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Towards Reliability-Oriented Mission Profiles for Electric Aircraft Propulsion Converters

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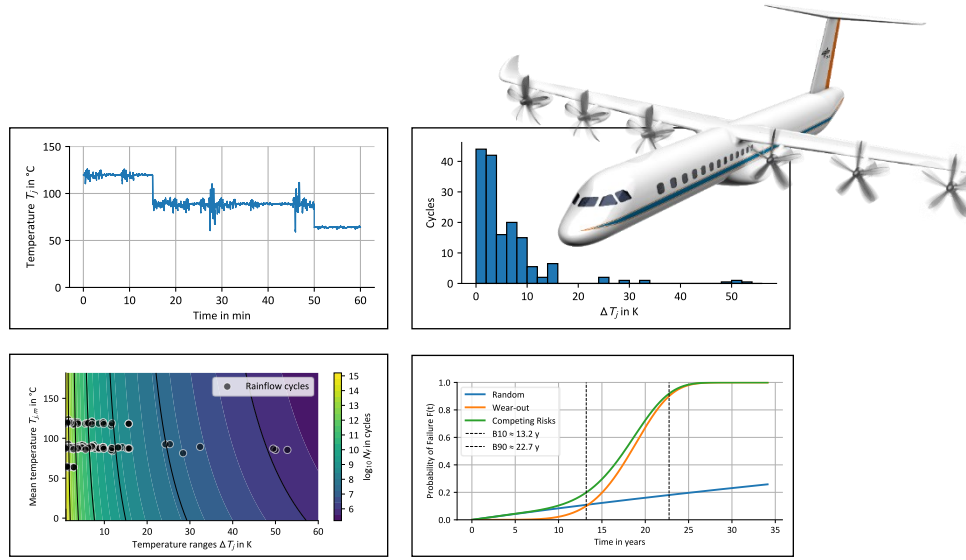
Agenda

1. Introduction
2. Mission-based Reliability Assessment
3. Methodology
4. Synthetic Mission Profiles
5. Conclusion

Reliability-Oriented Mission Profiles for Electric Aircraft

- Power converter reliability depends on **mission-dependent operational stress**
- Reliability assessments require **representative loads** (AQG324, FIDES, PoF)



✓ Standardized baseline cycles (WLTC) for automotive investigations

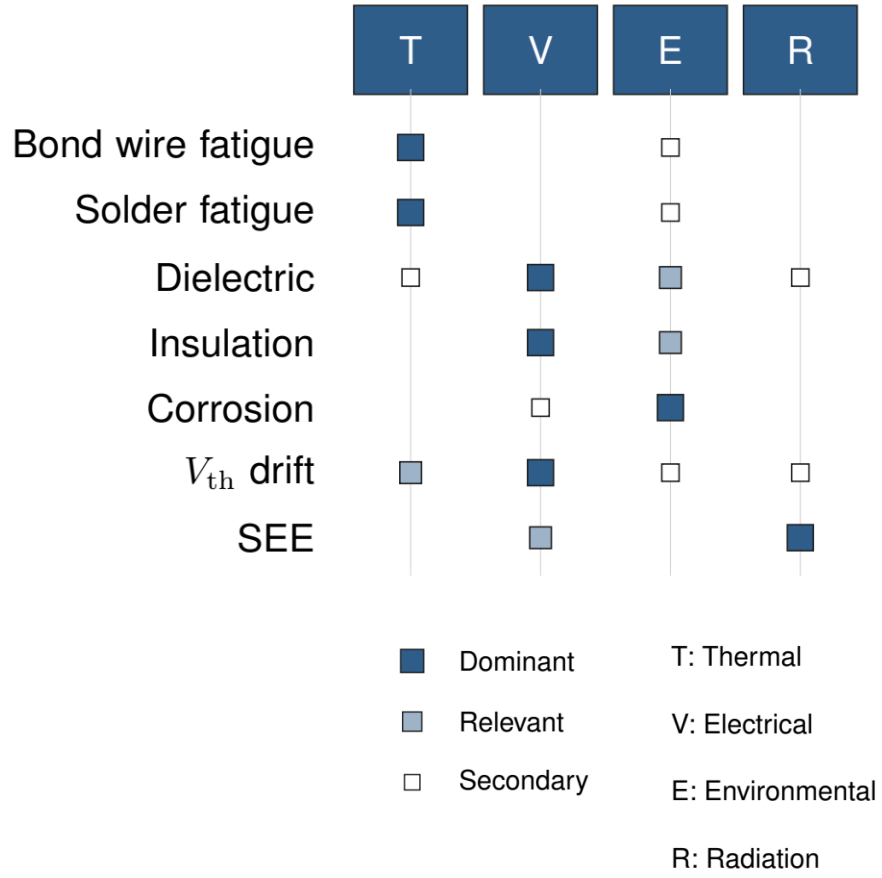
✓ List of Standardization needs for hybrid electric propulsion EUROCAE ER-025

