Leonardo Helicopters

Effective Usage Monitoring through Machine Learning Approaches

EASA - Rotorcraft Structures Workshop

Dr. Andrea Baldi – Leonardo Helicopters

Cologne, February 18th 2025

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Electronics

Helicopters

Aircraft

Cyber & Security

Space

Aerostructures

SUMMARY

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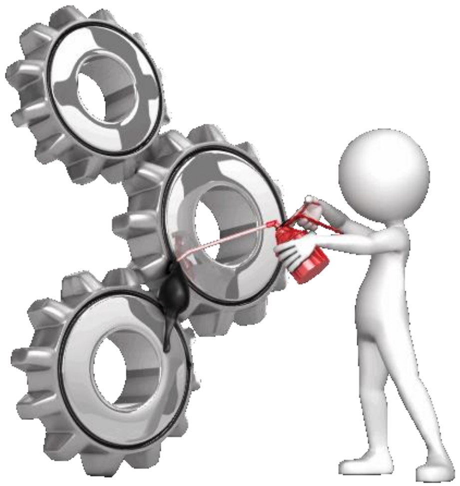
Context and Problem Statement

Helicopter **Different Usages** imply the definition of **Diversified Maintenance Plans** tailored to the actual usage of every specific fleet

Helicopter **Maintenance Plans** are usually defined based on **Design Usage Assumptions** that may differ from the actual operating scenario

Flight Condition Recognition (FCR) for an Effective Structural Usage Monitoring



Effective Maintenance Plans can be defined through a **Periodical Validation** of the **Design Usage Assumptions** with the following benefits:

- **Costs Reduction** and **Flight Safety Assurance**
- **Customised and Flexible Maintenance Operations** instead of **Time-Based Maintenance** (TBM)

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Context and Problem Statement – LHD Proposal

Health and Usage Monitoring System (HUMS)

- Time-histories flight parameters

Data-driven Algorithms

- Trained on Load Survey Flights data

Load Survey Flights

Multi-Strategy

- 2 classification levels
- 2 strategies in the 1st Level

1st Classification Level
(Macro-regimes)
Strategy 1 | Strategy 2

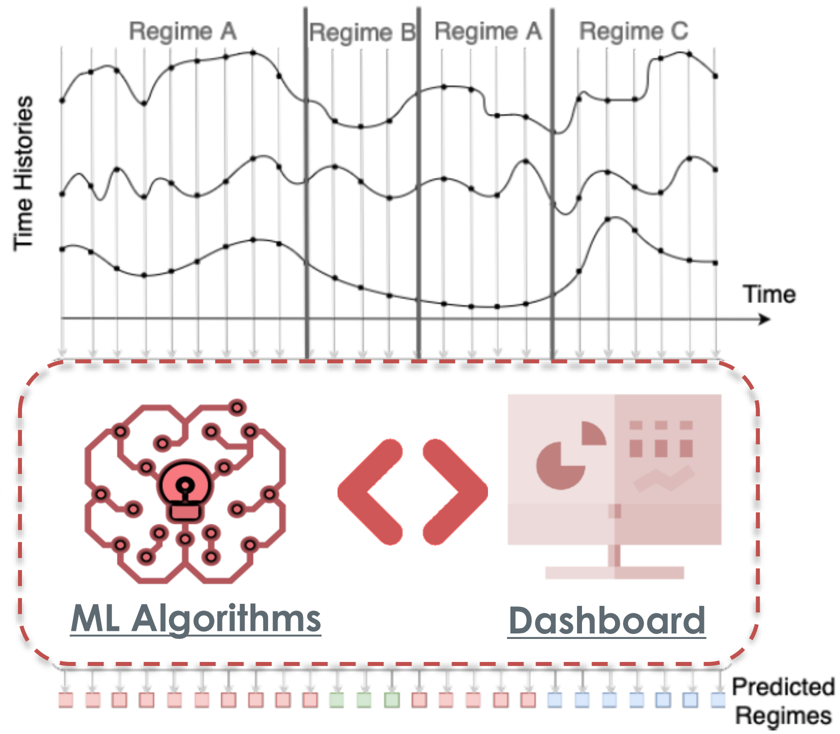
2nd Classification Level
(Spectrum regimes)

Flight Conditions Recognition (FCR)

Effective Structural Usage Monitoring

- Actual Usage Spectrum (AUS) vs Design Usage Spectrum (DUS)

POLITECNICO
MILANO 1863



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SUMMARY

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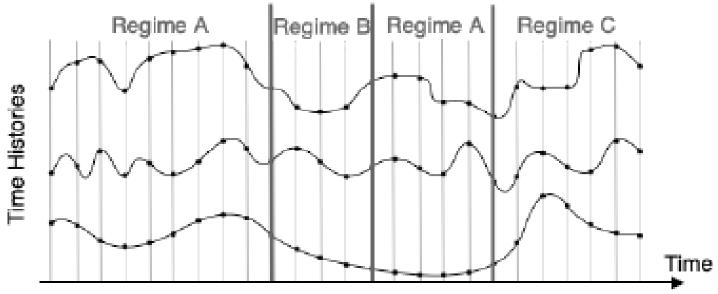
Dataset description

- **Load Survey Flights**: Time-series of **28 Flight Parameters** & **Labelled Regimes**
  - ✓ (2/3) of Dataset for Training (on partitioned manoeuvres) the Supervised ML Algorithm
  - ✓ (1/3) of Dataset for Testing & Verifying (on full flights) the Supervised ML Algorithm

Category	# variables
Pilot Commands	4
Engines	6
Attitudes and Rates	6
Ground Speeds	2
Speeds and Accelerations	6
Environmental Conditions	4



AW189

Number of maneuvers	> 5100
Number of flights	> 230

AW169

Number of maneuvers	> 5200
Number of flights	> 220

AW139

Number of maneuvers	> 8000
Number of flights	≈ 600

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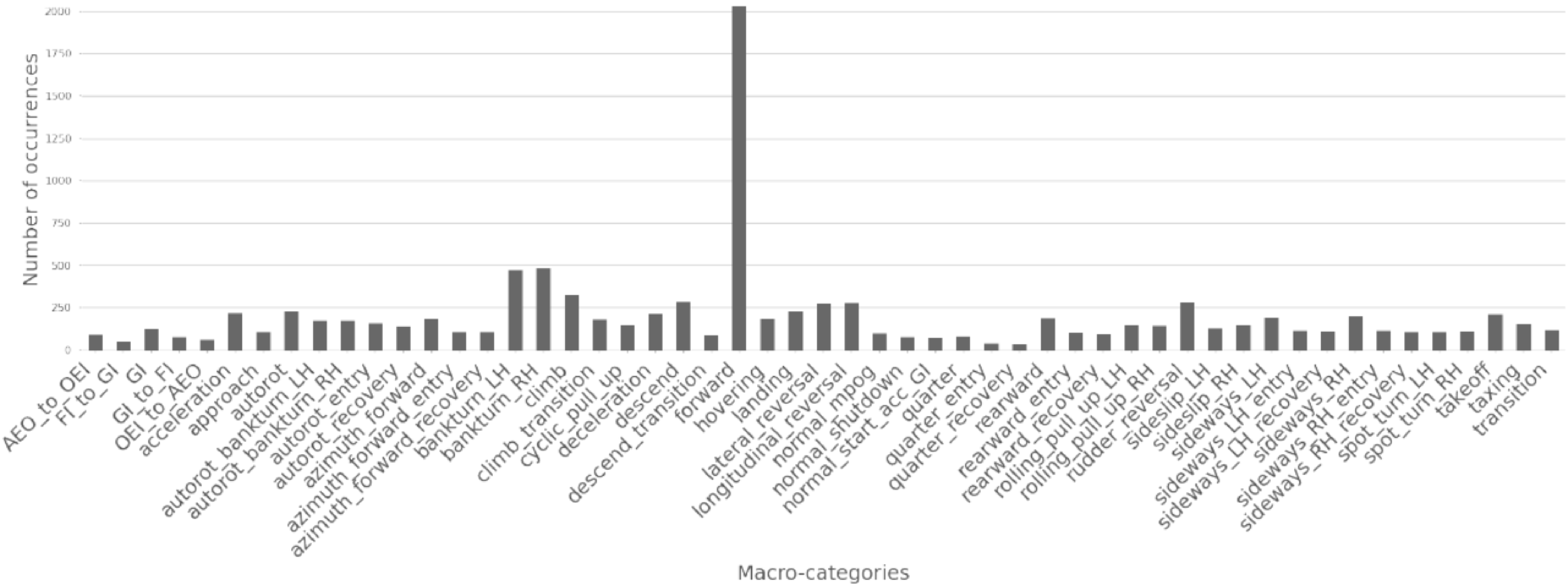
Dataset description – Exploratory Data Analysis and Pre-processing

- **Unbalanced Dataset** ➤ Over 300 standard flight regimes aggregated into **53 Macro-categories**



