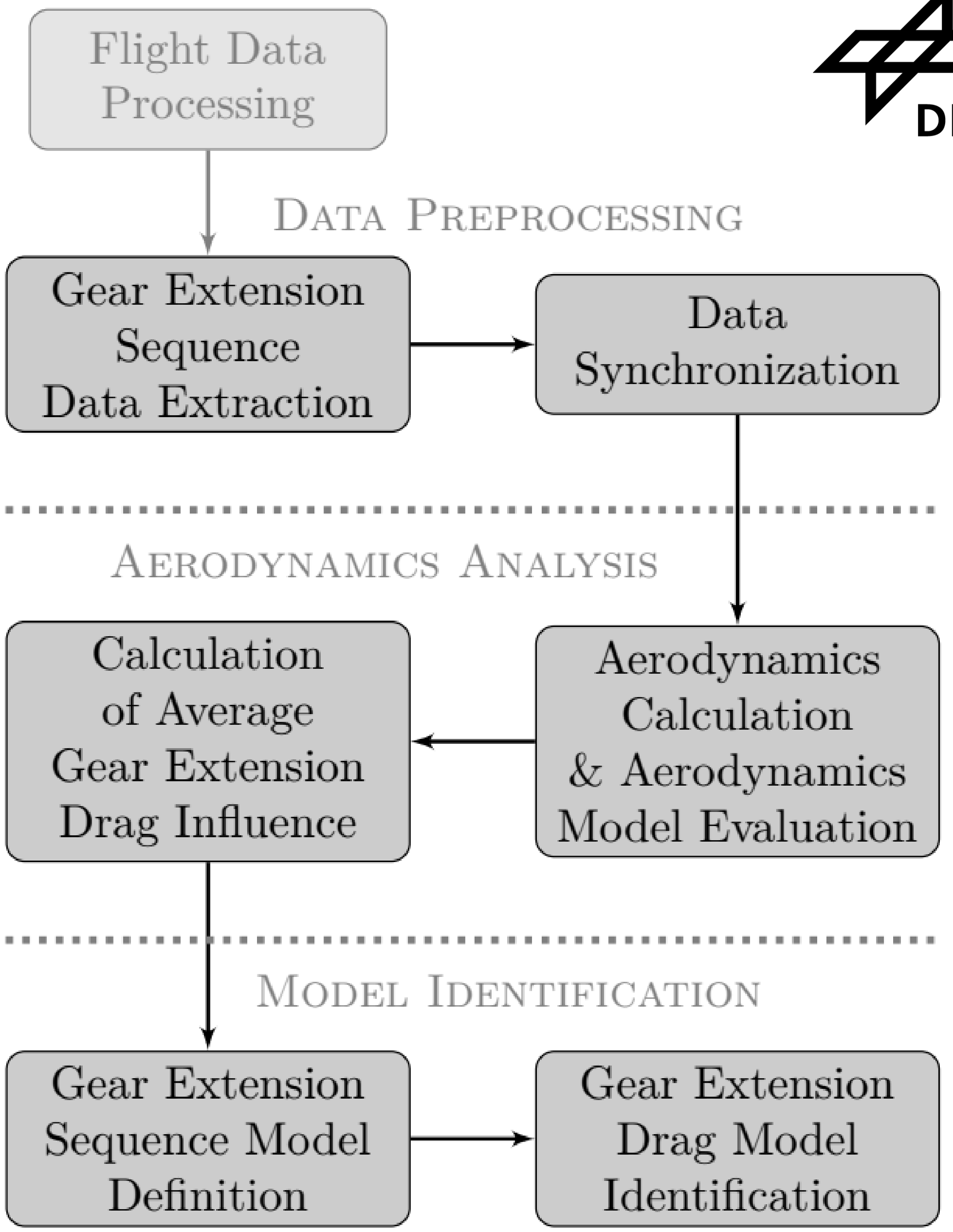


# Simplified Extension Sequence

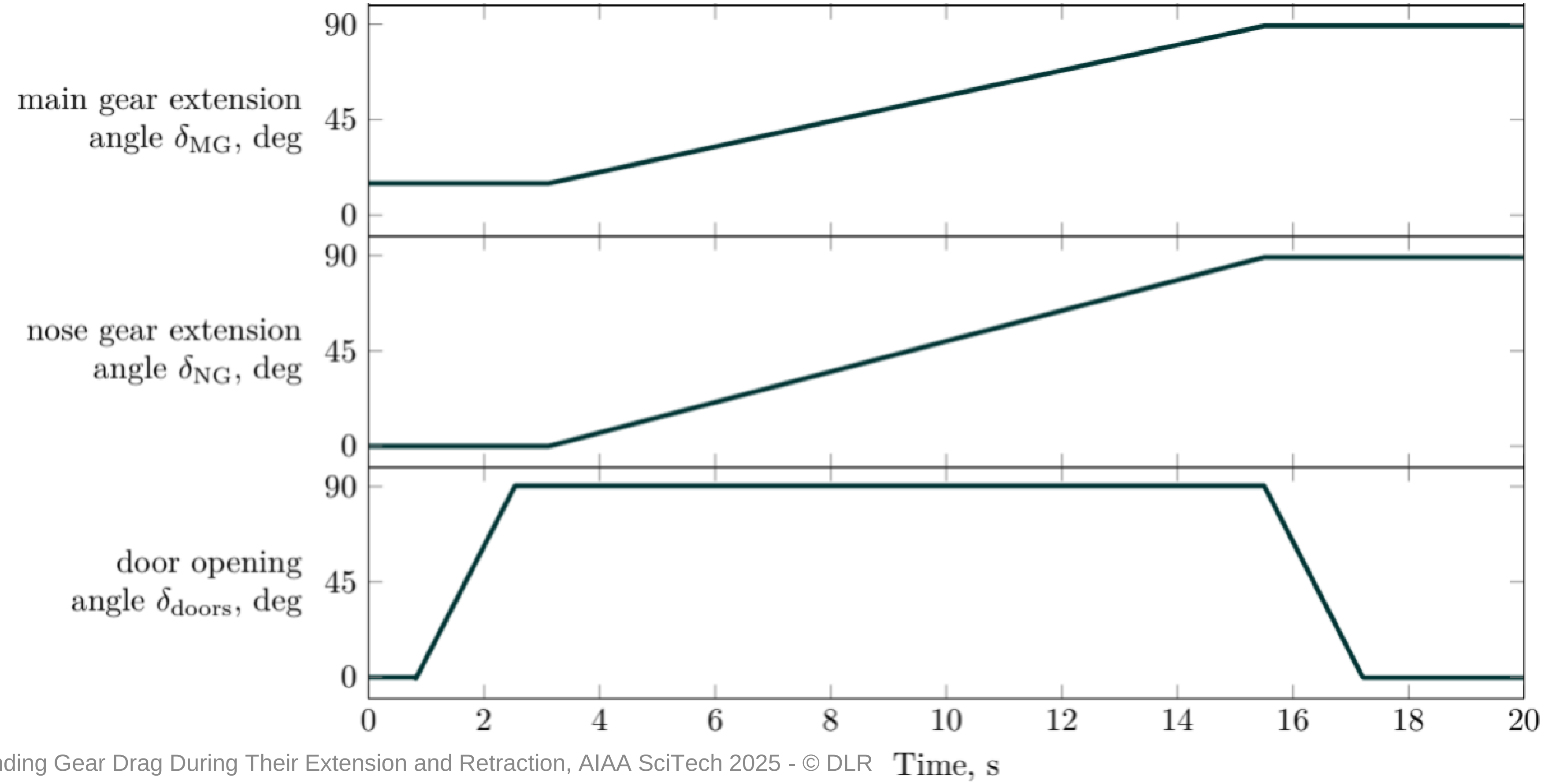
- Simplified set of 3 parameters and motion with constant angular rate

| position | gear doors ($\delta_{doors}$) | nose gear ($\delta_{NG}$) * | main gear ($\delta_{MG}$) |
|---|---|---|---|
| closed/retracted (min) | 0° | 0° | 15° |
| opened/extended (max) | 90° | 90° | 90° |

* 0 deg reference for nose gear is not horizontal: the nose gear leg points slightly upwards when retracted and slightly forwards when extended.