❑ Limited representative mission datasets for electric aircraft

➢ **Derive representative and reproducible aircraft load profiles for reliability assessment**

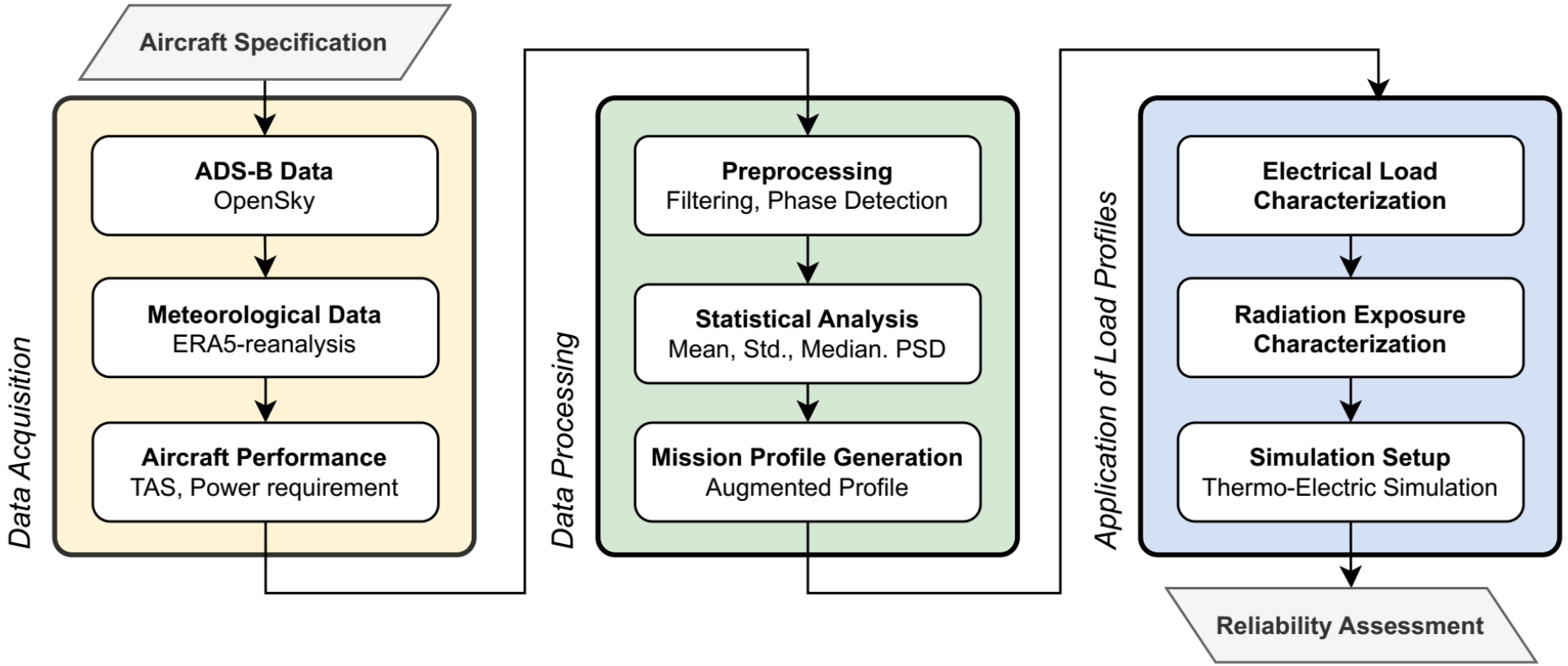
Reliability-Relevant Stressors and Failure Mechanisms