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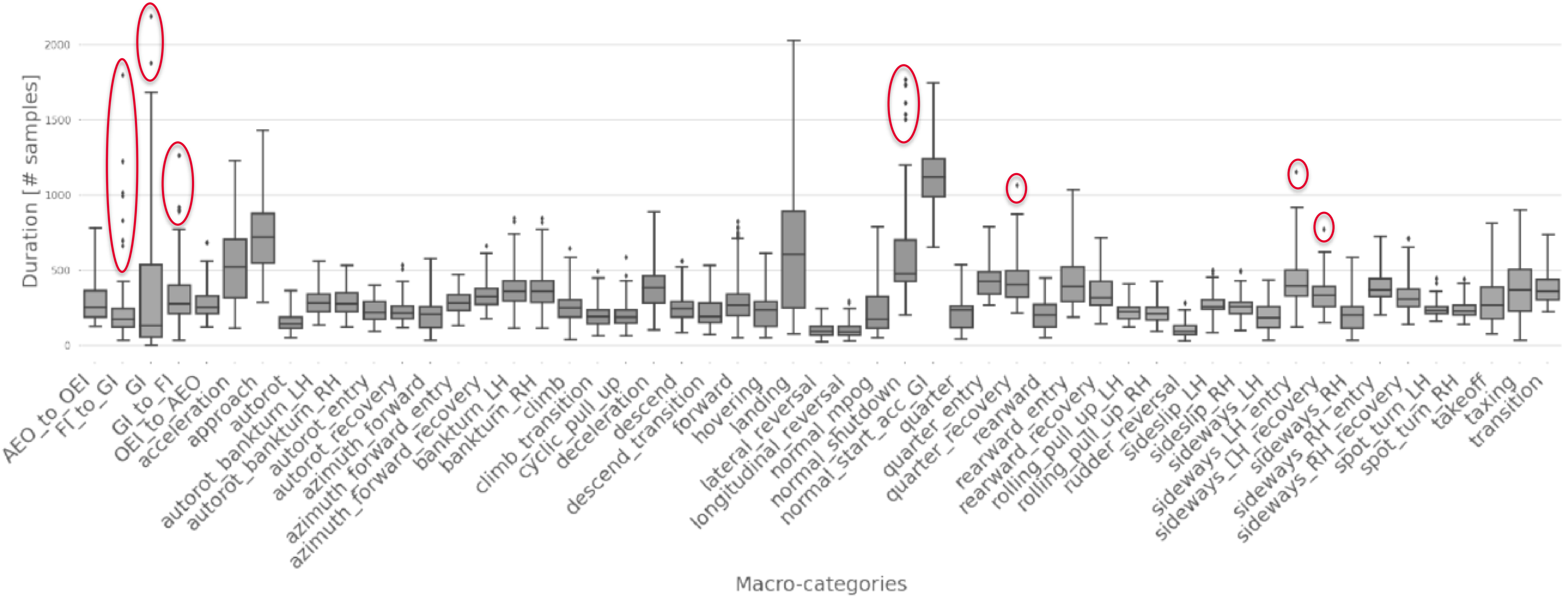
Dataset description – Exploratory Data Analysis and Pre-processing

- Outliers removed from Training/Testing Dataset
- **Non-uniform duration** distribution of the **53 Macro-categories** › **Sliding Windows Approach**



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SUMMARY

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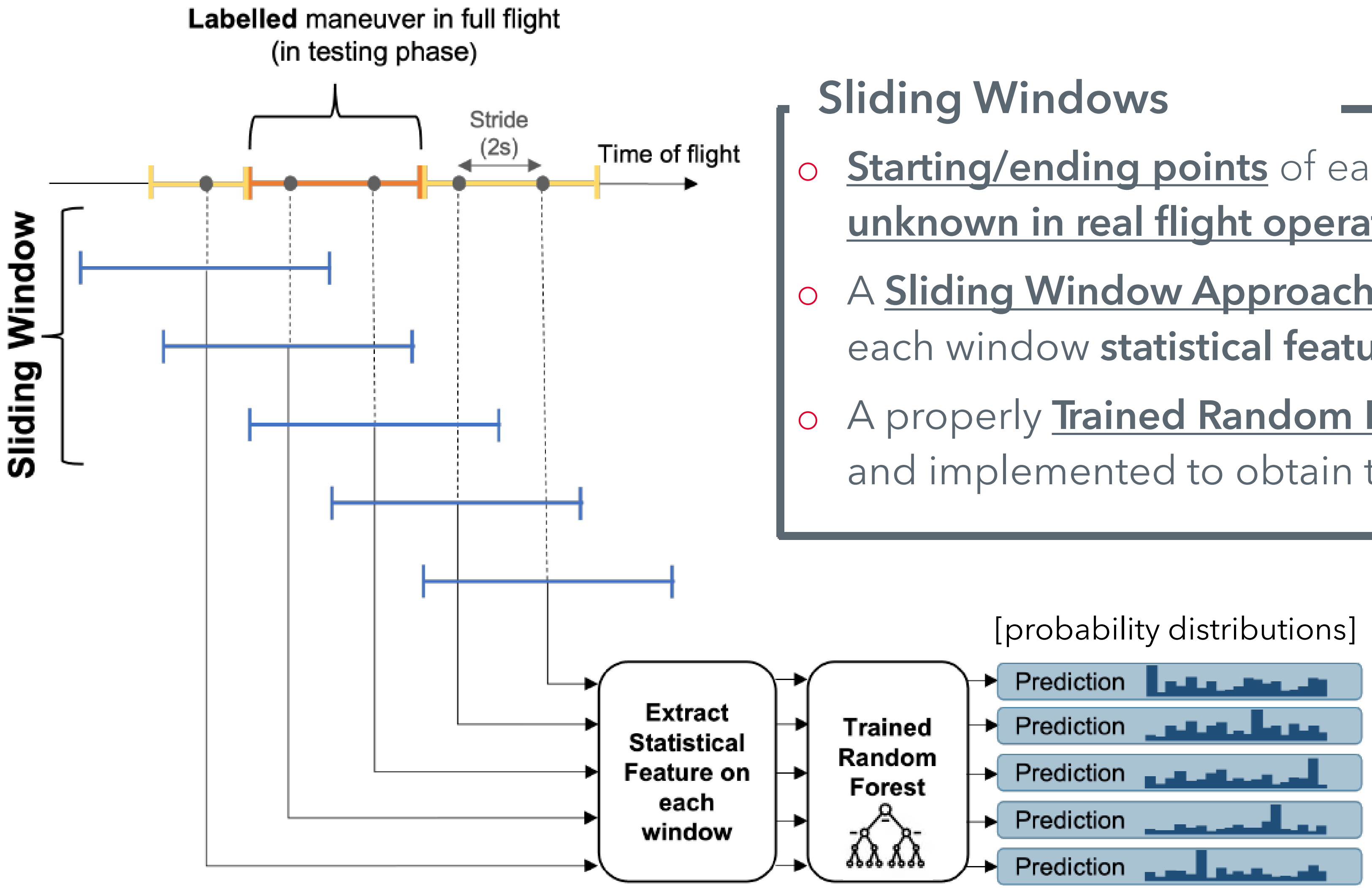
FCR through ML Algorithms – Design phase/Sliding Windows Approach

➢ Single Sliding Window



Sliding Windows

- Starting/ending points of each flight regime are a priori unknown in real flight operations
- A Sliding Window Approach has been applied to extract from each window **statistical features (MEAN, STD, MIN, MAX)**
- A properly Trained Random Forest Model has been designed and implemented to obtain the prediction for each time-step

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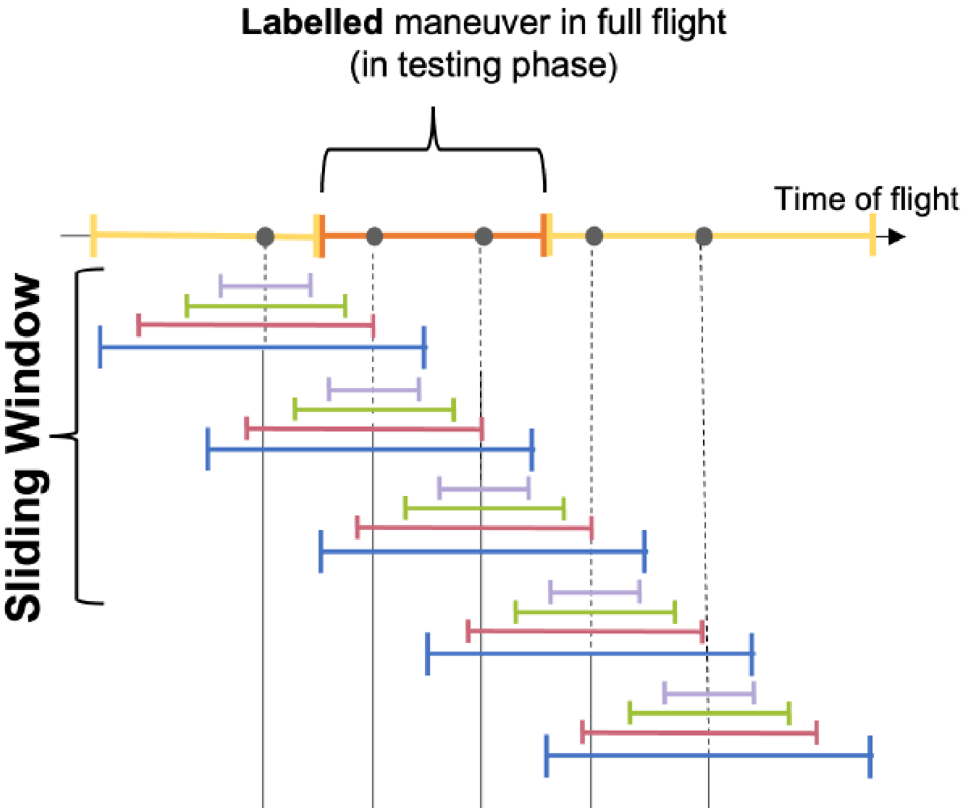
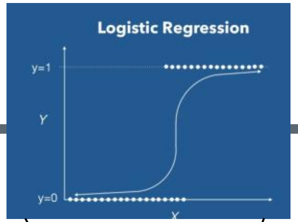
FCR through ML Algorithms – Design phase/Sliding Windows Approach