| | nose gear extension | main gear extension |
|---|---|---|
| start | 3.1 s | 3.1 s |
| end | 15.6 s | 15.6 s |
| duration | 12.5 s | 12.5 s |
| rate | 7.20°/s | 6.00°/s |

| | gear doors opening | gear doors closing |
|---|---|---|
| start | 0.8 s | 15.5 s |
| end | 2.5 s | 17.2 s |
| duration | 1.7 s | 1.7 s |
| rate | 52.94°/s | –52.94°/s |



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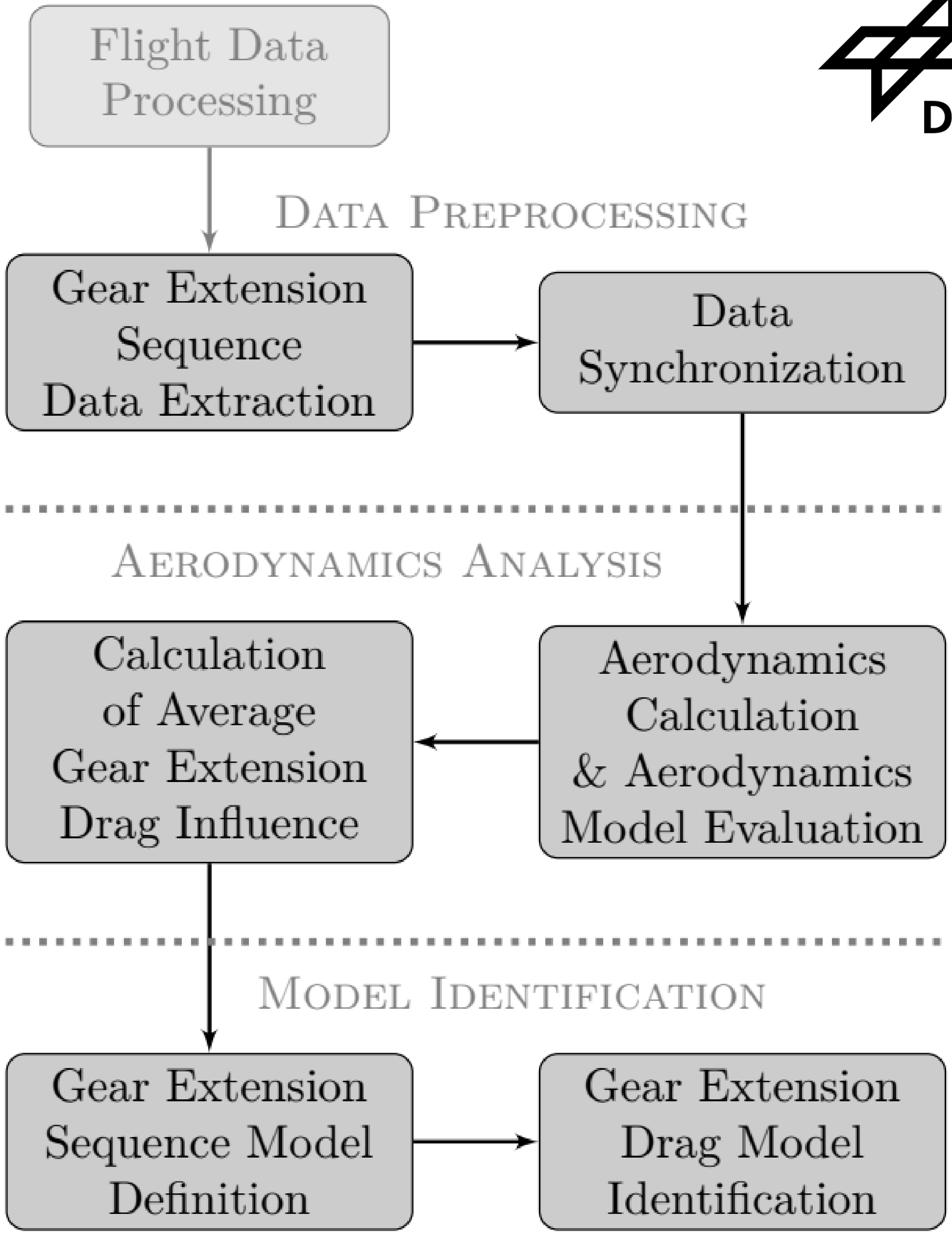


