Comparing Fuel Flow using a Cluster Method

EOFDM Conference 2016

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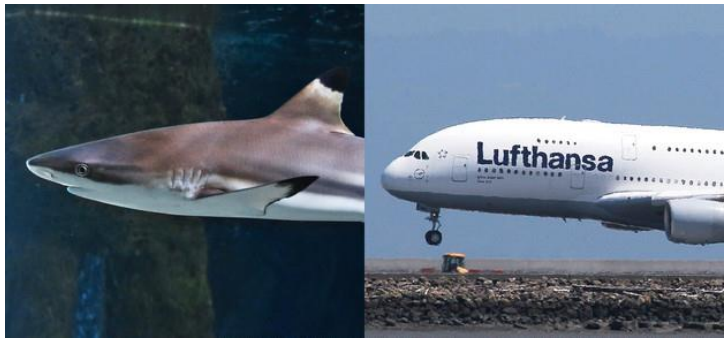
Motivation

Use Shark Skin Effect with Riplet Structure

Expected drag reduction: ≈1%

Measurable effect in normal Operation?

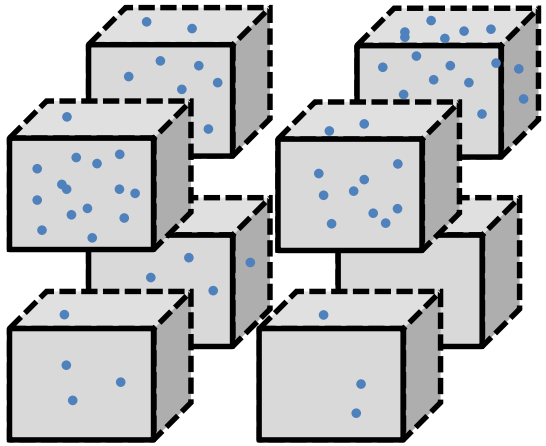


Alexander Klein/AFP/Getty Images, Justin Sullivan/ Getty Images

Idea: Cluster fuel flow data based on influencing factors

Fuel flow distributions at operating points / areas

Compare data sets at operating points



Application possibilities: fuel flow over time, measure effects of constructive aerodynamic changes, compare fuel flow of a fleet

Potential Influencing Factors of Fuel Flow

Aircraft States
- Ma, TAS, CAS, q
- Angle of Attack
- Altitude

Environment
- Temperature
- Pressure
- Density
- Wind / Turbulences

Source: AirBaltic

Aircraft
- Mass
- Center of Gravity
- Exit Doors
- Hull Damages
- Dirt on Surfaces

Engines
- Fan Speed (N1)
- Exhaust Gas Temperature (EGT)
- Engine Pressure Ratio (EPR)
- Degradation of Components

Operational Aspects
- Anti Icing (1%)
- Pack Flow (high/low)