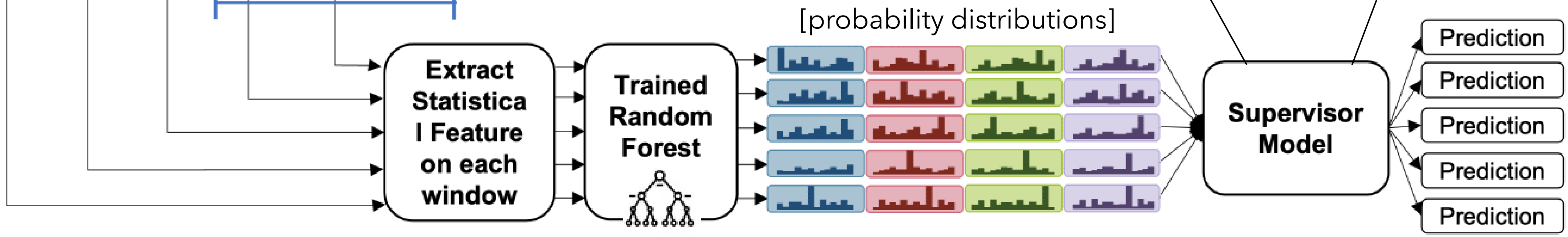
➢ Multiple Sliding Windows & Supervisor Model



Windows Sizes

- To address the problem of **manoeuvres with different duration**, 4 windows sizes are defined: **8s, 16s, 32s and 64s**
- The predictions obtained in these 4 different scenarios are then summarized in a **final prediction by means of a Supervisor Model** (i.e. a simple Logistic Regression)





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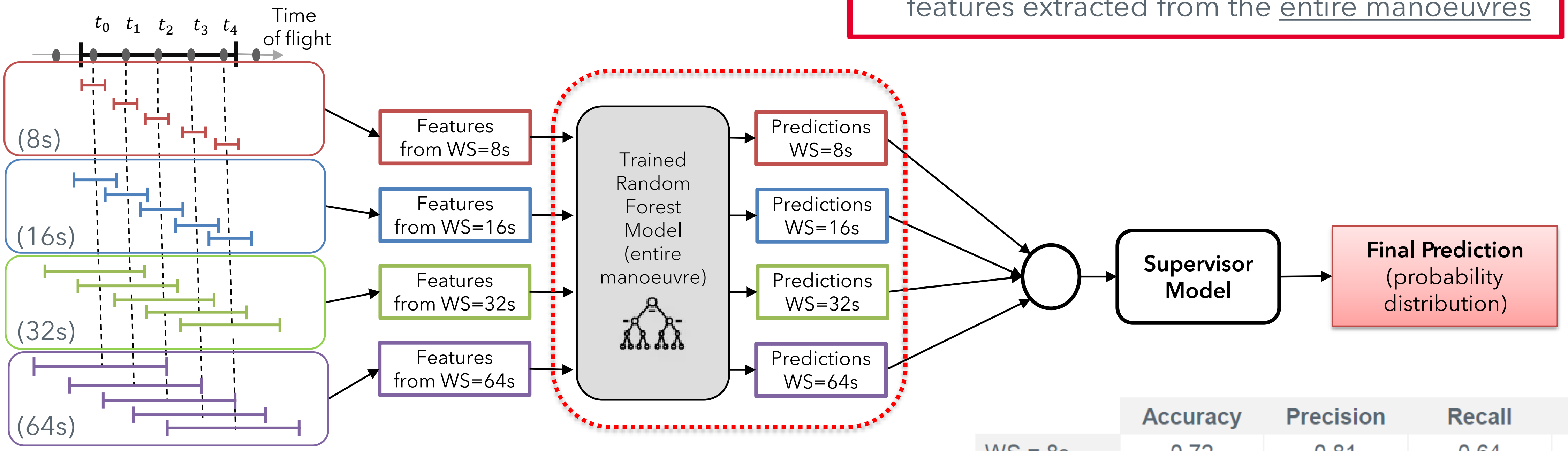
FCR through ML Algorithms – The Single Strategy Approach: 1st Strategy

➢ 1st Strategy for the 1st classification Level (Fully Data-Driven Approach)

1 Entire-manoeuvres Approach

Random Forest Model Trained on statistical features extracted from the entire manoeuvres

Sliding Windows



Statistical features: (MEAN, STD, MIN, MAX)

	Accuracy	Precision	Recall	F-1 score
WS = 8s	0.72	0.81	0.64	0.63
WS = 16s	0.83	0.85	0.78	0.78
WS = 32s	0.87	0.85	0.83	0.83
WS = 64s	0.73	0.72	0.65	0.63
Supervisor	**96%**	**94%**	**95%**	**94%**

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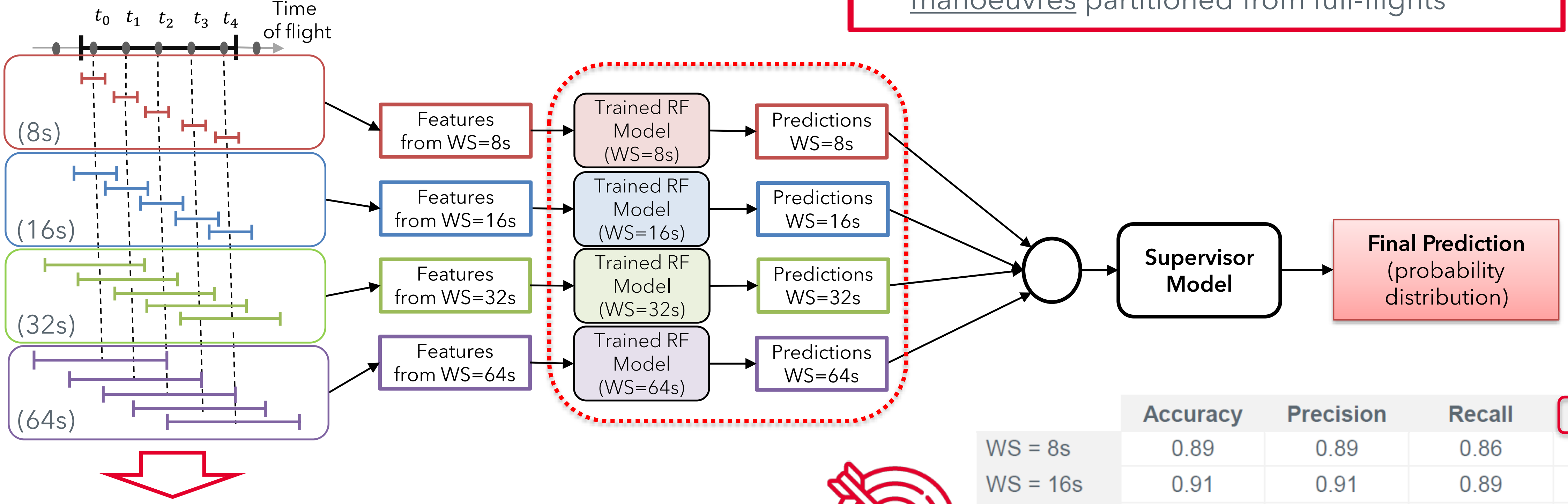
FCR through ML Algorithms – The Single Strategy Approach: 2nd Strategy

➢ 2nd Strategy for the 1st classification Level (Fully Data-Driven Approach)

2 Sliced-manoeuvres Approach

Multiple RF Models Trained on sliced manoeuvres partitioned from full-flights

Sliding Windows



Statistical features: (MEAN, STD, MIN, MAX)

	Accuracy	Precision	Recall	F-1 score
WS = 8s	0.89	0.89	0.86	0.88
WS = 16s	0.91	0.91	0.89	0.90
WS = 32s	0.85	0.87	0.83	0.85
WS = 64s	0.72	0.72	0.62	0.70
Supervisor	**96%**	**96%**	**95%**	**96%**