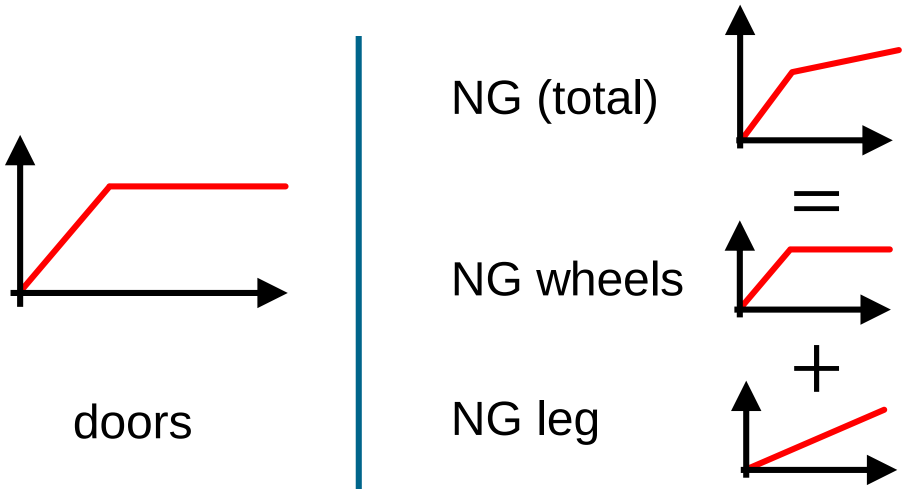
# Gear Drag Model and Parameters

- How to define the mapping between a set of kinematic parameters and corresponding drag?

$$\widetilde{C}_{D,\mathrm{LG}}(\delta_{\mathrm{doors}}, \delta_{\mathrm{NG}}, \delta_{\mathrm{MG}})$$

- Superposition of three separate contributions

$$C_{D,\mathrm{doors}}(\delta_{\mathrm{doors}}) + C_{D,\mathrm{NG}}(\delta_{\mathrm{NG}}) + C_{D,\mathrm{MG}}(\delta_{\mathrm{MG}})$$