Concept of Clustering – General Idea

Assumption: fuel flow is function of influencing factors

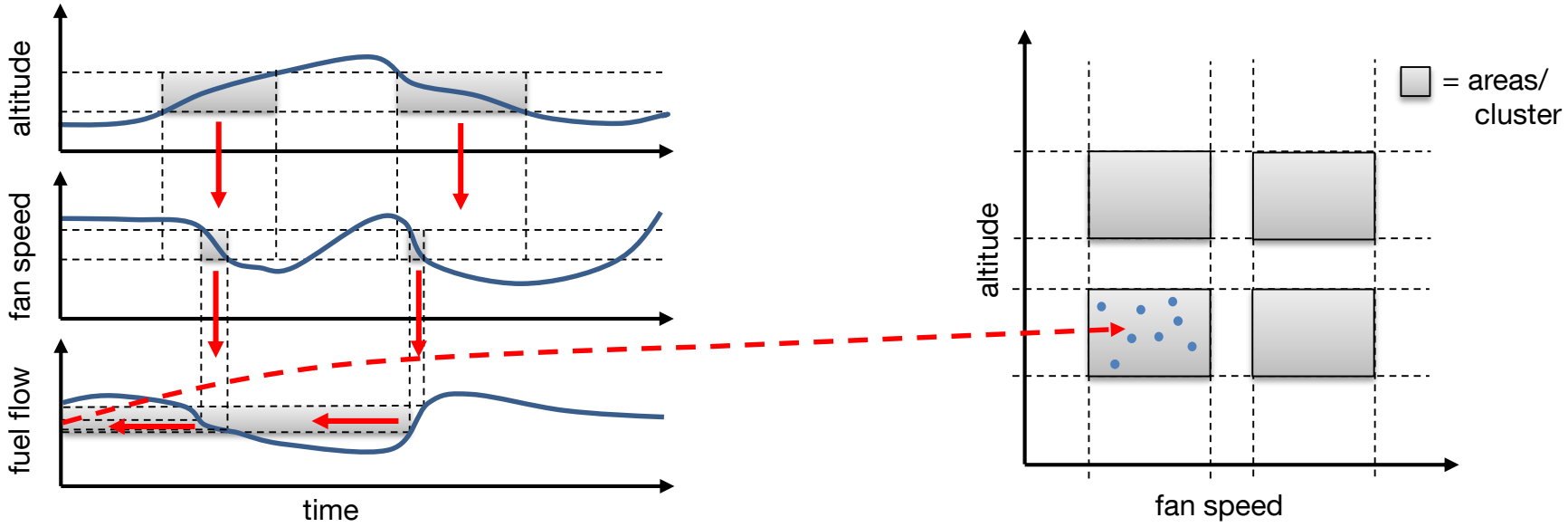
$$fuel\ flow = f(N1, Ma, h, m, \dots)$$

Perfect comparability:
(if function were known)

Evaluating the function at specific points
→ Single values of influencing factors

Clustering:
(function not known)

Retract measured fuel flow data in different areas
→ Value intervals of influencing factors

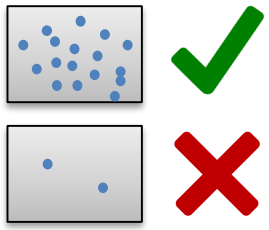


Extendable to any number of influencing factors

Concept of Clustering – Single Cluster Analysis

Only „**full clusters**“ are analyzed

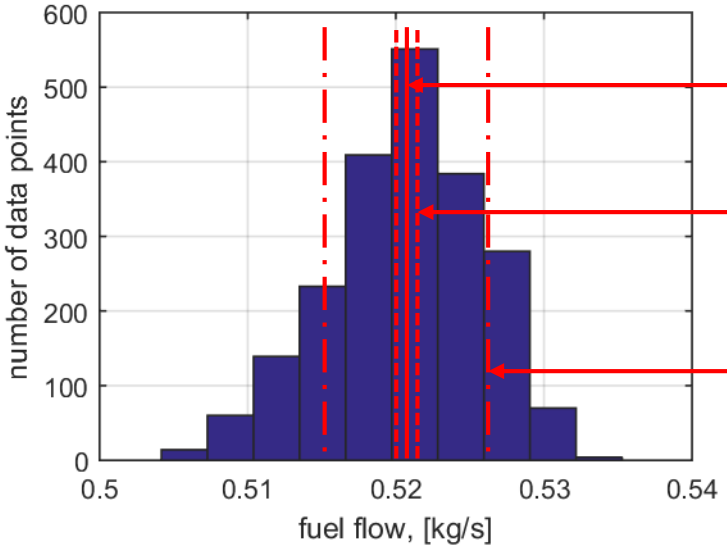
- Minimum number of data points within cluster for statistical confidence



Analysis figures per full cluster:

number of data points

number of contributing flights



mean value

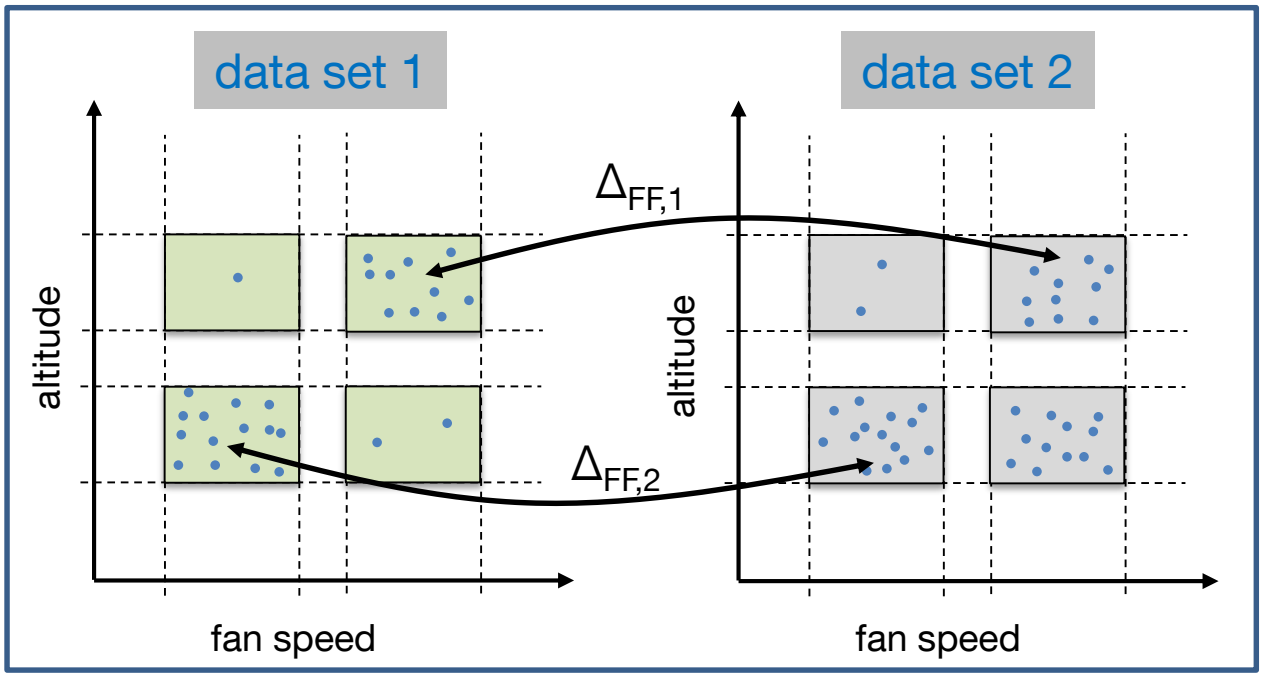
confidence interval

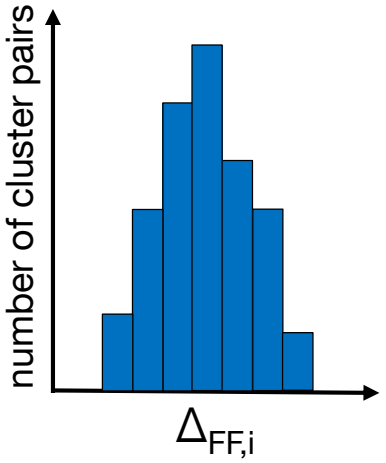
standard deviation

Concept of Clustering – Comparing Data Sets

Compare **pairs of full clusters** of **two different data sets**

- Calculate difference of mean values of both full clusters ($\Delta_{FF,i}$)





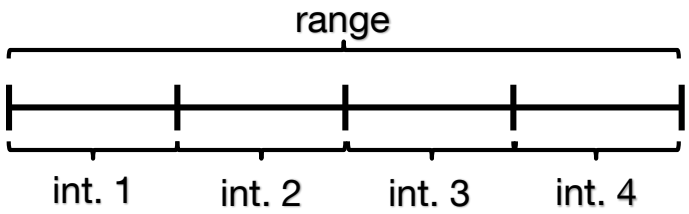
Comparison of multiple data sets via: **Mean values of Δ_{FF}-distributions of each pairwise combination of data sets** (more than two)

Analysis – Basic Information

Influencing Factor	Unit	Resolution	Range	Number of Intervals	Width of Intervals
Pressure Altitude	[m]	0.3	FL360 ± 25m	1	50
Fan Speed	[-]	0.001	0.82 - 0.9	8	0.01
Mach Number	[-]	0.002	0.72 - 0.76	4	0.01
Temperature	[K]	0.025	230 - 258	4	7

Four influencing factors divided into equally spaced intervals

- 1 x 8 x 4 x 4 = 128 clusters per analysis



100 Flights of one aircraft (B737–500)

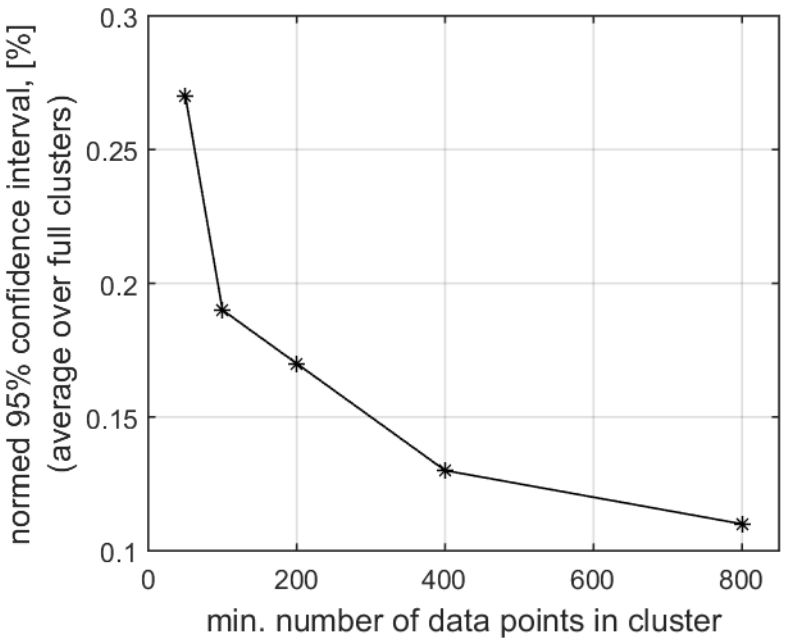
- Mainly short cruise phases
- Flights recorded between January 2013 and July 2014
- Lowest sampling rate defines data points (1 Hz)

Note:

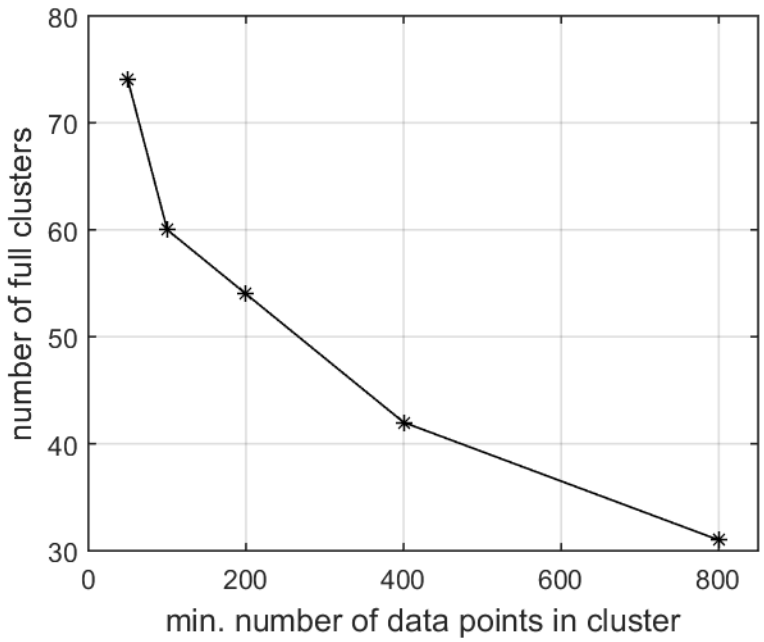
- Confidence interval and standard deviation normed by mean value
- Averaged analysis figures of full clusters

Analysis – Minimum Number of Data Points

confidence interval



number of full clusters



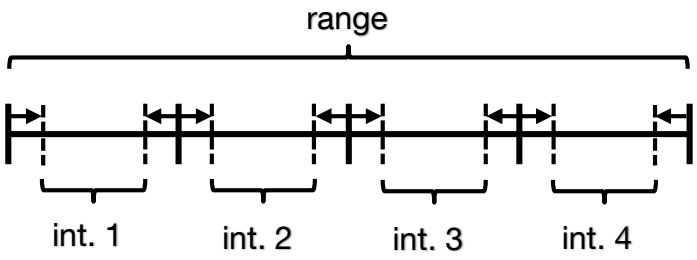
Normed standard deviation is approximately constant!

For further analyses: min. number of data points = 2 x number of flights

Analysis – Interval Width

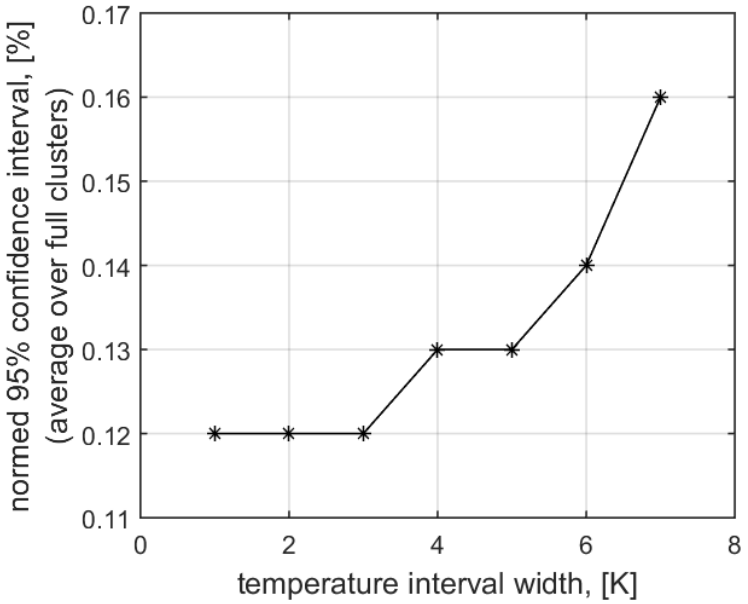
Variation of temperature interval width

- From 7K to 1K

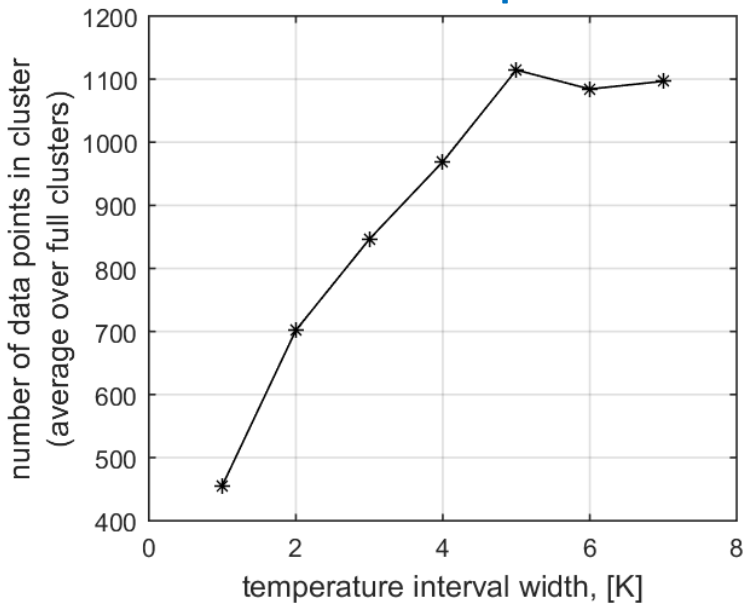


Contributing Factor	Unit	Width of Interval
Pressure Altitude	[m]	50
Fan Speed	[-]	0.006
Mach Number	[-]	0.006
Temperature	[K]	7 → 1