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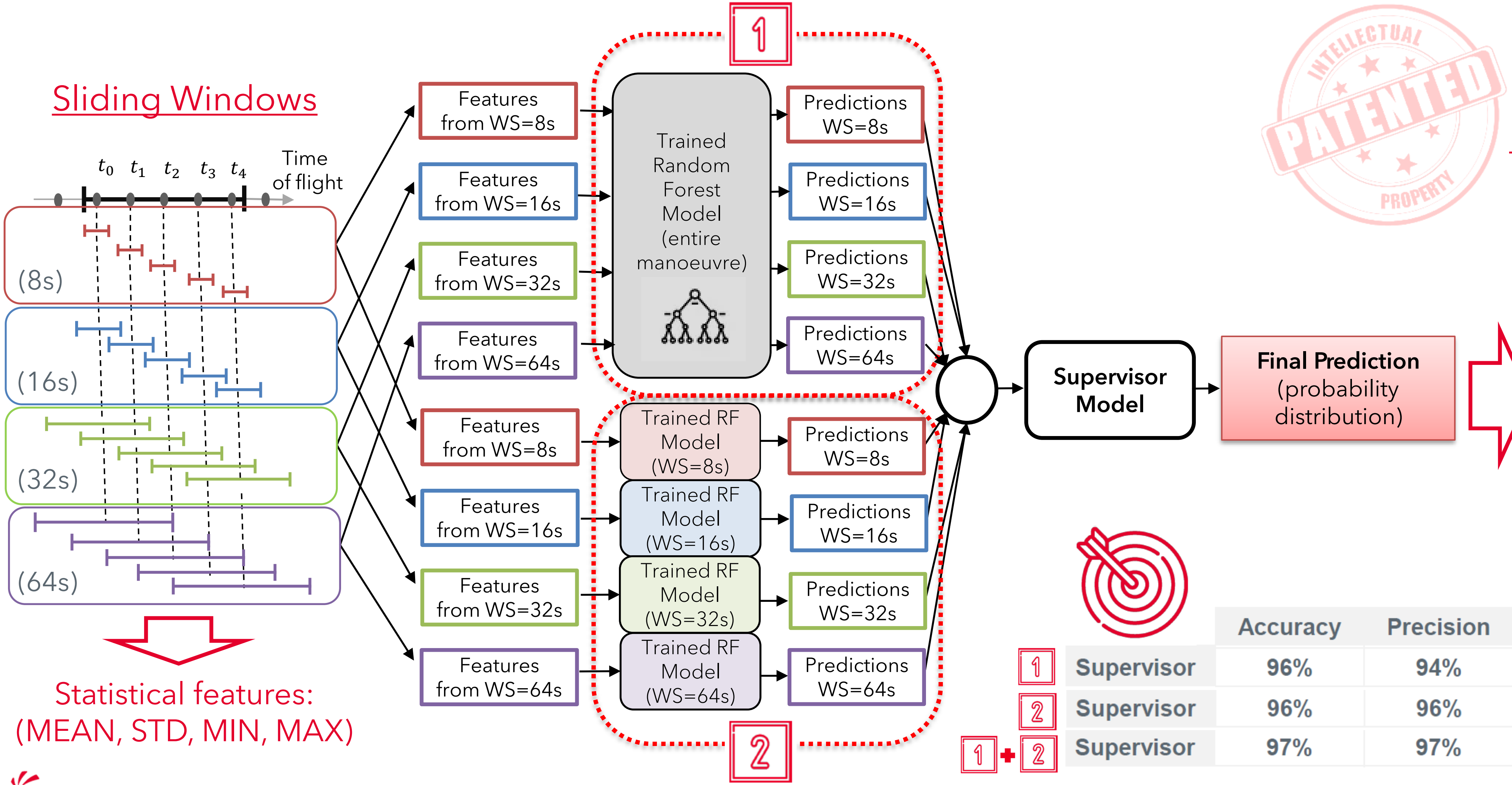
FCR through ML Algorithms – Optimised Multi-strategy Approach: 1st & 2nd Strategies

➢ 1st & 2nd Strategies implemented in parallel for the 1st classification Level



n.3 Patents granted

Dashboard

Manoeuvres Classification

	Accuracy	Precision	Recall	F-1 score
1 Supervisor	96%	94%	95%	94%
2 Supervisor	96%	96%	95%	96%
1 + 2 Supervisor	97%	97%	96%	97%

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FCR through ML Algorithms – Design phase/Macro-categories vs Usage Spectrum

➢ Dataset rebalancing through Aggregation

✓ **Dataset rebalancing** procedure to improve the performance of Supervised ML algorithm

- **FCR @ 1st Classification Level**: Fully Data-driven approach for the recognition of the **53 Macro-categories**
- **FCR @ 2nd Classification Level**: Data- & Model-driven approaches to recognise **usage spectrum regimes**

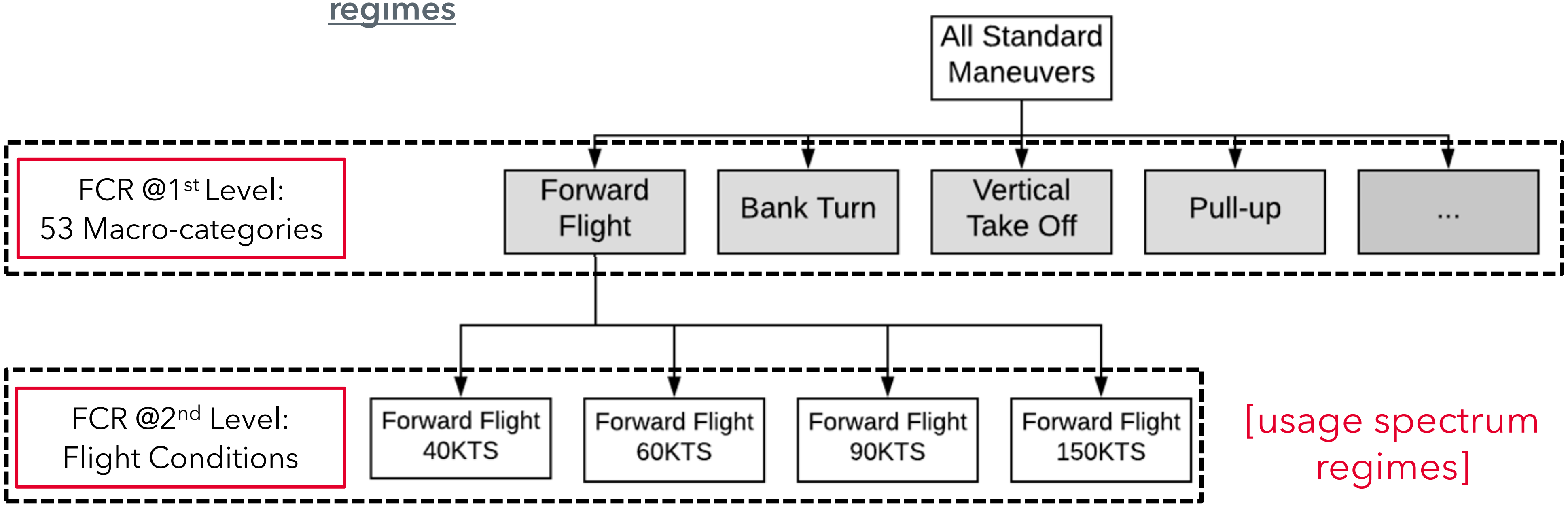
1st Classification Level
(Macro-regimes)

Strategy 1 | Strategy 2

2nd Classification Level
(Spectrum regimes)

Fully Data-driven approach

Data- & Model-driven approaches



[usage spectrum regimes]

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FCR through ML Algorithms – Performance for Load Survey Flights

AW189

PREDICTION ACCURACY ON PARTITIONED MANEUVERS

98.5%

(HUMS Family)

PREDICTION ACCURACY ON FULL FLIGHTS at 1st Classification Level

97.3%

AW139

PREDICTION ACCURACY ON PARTITIONED MANEUVERS

96.8%

(HUMS LH)

PREDICTION ACCURACY ON FULL FLIGHTS at 1st Classification Level

96.4%

AW169

PREDICTION ACCURACY ON PARTITIONED MANEUVERS

98.5%

(HUMS Family)