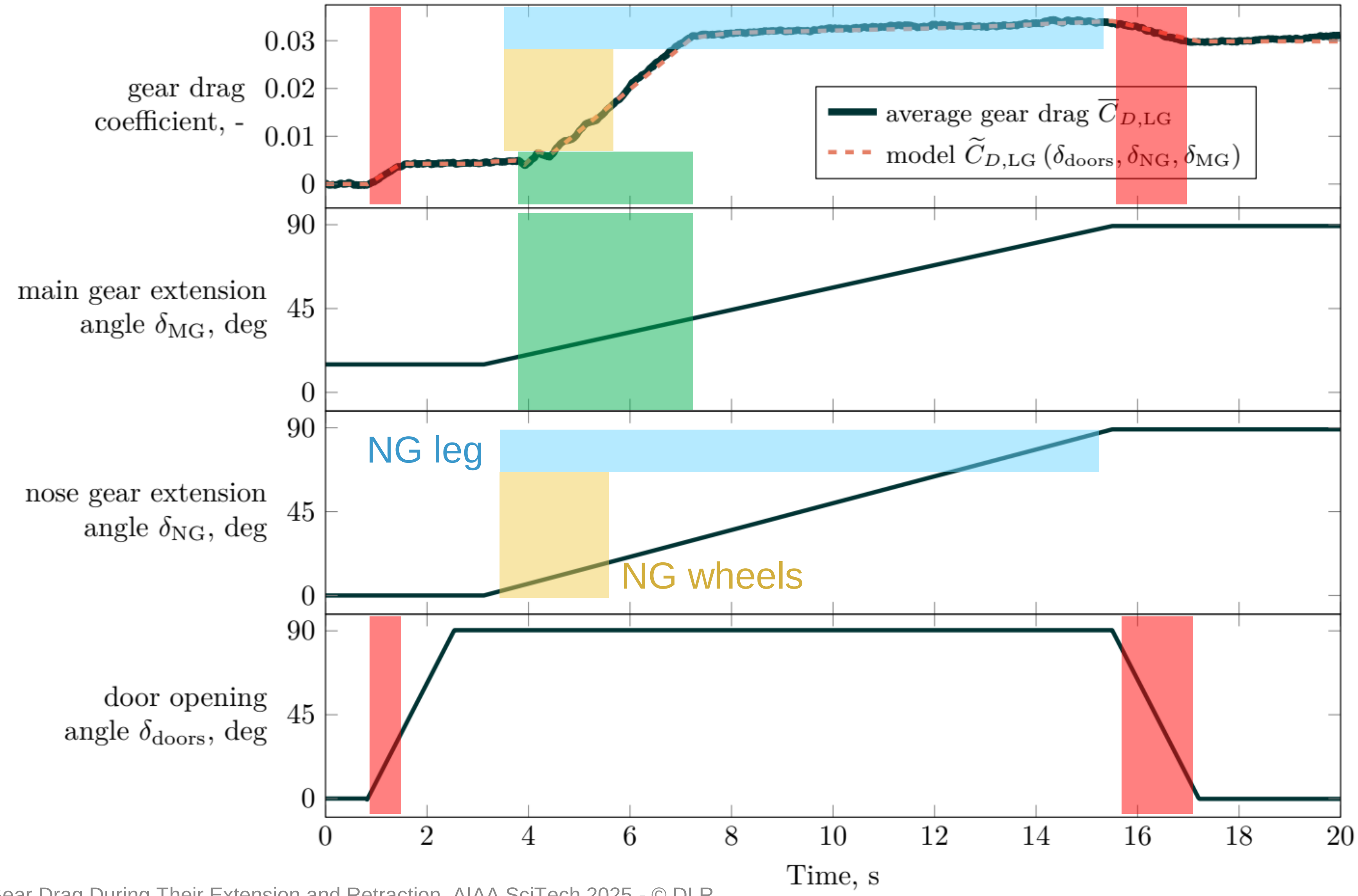

Drag fluctuations (secondary effect): 15.0° – 21.4°

Main drag increase: 22.8° → 39.6°

| extension angle $\delta_{\mathrm{MG}}$ | $f_{\mathrm{MG}}(\delta_{\mathrm{MG}})$ | | drag coefficient $C_{D,\mathrm{MG}}(\delta_{\mathrm{MG}})$ |
|---|---|---|---|
| 15.0° | 0.00 | | 0.0000 |
| 16.0° | 0.01 | | 0.0002 |
| 18.9° | −0.01 | | −0.0002 |
| 19.8° | −0.06 | $\Rightarrow$ | −0.0013 |
| 21.4° | 0.05 | | 0.0011 |
| 22.8° | 0.00 | | 0.0000 |
| 39.6° | 0.93 | | 0.0208 |
| 70.0° | 0.95 | | 0.0213 |
| 90.0° | 1.00 | | 0.0224 |

# Gear Drag Model and Parameters

- Equation error assessment
- Overall very good match with the data
- Split between the different parts remain uncertain
  (no data with only one leg or no wheels, etc. are available)
  ➔ split model is our own educated guess



# Summary and Outlook

- Practical approach to model drag evolution during landing gear extension/retraction leveraging operational data ➔ without needing dedicated flight tests
- New model for the drag increment caused by the landing gears and landing gear doors of the Airbus A320 during transitions (extension / retraction)
- Unusual case with specific challenges (e.g., low SNR, lack of instrumentation of the gear doors and legs, not stabilized flight conditions)
- Key factors for successfully obtain a model:
  - Availability of a very good performance model of the aircraft in each high-lift configuration and with gear-up
  - Averaging on many cases (804) allowed compensating some of these effects
- Future work:
  - Refine the split between gears, possibly leveraging additional data
  - Extend the model to include pitching and yawing moment coefficients

# Impressum

| | |
|---|---|
| Topic: | **Modeling of the A320 Landing Gear Drag During Their Extension and Retraction** |
| Date: | January 8th, 2024 |
| Series: | AIAA SciTech (AFM), Orlando, FL, USA |
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