confidence interval



number of data points

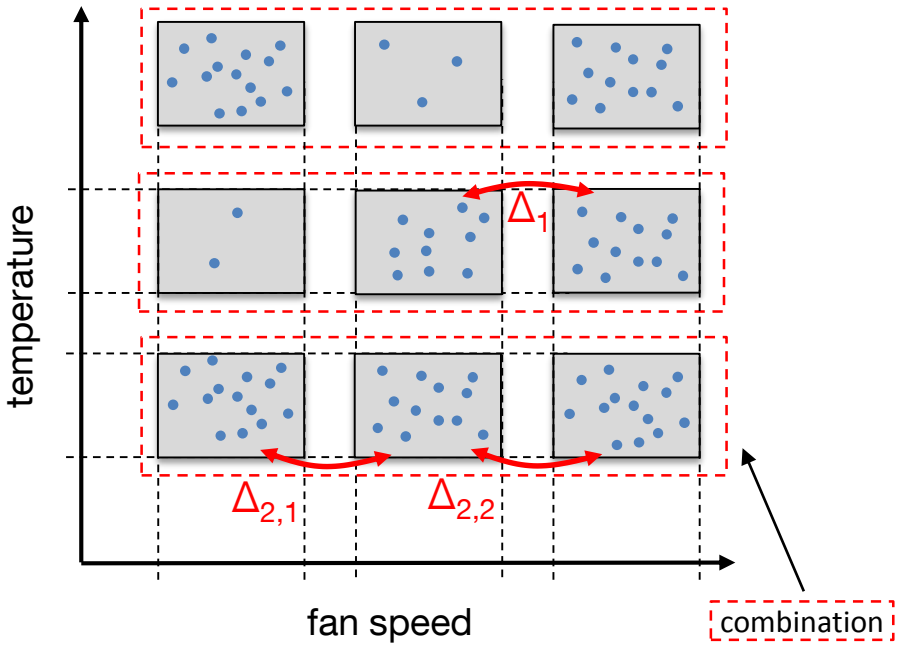


Analysis – Sensitivity Analysis

How well do influencing factors separate the fuel flow?

Separation of adjacent full clusters

- Difference of mean values Δ_i of fuel flow distributions in full clusters
- Only difference in direction of one influencing factor
  - Separation for all combinations of remaining influencing factors
  - Only combinations considered, where adjacent full clusters exist
  - Example: 3 “combinations” of temperature



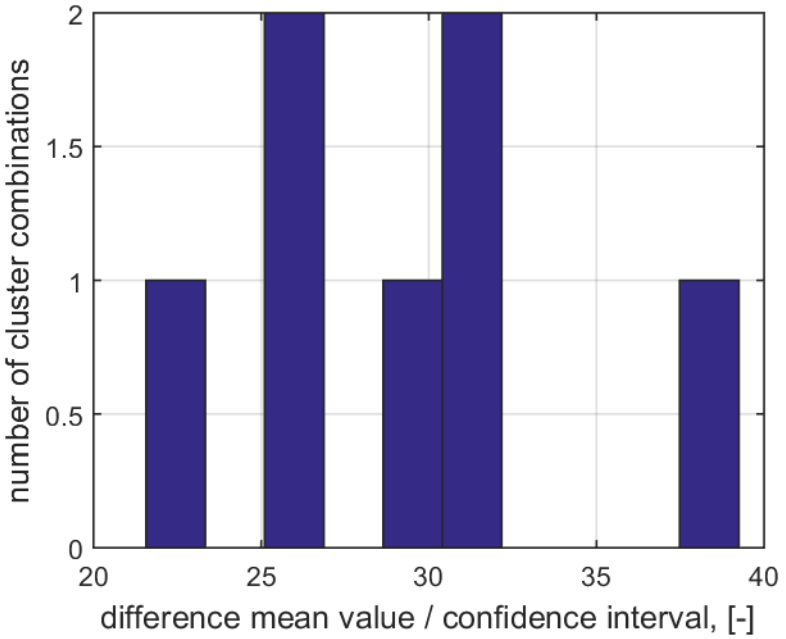
Mean value of $\Delta_{i,k}$ for one combination of remaining influencing factors

$$\Delta_i = mean(\Delta_{i,1}, \Delta_{i,2}, \dots \Delta_{i,k})$$

Analysis – Sensitivity Analysis

Example: separation through fan speed

- decreased intervals of influencing factors
- Δ's normed by confidence interval widths