- **Reliability-oriented mission profiles capture relevant operational stressors**
- Based on JEDEC JEP122H [1] and aircraft-specific radiation effects
  - ➢ Power profile and load conditions
  - ➢ Maneuver-induced power fluctuations
  - ➢ Altitude- and location-dependent radiation exposure
  - ➢ Ambient temperature and humidity

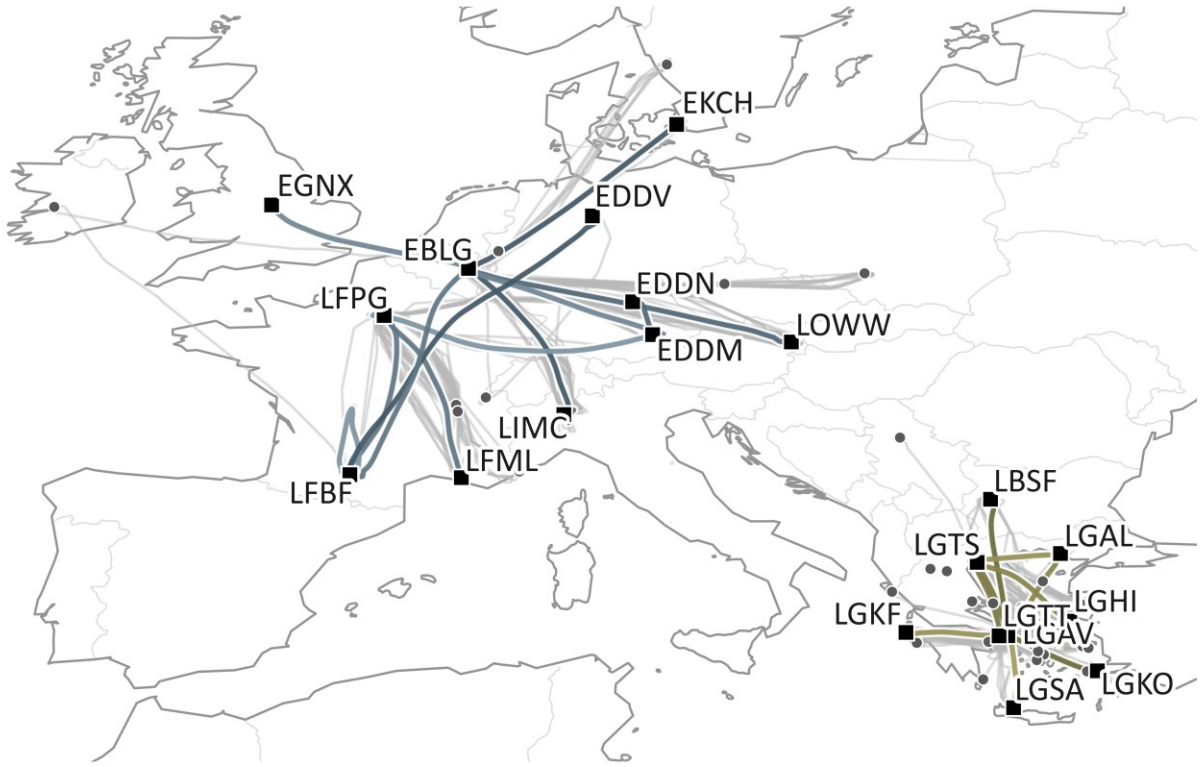


[1] JEDEC Solid State Technology Association, JEP122H - Failure Mechanisms and Models for Semiconductor Devices, 2016