PREDICTION ACCURACY ON FULL FLIGHTS at 1st Classification Level

97.3%

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SUMMARY

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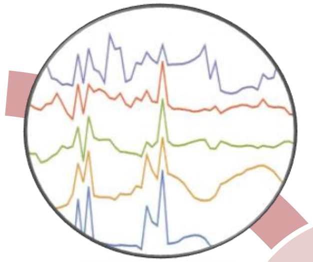
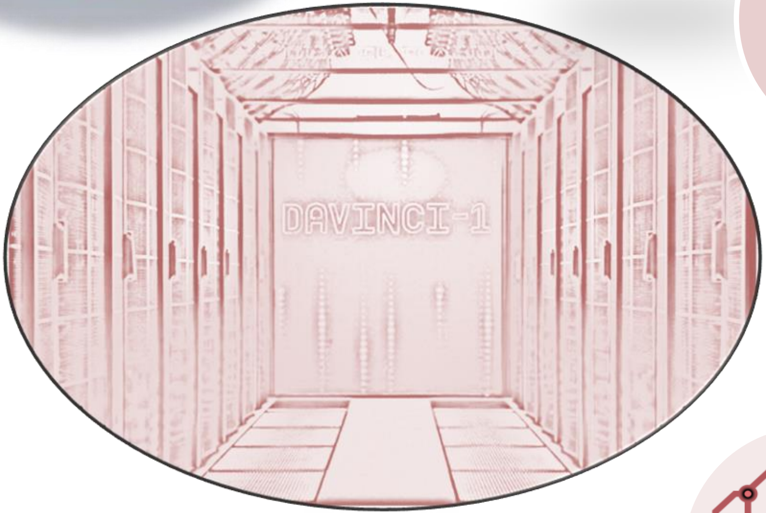
Application to Operative Fleets – End-to-end flight data analysis process

- Usage Monitoring of operative Helicopters Fleets through HUMS



- Verification & Validation of the Time history of the flight parameters recorded by HUMS - Ongoing
- Pipeline designed for Data acquisition and Data Lake ingestion
- Data Lake population
- Verification & Validation of Output of the ML-FCR algorithm for real flight - Ongoing



- Dashboard

Flight Condition Recognition (FCR)

Effective Structural Usage Monitoring

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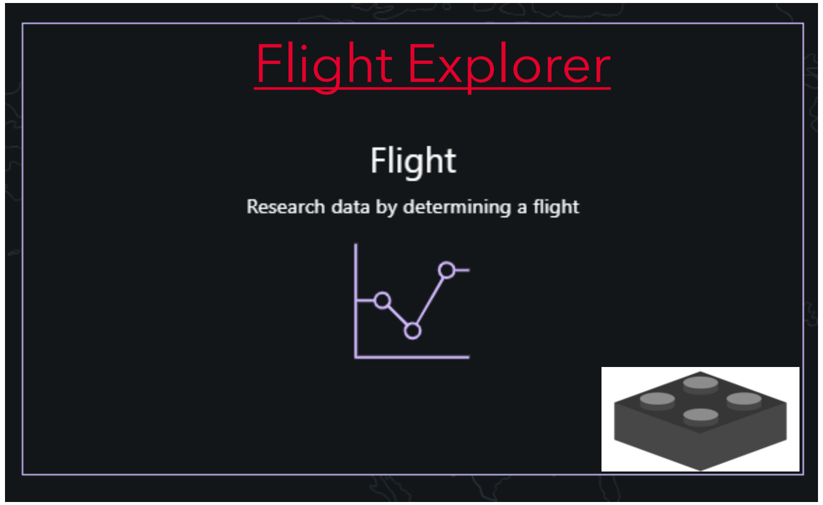
Application to Operative Fleets – Results and Discussion

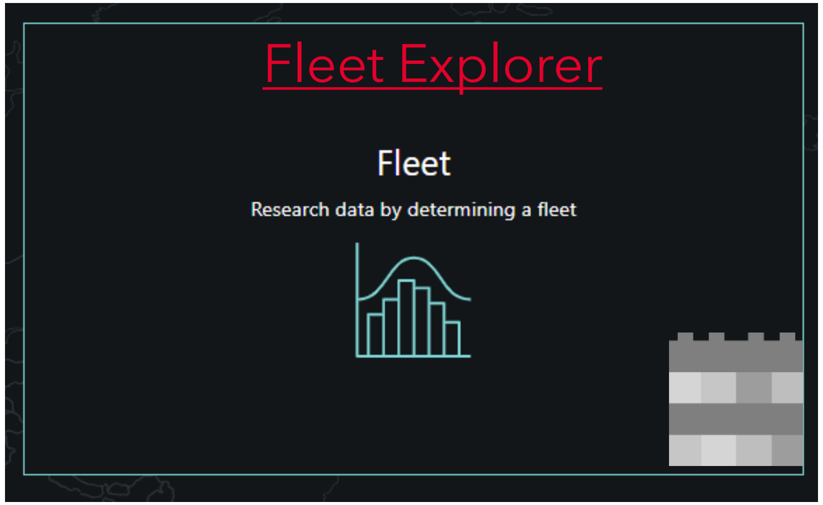
➢ Dashboard

- The Dashboard allows visualizing the results of the ML-FCR Algorithm in terms of classified manoeuvres both in Detailed and Aggregated way through **3 Environments**



- Visualize a single flight and explore how it was segmented in terms of recognised manoeuvres
- Access to the individual recognised manoeuvre to verify the trends of the characteristics flight parameters
- Visualize useful information: %-of-time and occurrences of the recognised flight regimes

- Explore how a generic helicopter has been used across several different flights
- Visualize the total time spent by the considered helicopter in each recognised manoeuvres
- Visualize useful information: %-of-time and occurrences of the recognised flight regimes



- Explore how a generic helicopter fleet has been used across several different flights
- Visualize the total time spent by the considered fleet in each recognised manoeuvres
- Visualize useful information: %-of-time and occurrences of the recognised flight regimes

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Application to Operative Fleets – Results and Discussion

➢ Dashboard – Flight Explorer: Flight Segmentation Visualizer – 1st Classification Level

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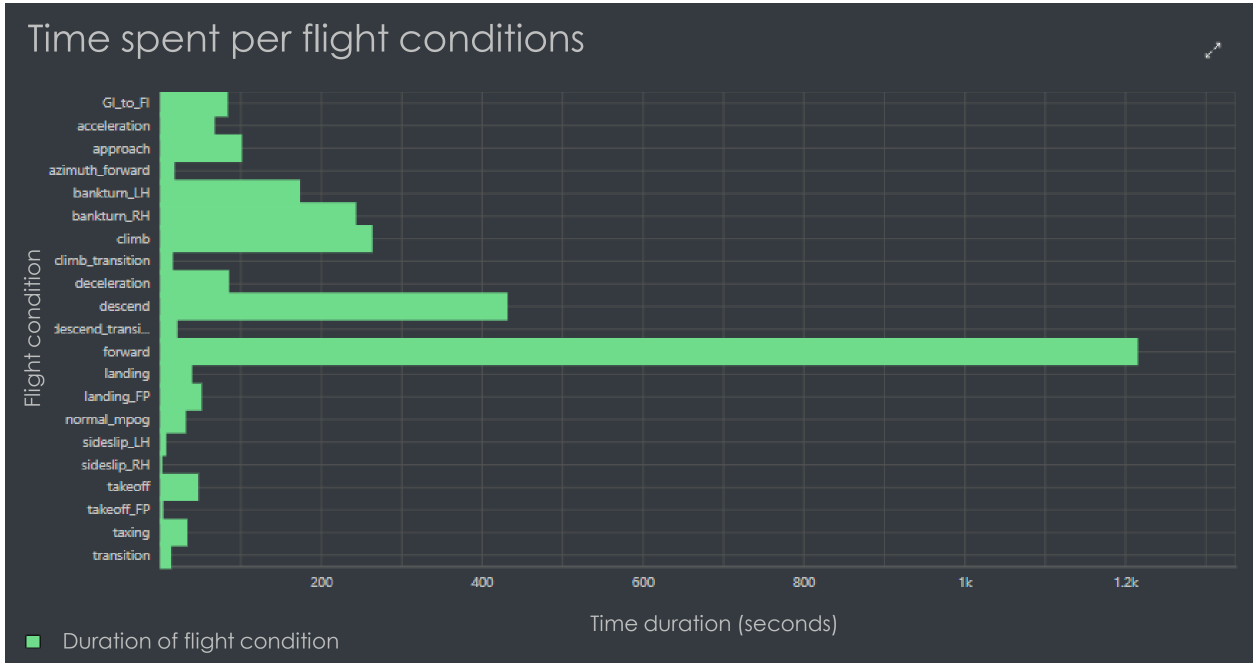
Application to Operative Fleets – Results and Discussion