7 combinations with adjacent full clusters

Fan speed leads to best separation

Separated by 22-39 confidence intervals

Separation increases for smaller intervals of influencing factors

- Clustering by temperature also delivers wide separation
- Number of influencing factors has no great influence

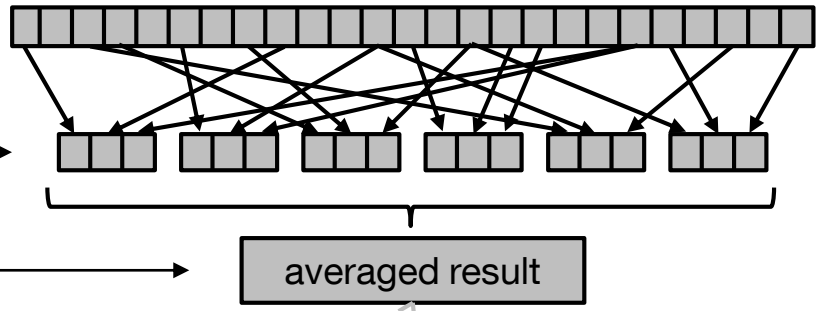
Analysis – Number of Flights

Data base:

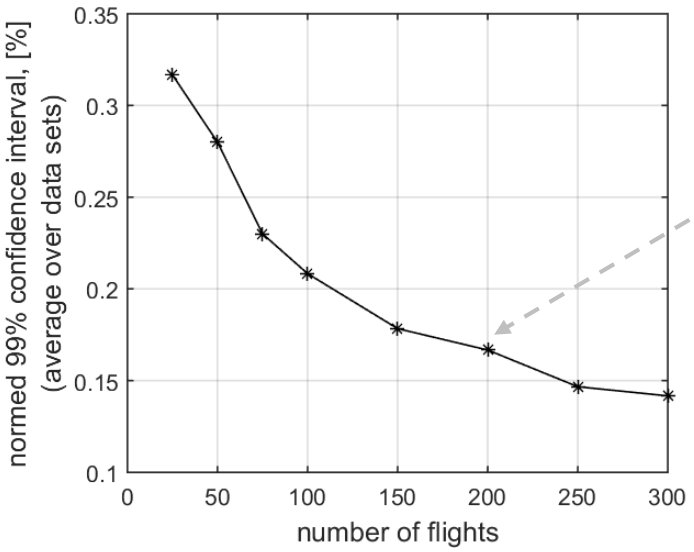
- 352 Flights of one aircraft

Method:

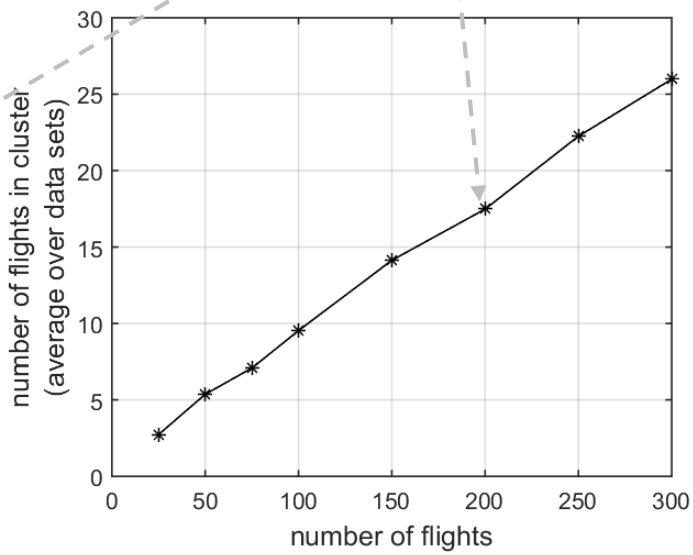
- For each number of flights, random pick of 6 data sets of flights
- Average over results of the 6 random sets