Methodology



Aircraft Tracking



- ICAO 4CAE87 / FedEx
  - ➢ Cargo Lifter in Central Europe
- ICAO 46D2F2 / Sky Express
  - ➢ Island Hopper in Greece
- ADS-B flight data from OpenSky Network [2]
- ERA5 reanalysis weather data [3]

[2] M. Schafer, M. Strohmeier, V. Lenders, I. Martinovic, and M. Wilhelm, "Bringing up opensky: A large-scale ads-b sensor network for research," 2014. DOI: 10.1109/IPSN.2014.6846743

[3] Copernicus Climate Change Service, Climate Data Store, Era5 hourly data on single levels from 1940 to present, 2023. DOI: 10.24381/CDS.ADBB2D47

Performance Modeling

- ADS-B provides trajectory and ground speed data
- Wind correction enables TAS estimation

$$v_{TAS}(t) = \sqrt{\left(v_{GS_{EW}}(t) - w_{EW}\ (t)\right)^2 + \left(v_{GS_{NS}}(t) - w_{NS}\ (t)\right)^2}$$

- Flight mechanics estimate propulsive power demand [4]

$$P_{\text{req}} = \left(qS\left(C_{\text{D0}} + \frac{C_L^2}{\pi Ae}\right) + \frac{W\dot{h}(t)}{v_{\text{TAS}}(t)}\right) v_{\text{TAS}}(t)$$

- TAS and power estimation introduce uncertainty

v	Velocity
TAS	True Airspeed
w	Windspeed
EW	East-West
NS	North-South
q	Dynamic pressure
S	Wing reference area
W	Aircraft weight load
C_L	Lift coefficient
C_D	Drag coefficient
C_{D0}	Zero-lift drag coefficient
A	Wing aspect ratio
e	Oswald efficiency factor
$\delta h/\delta$	Climb rate

[4] B. Jux, S. Foitzik and M. Doppelbauer, "A Standard Mission Profile for Hybrid-Electric Regional Aircraft based on Web Flight Data," 2018, DOI: 10.1109/PEDES.2018.8707564

Flight Data

- ADS-B and ERA5 data merged into a unified mission dataset
- Operational and environmental conditions mapped along the trajectory
- TAS and propulsive power demand derived from flight and weather data

➢ **Baseline for mission-dependent stress and power estimation**

ADS-B Data	Units
time	s
Position (lat, lon)	°
Ground speed	m/s
Heading	°
Vertical speed	m/s
Barometric altitude	m

ERA5 Data	Units
Geopotential height	m^2/s^2
Temperature	K
Relative humidity	%
U/V wind components	m/s