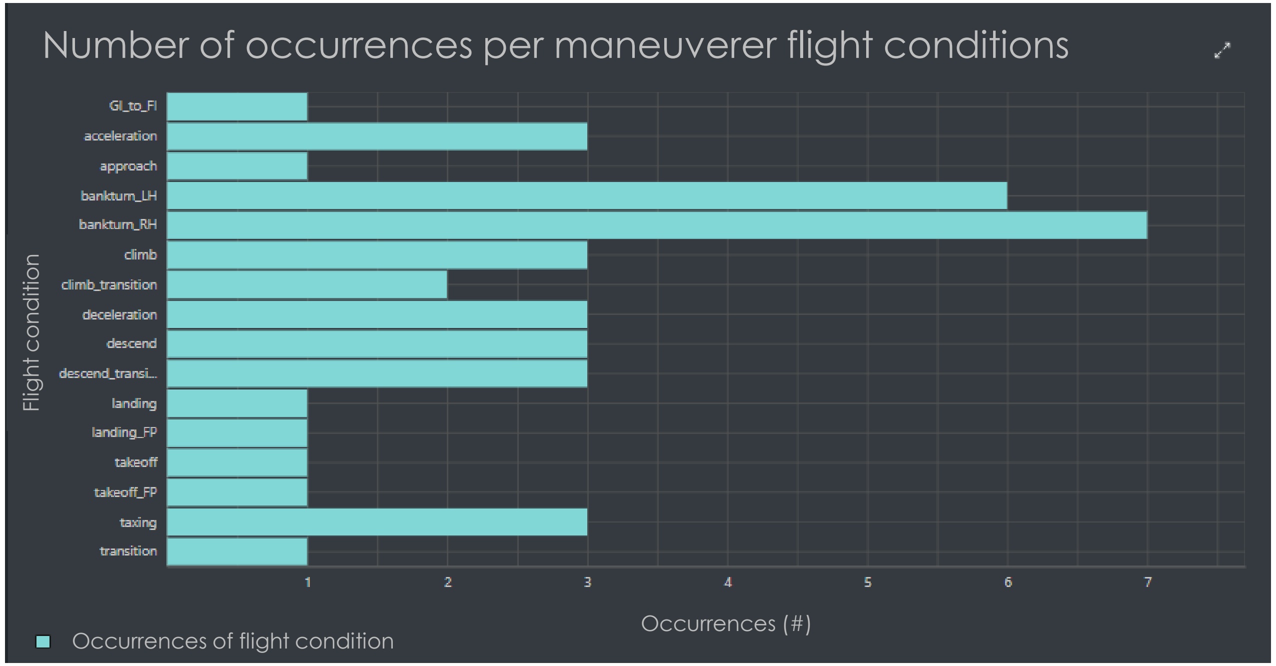
➢ Dashboard – Flight Explorer @ 1st Classification Level

- Duration of flight conditions and Manoeuvres counting

1st Classification Level
(Macro-regimes)

Strategy 1 | Strategy 2





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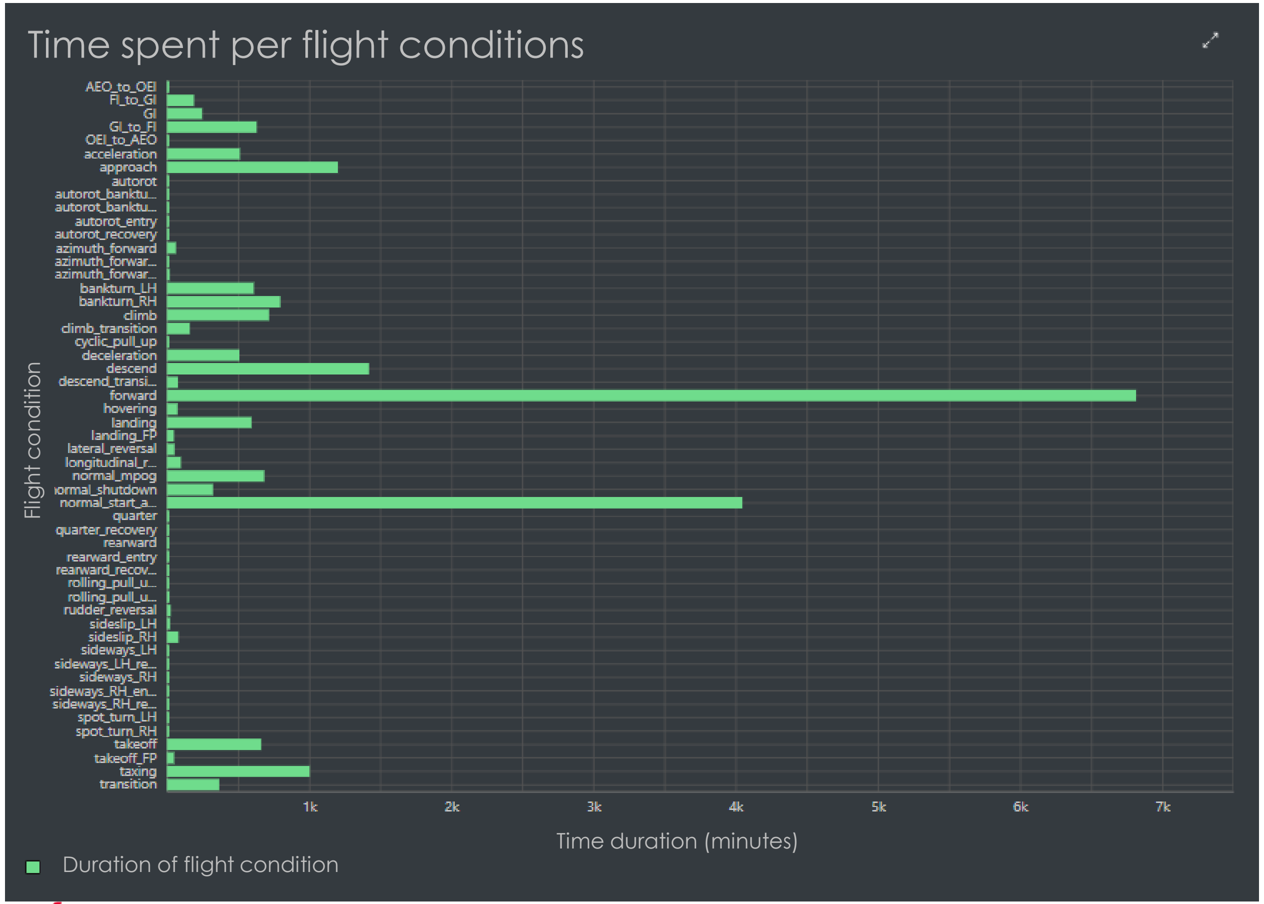
Application to Operative Fleets – Results and Discussion

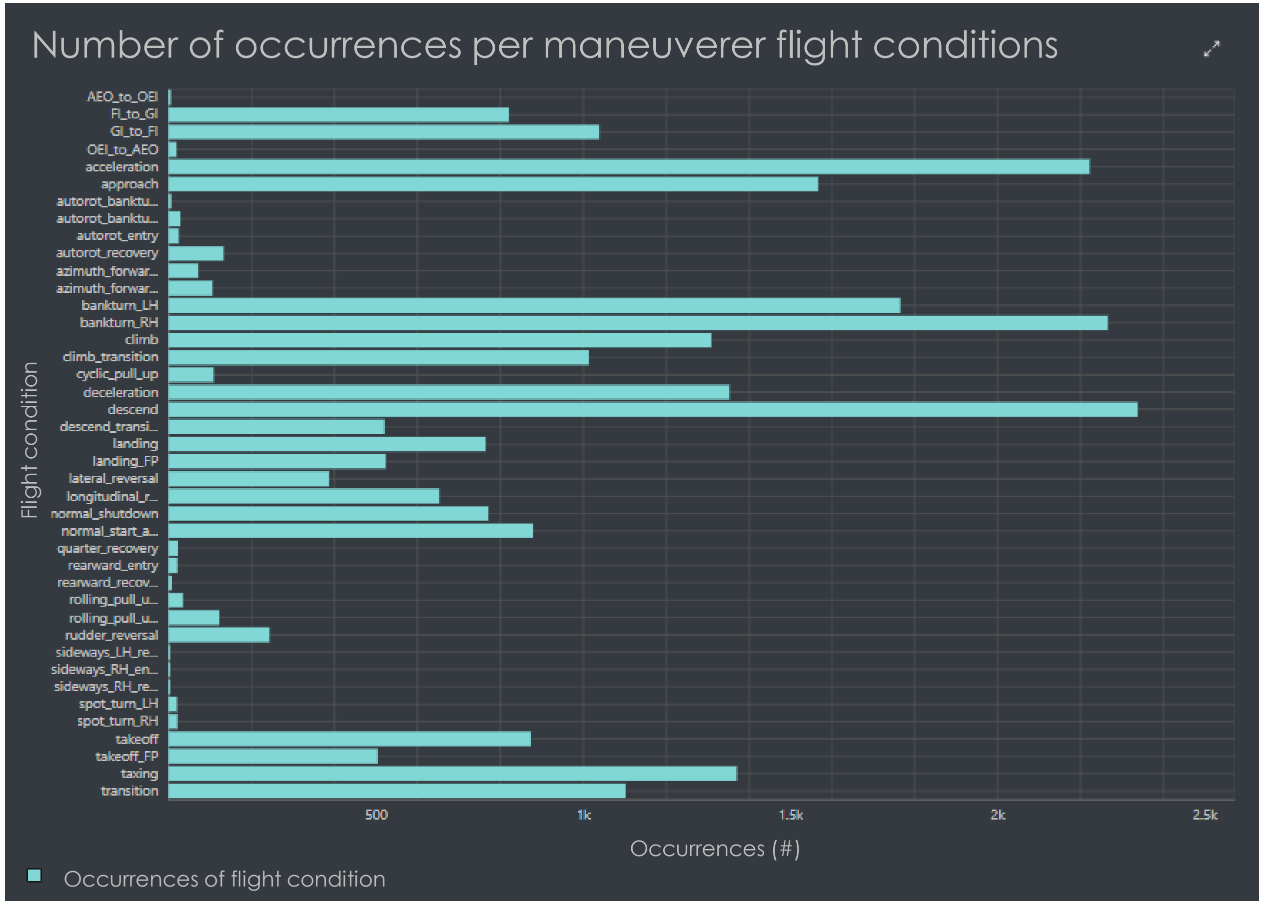
➢ Dashboard – Helicopter Explorer @1st Classification Level