confidence interval



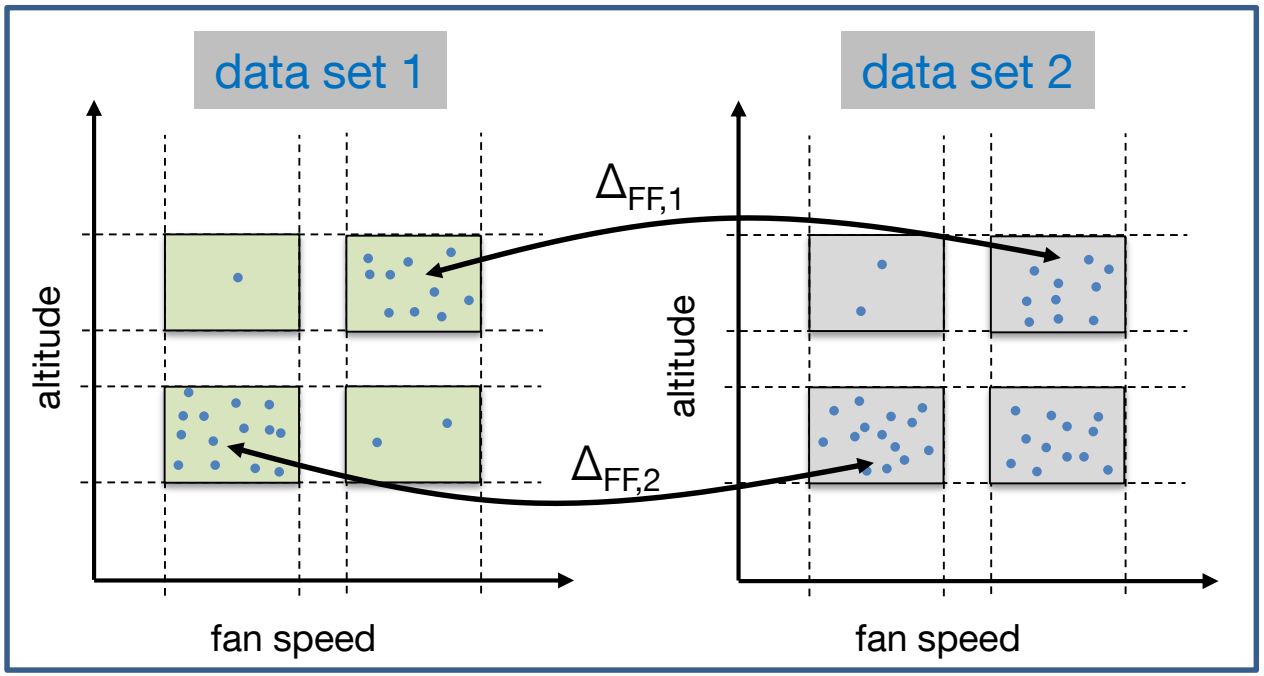
number of flights in cluster

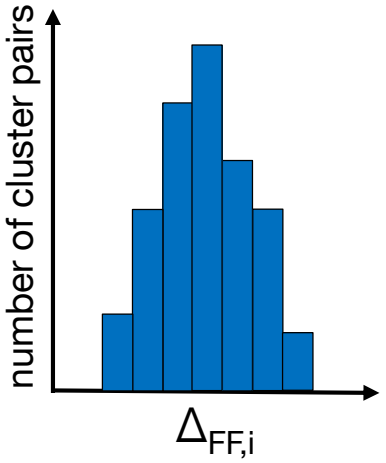


Concept of Clustering – Comparing Data Sets (Reminder)

Compare **pairs of full clusters** of **two different data sets**

- Calculate difference of mean values of both full clusters ($\Delta_{FF,i}$)





Comparison of multiple data sets via: **Mean values of Δ_{FF}-distributions of each pairwise combination of data sets** (more than two)

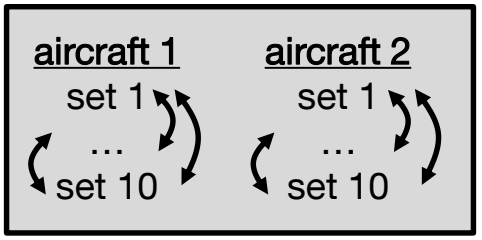
Comparison of two Sets of Flights

Data Base:

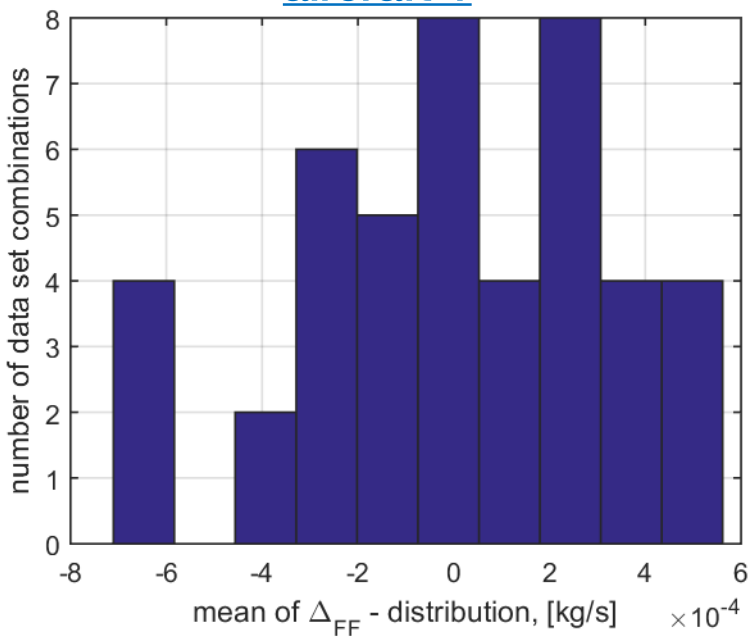
- Two aircraft of same type, data from June and July 2014
- 10 random data sets of 100 flights for each aircraft