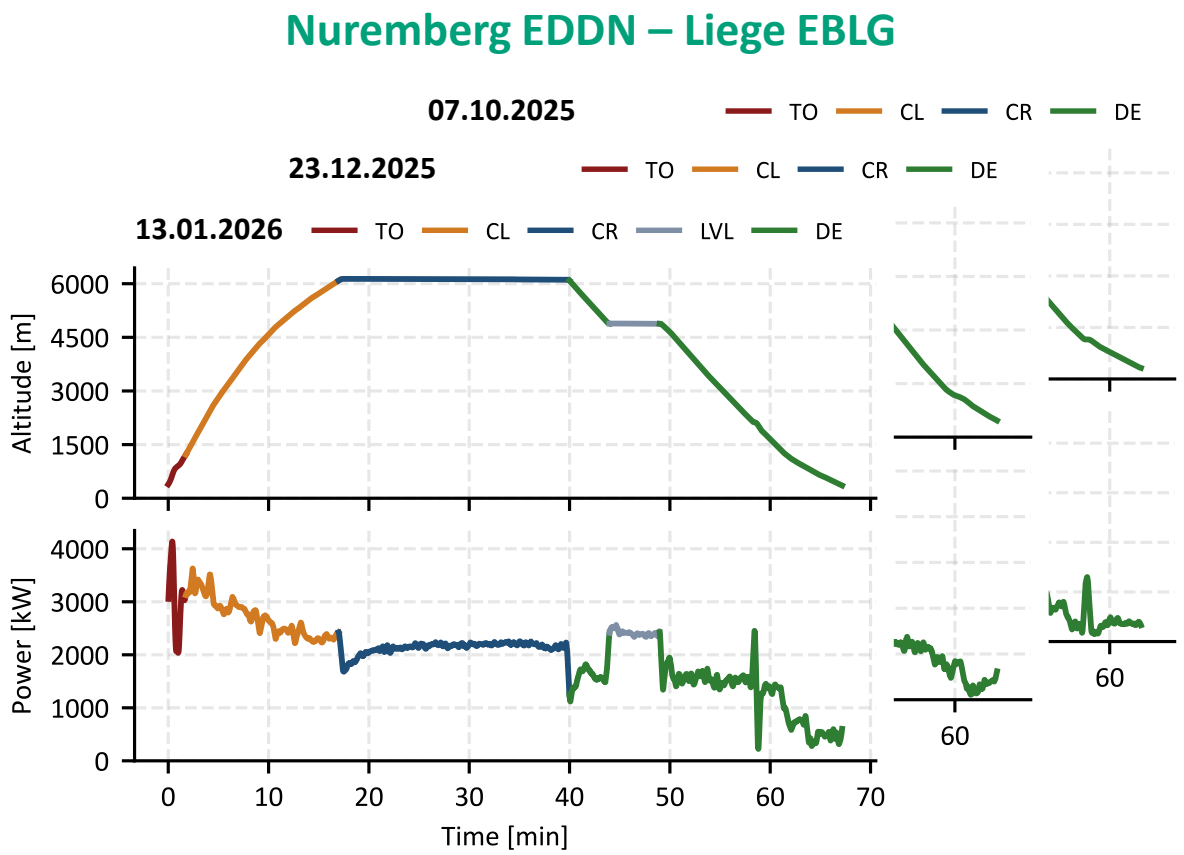
Derived Metrics	Units
True airspeed	m/s
Propulsive power	W