- Duration of flight conditions and Manoeuvres counting

1st Classification Level
(Macro-regimes)

Strategy 1 | Strategy 2





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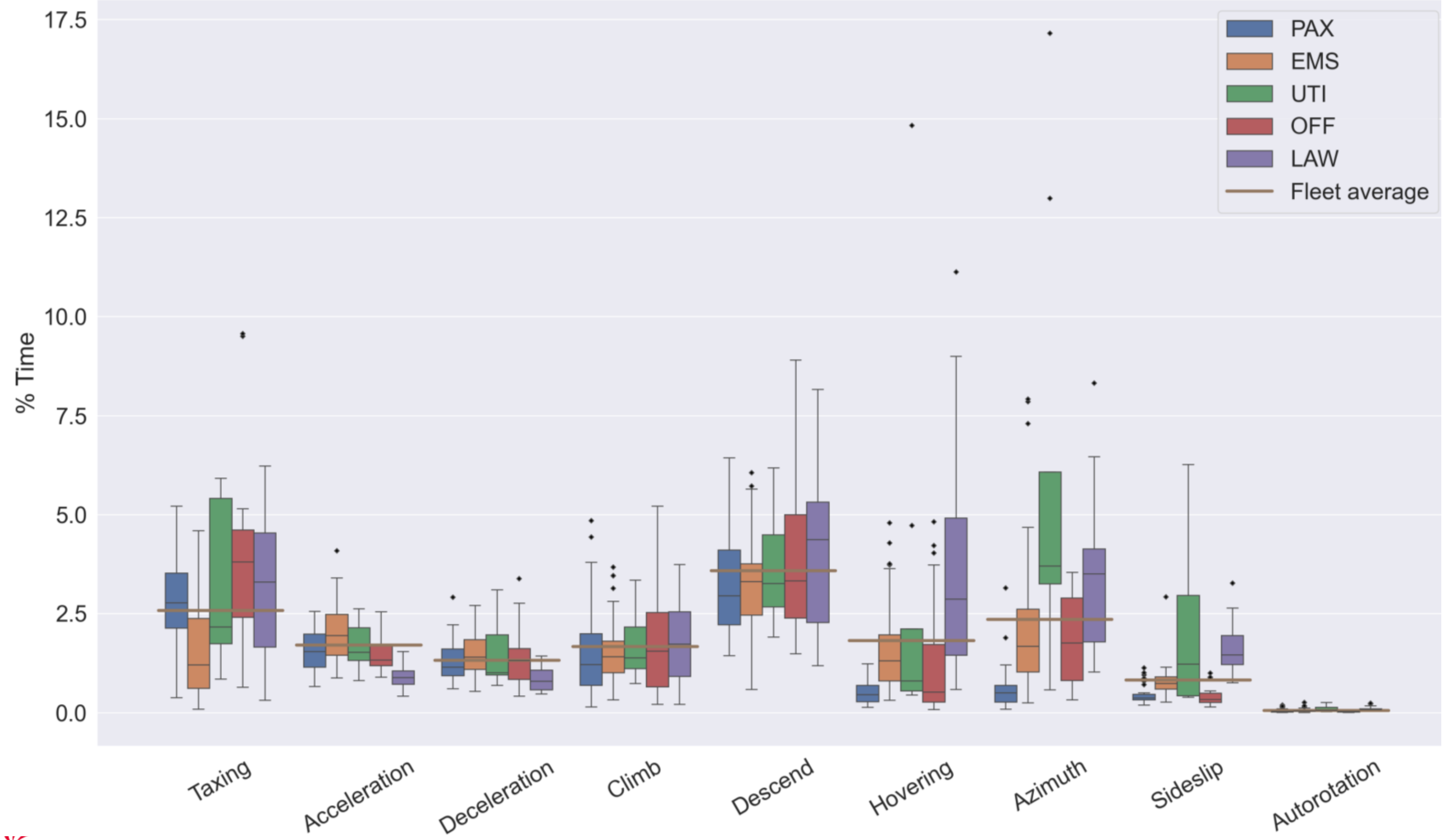
Application to Operative Fleets – Results and Discussion

➢ Dashboard – Fleet Explorer @1st Classification Level

- Mission comparison – Flight Conditions (% Time)



1st Classification Level
(Macro-regimes)

Strategy 1 | Strategy 2

- Clustering of typical mission profiles of an operative fleet of a specific helicopter model

- Actual Usage Spectrum (AUS)
  VS
  Design Usage Spectrum (DUS)

- Effective Structural Usage Monitoring

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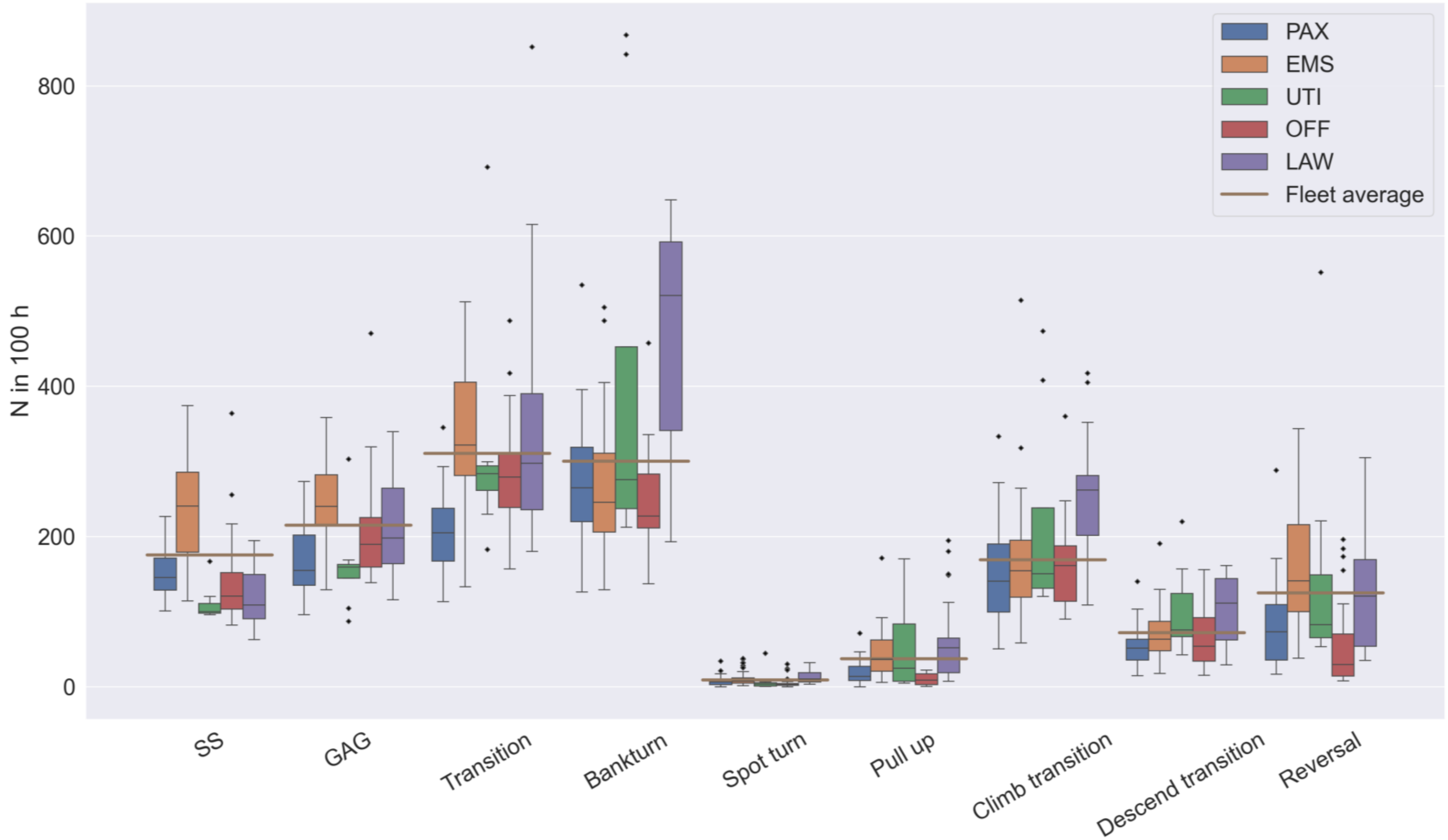
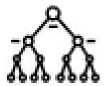
Application to Operative Fleets – Results and Discussion