Method (part 1):

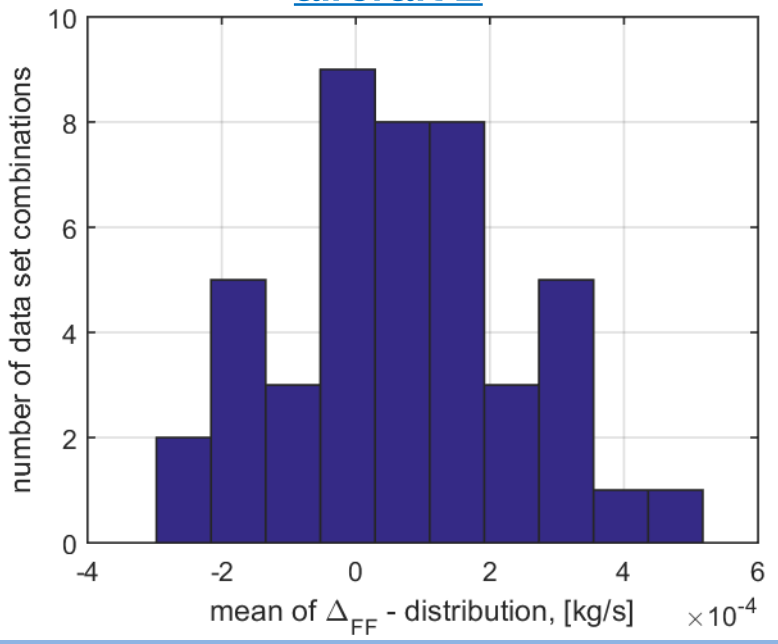
- Compare 10 data sets of one aircraft amongst each other
- Mean value of Δ-distribution for every combination of two data sets (10 sets → 45 combinations)



aircraft 1



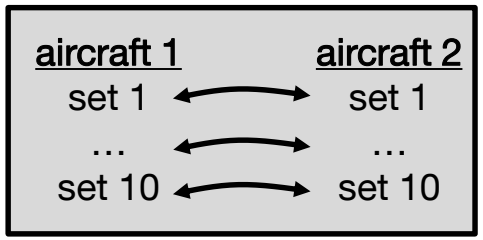
aircraft 2



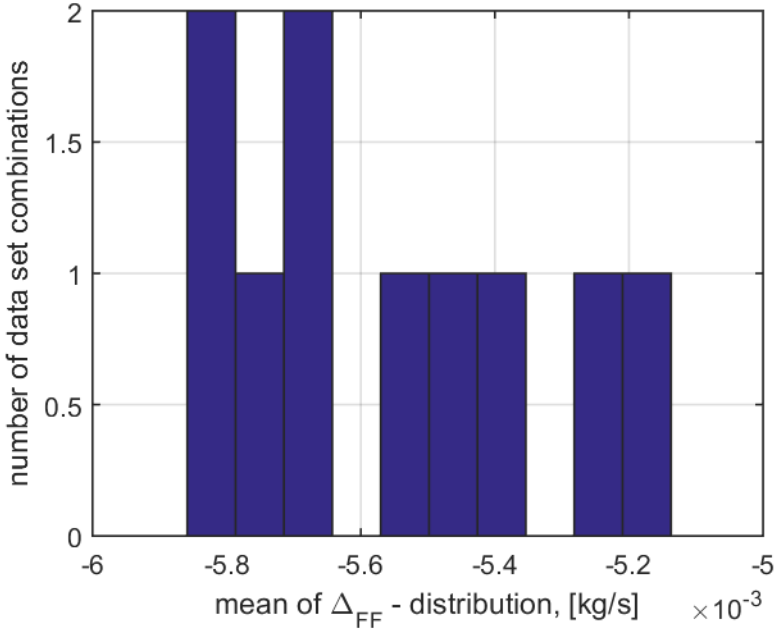
Comparison of two Sets of Flights

Method (part 2):

- Mean value of Δ-distribution between sets 1-10 of both aircraft



both aircraft compared



Value range for each aircraft:

- Aircraft 1: (-8) – (+6) x 10^{-4} kg/s
- Aircraft 2: (-4) – (+6) x 10^{-4} kg/s

Value range for comparisson:

- (-6) – (-5) x 10^{-3} kg/s
- About 1% difference between aircraft

→ **significant difference evident**

Summary / Conclusion

- Significant difference for two aircraft found with only four influencing factors
- Clusters best separated by fan speed
- Saturation for confidence intervals for increasing number of flights/data points
- Smaller intervals for fan speed and temperature lead to smaller confidence intervals

Source: AirBaltic

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Thank you for your attention