Sample Trajectories

TO	Takeoff	DE	Descent
CL	Climb	LVL	Level
CR	Cruise	DE	Descent

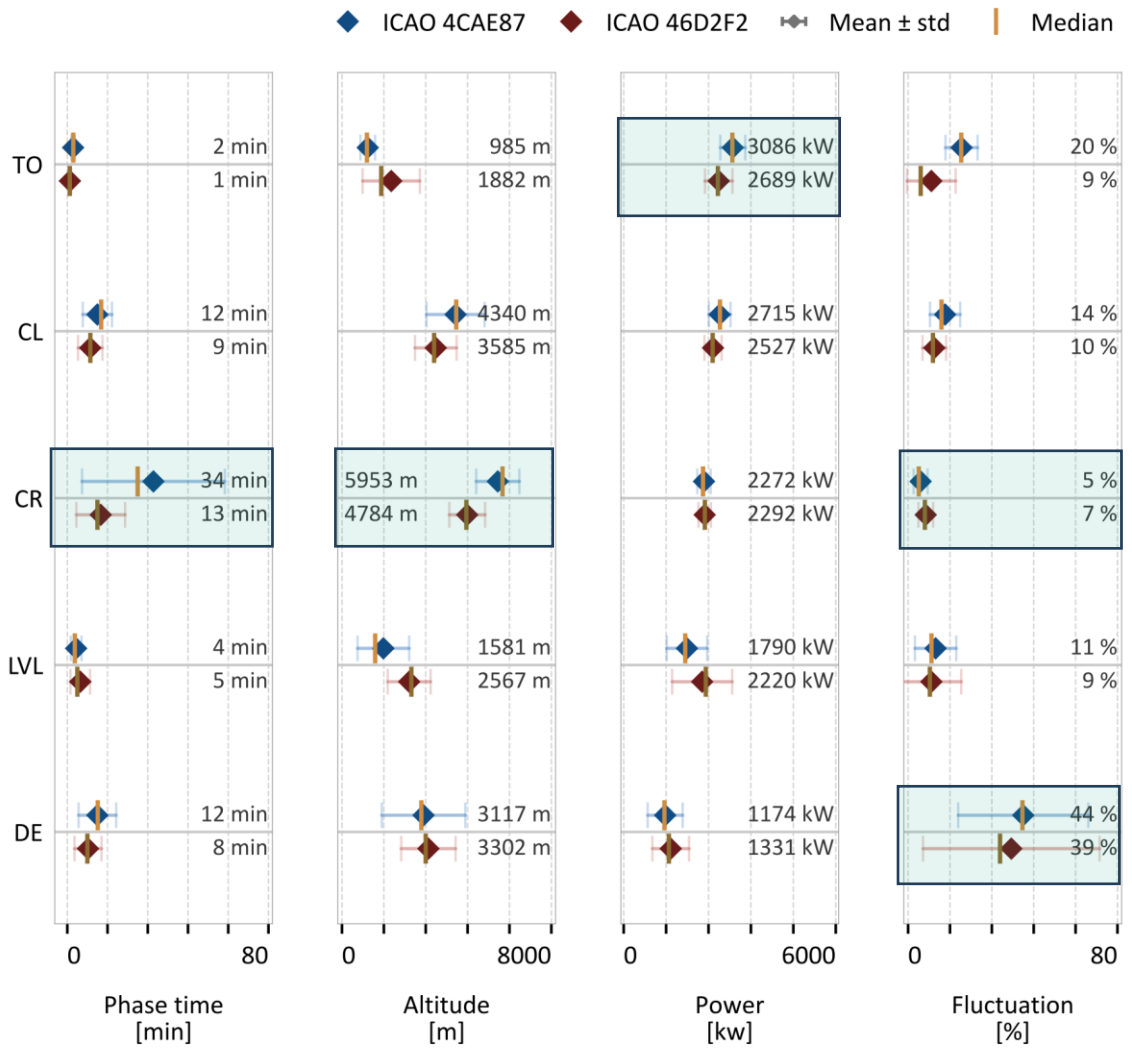
- Flight phase segmentation (TO, CL, CR, DE, LVL)
- Large operational variability
- Varying atmospheric conditions between flights and routes
- Variations in power demand and stress conditions

➢ **Need for representative mission synthesis**



Flight Statistics

	Mean	Std	Median
ICAO 4CAE87			
Flights [-]	334	–	–
Timeframe [days]	667	–	–
Flights per year [yr^{-1}]	347	–	–
Flight time [min]	91	25	92
TO ambient temp. [K]	282	7	282
CR ambient temp. [K]	251	8	252
TO ambient humidity [%]	74	16	76
CR ambient humidity [%]	52	25	49
ICAO 46D2F2			
Flights [-]	4902	–	–
Timeframe [days]	721	–	–
Flights per year [yr^{-1}]	2483	–	–
Flight time [min]	33	16	32
TO ambient temp. [K]	282	9	283
CR ambient temp. [K]	265	9	266
TO ambient humidity [%]	53	21	51
CR ambient humidity [%]	35	25	28