➢ Dashboard – Fleet Explorer @1st Classification Level

- Mission comparison – Flight Conditions Occurrences (Num. Man. in 100h)



1st Classification Level
(Macro-regimes)



Strategy 1 | Strategy 2

- Clustering of typical mission profiles of an operative fleet of a specific helicopter model

- Actual Usage Spectrum (AUS)
VS
Design Usage Spectrum (DUS)

- Effective Structural Usage Monitoring

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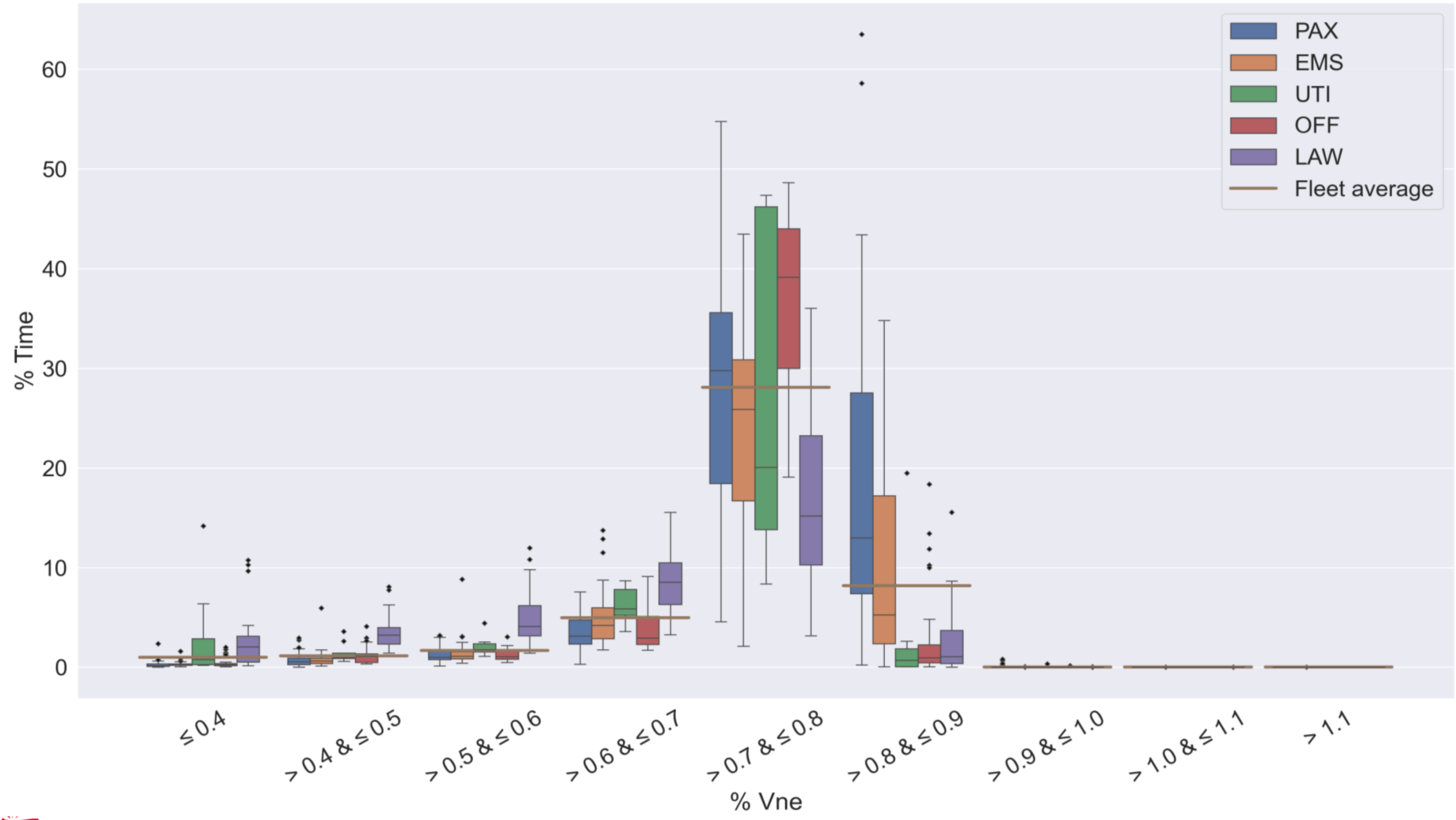
Application to Operative Fleets – Results and Discussion

➢ Dashboard – Fleet Explorer @2nd Classification Level

- Mission comparison – Forward Flight regimes (%Time)



1st Classification Level
(Macro-regimes)

Strategy 1 | Strategy 2

2nd Classification Level
(Spectrum regimes)

- Actual Usage Spectrum (AUS)
  VS
  Design Usage Spectrum (DUS)

- Effective Structural Usage Monitoring

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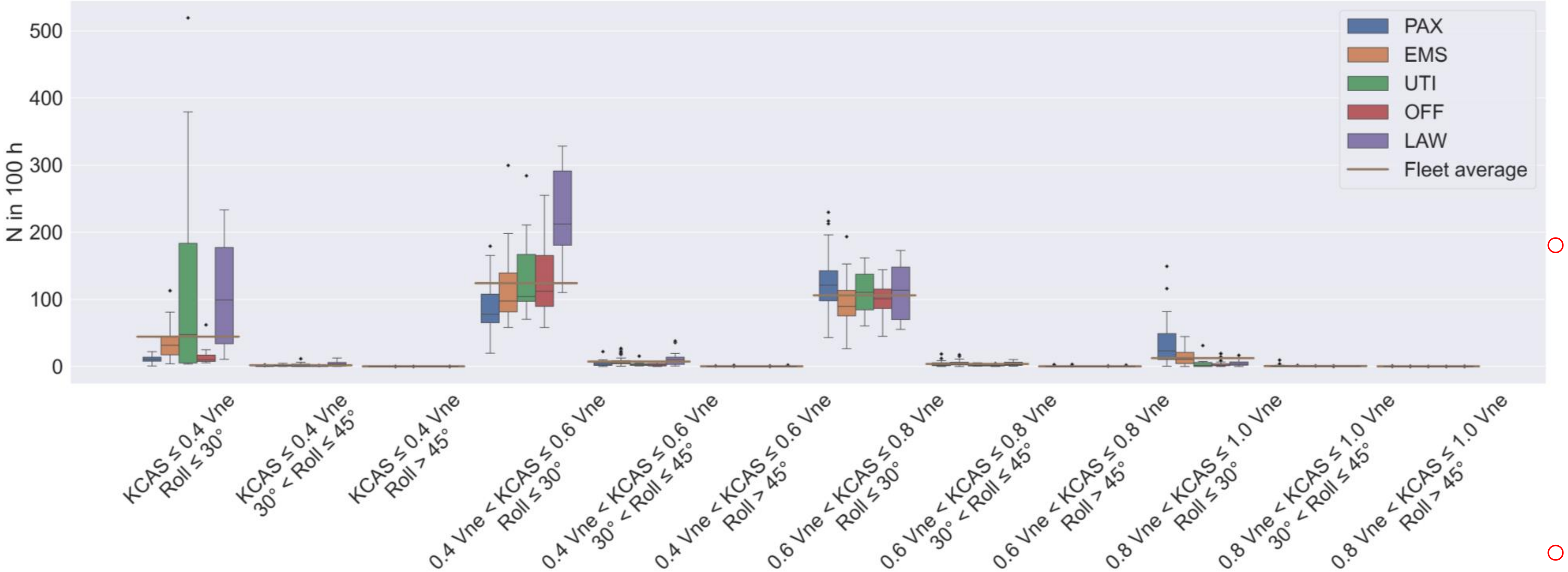
Application to Operative Fleets – Results and Discussion

- **Dashboard – Fleet Explorer @2nd Classification Level**
  - Mission comparison – Bank Turns Occurrences (Num. Man. in 100h)



1st Classification Level
(Macro-regimes)

Strategy 1 | Strategy 2

2nd Classification Level
(Spectrum regimes)

- Actual Usage Spectrum (AUS)
  VS
  Design Usage Spectrum (DUS)

- Effective Structural Usage Monitoring

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SUMMARY

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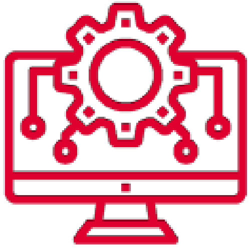
Concluding Remarks



The proposed **Multi-Strategy ML-based approach** is

- **Robust**
- **Flexible** (easily adaptable to different aircraft variants)
- **Scalable** (with the number of available measurements)
- **Easily re-trainable** (if more or different measurements are available)

Effectively addresses the FCR problem enabling an

Effective Structural Usage Monitoring

Customised and Flexible Maintenance Operations

instead of **Time-Based Maintenance** (TBM)

Maintenance Costs Reduction

Flight Safety Assurance

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