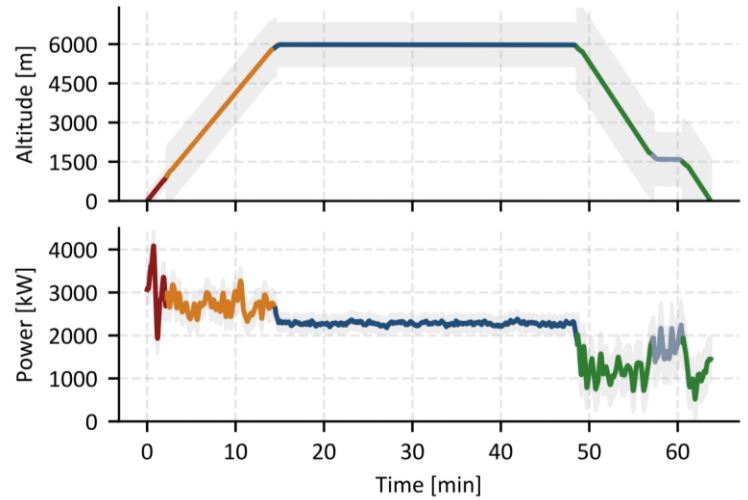


Synthetic Mission Profiles

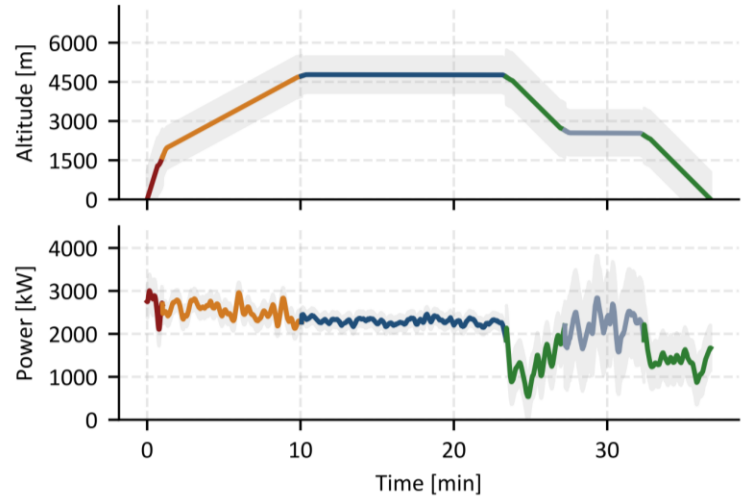
- Statistical aggregation of flight trajectories
- Statistical variability via ±Std.
- Phase-resolved mission profiles
- PSD-based synthesis of power fluctuations

➢ **Representative profiles capture distinct operational strategies**

Cargo Lifter in Central Europe



Island Hopper in Greece



Conclusion

Data Repository
doi: 10.83196/aircraft-mission-profiles

- Developed a methodology for **mission-specific stress estimation** using **data-driven mission profiles**
- Captures flight phase-specific power fluctuations and dynamics
- Supports mission-driven converter reliability evaluation

Future Work

- ❑ Improved preprocessing and transient representation
- ❑ Higher-fidelity drivetrain modeling
- ❑ Validation with real flight-test measurements
- ❑ Extension to additional aircraft and mission scenarios

➢ **Towards Open-Access Mission Profile Repository for Reproducible Reliability Studies**

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Data Repository
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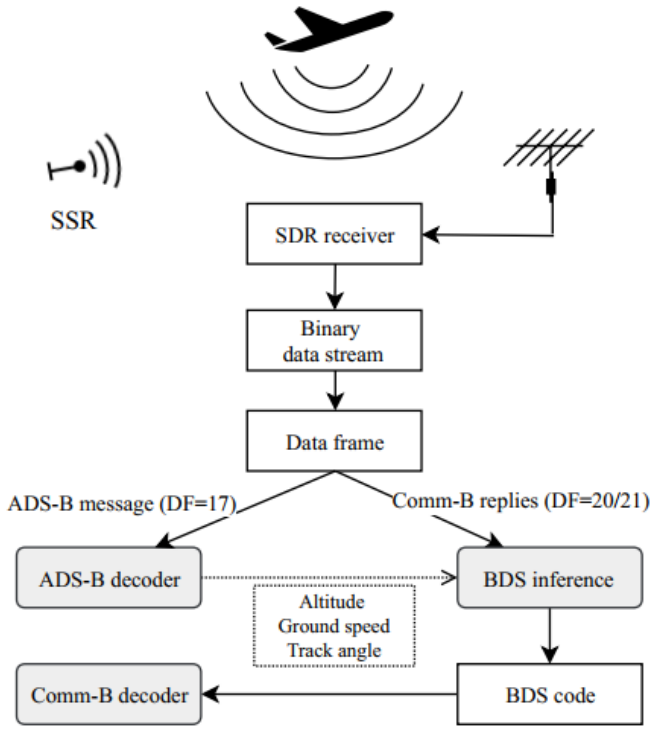
Automatic Dependent Surveillance–Broadcast ADS-B

- Aircraft determine their position via GNSS/GPS onboard navigation
- Flight data are automatically broadcast via radio transponders (1090 MHz)
- Broadcast messages include position, altitude, speed, heading and climb rate
- ADS-B enables real-time air traffic surveillance by ground stations and satellites



The Mode-S inference and decoding pipeline

J. Sun, *Open Aircraft Performance Modeling: Based on an Analysis of Aircraft Surveillance Data*, Ph.D. dissertation, Delft University of Technology, Delft, The Netherlands, 2019

OpenSky Network

The OpenSky Network is a non-profit association providing open access to
real-time and **historical air traffic** surveillance data collected from a global community of **ADS-B** and **Mode-S** receivers.

- Real-time aircraft tracking
- Historical flight trajectories
- Aircraft states & metadata

https://opensky-network.org/

state_vectors_data4	Short description
time	Timestamp of the state vector
icao24	Unique 24-bit aircraft transponder ID
lat, lon	Last known latitude & longitude
velocity	Ground speed (m/s)
heading	Movement direction in degrees
vertrate	Vertical speed (m/s)
callsign	Broadcast flight identifier
onground	True = on ground, False = airborne
alert, spi	ATC alert or special indicator
squawk	4-digit ATC transponder code
baroaltitude	Barometric altitude
geoaltitude	GNSS-based altitude
lastposupdate	Time of last position update
lastcontact	Last signal received time
hour	Hour block reference

ERA5 Reanalysis Data

ERA5 is a comprehensive global climate reanalysis dataset produced by ECMWF.

It **combines historical weather observations** with **modern weather models** to create a consistent record of the atmosphere.

ECMWF - *European Centre for Medium-Range Weather Forecasts*

https://cds.climate.copernicus.eu/datasets/reanalysis-era5-pressure-levels

Table 9: pressure level parameters: instantaneous

(stream=oper/enda/mnth/moda/edmm/edmo, levtype=pl)
(The native grid is the reduced Gaussian grid N320 (N160 for the EDA) or T639 spherical harmonics (T319 for the EDA), as indi

count	name	units	variable name in CDS	shortName
1	Potential vorticity	K m**2 kg**-1 s**-1	potential_vorticity	pv
2	Specific rain water content	kg kg**-1	specific_rain_water_content	crwc
3	Specific snow water content	kg kg**-1	specific_snow_water_content	cswc
4	Geopotential	m**2 s**-2	geopotential	z
5	Temperature	K	temperature	t
6	U component of wind	m s**-1	u_component_of_wind	u
7	V component of wind	m s**-1	v_component_of_wind	v
8	Specific humidity	kg kg**-1	specific_humidity	q
9	Vertical velocity	Pa s**-1	vertical_velocity	w
10	Vorticity (relative)	s**-1	vorticity	vo
11	Divergence	s**-1	divergence	d
12	Relative humidity	%	relative_humidity	r
13	Ozone mass mixing ratio	kg kg**-1	ozone_mass_mixing_ratio	o3
14	Specific cloud liquid water content	kg kg**-1	specific_cloud_liquid_water_content	clwc
15	Specific cloud ice water content	kg kg**-1	specific_cloud_ice_water_content	ciwc
16	Fraction of cloud cover	(0 - 1)	fraction_of_cloud_cover	cc

Spectral contents

- Welch’s method for phase-specific PSD estimation
- Preservation of spectral energy and variance
- Consistent electro-thermal stress representation
- Enables thermal cycle and lifetime analysis
- Outlook: Maneuver and gust spectral modeling