



# FTL Effectiveness

*– How much lower risk? At what cost?*

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- FTLs are primarily there to limit fatigue risk
- FTLs spring from rules designed to limit physical (not cognitive) fatigue
- The FTL updates in  $\approx$ 2010-2020 have been done mostly in a qualitative way:
  - “12 h of rest before a flight should be better than just 9 h” (...but we know rest may force crew out of bed)
  - “A shorter night duty should be more safe than a longer one” (...but more night duties, disrupting good sleep?)
- We lack a quantification of the effects of rules, on *overall* fatigue risk, when applied to (complex) crew management processes

Qualitative	Quantitative
'I bought the ice cream because I saw it when I was in the checkout line - I wanted to treat myself.'	'20% of survey respondents bought ice cream today'
'I like a lot of toppings on my pizza - cheese, sauce, pepperoni, olives.'	'The average amount spent on ice cream by 500 respondents was \$5'
'The grocery store has good options in general but the lines can be long and they are often out of stock of my favorite brands.'	'50% of people in New York strongly enjoy pizza'
	'On average, respondents rate their grocery store a 3.5 out of 5'



- Phase 1 – published in March 2019. Found ‘an increased probability of high fatigue levels during nights and duty periods with late finishes, among both pilots and cabin crew’
- Phase 2 – ongoing. NLR/DLR/scientists. Collecting data to further quantify ‘FTL Effectiveness’. At all possible?

# The platform



## FTLs (4)

- FAR 117
- CAAC-R6
- EASA FTLs
- EASA Subpart Q



## Periods (3 weeks) (OAG)

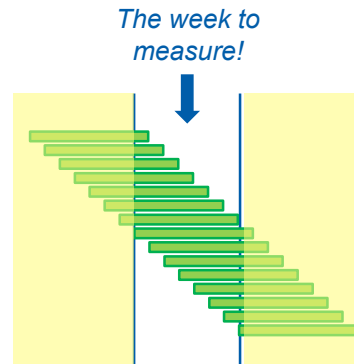
- 6 May 2019
- 10 Oct 2019
- 3 May 2021



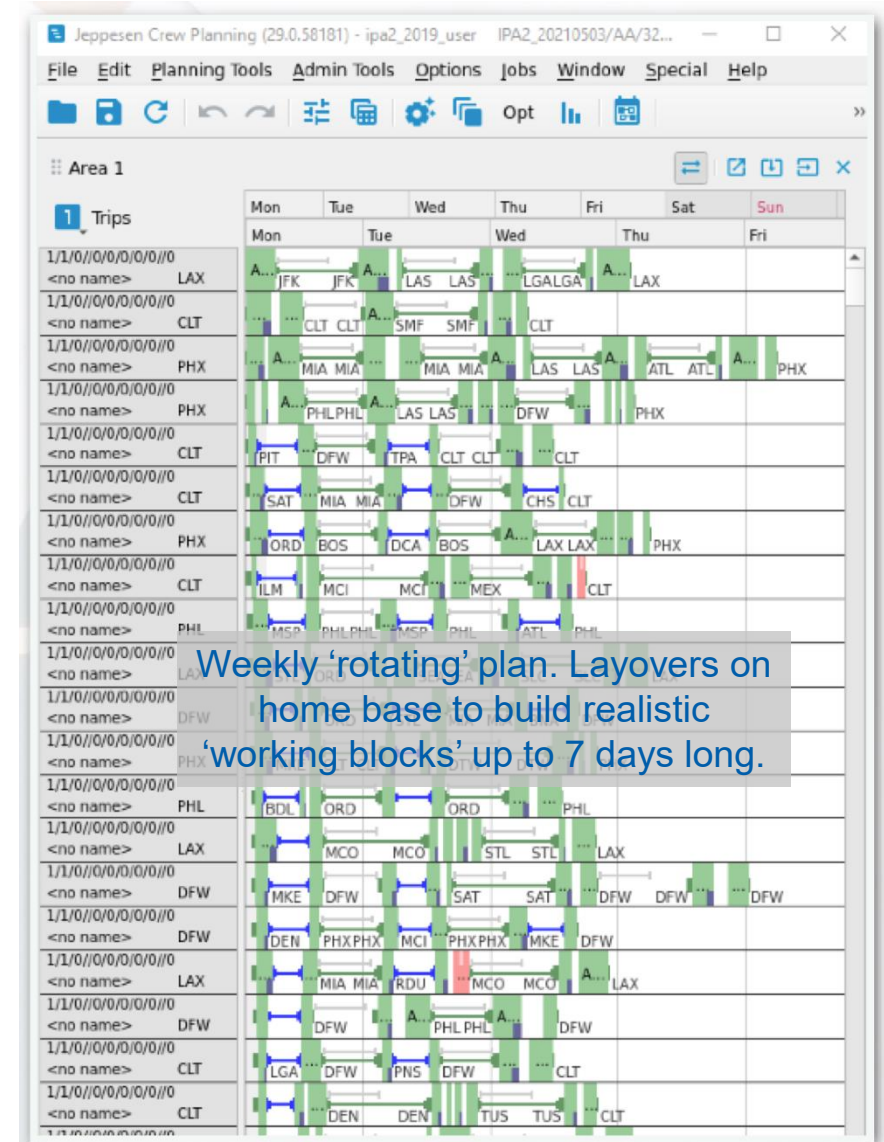
## Fleets (≈400)

- All Boeing and Airbus fleets
- NB > 200 f/w
- WB > 100
- Pax only

Crew Plans to produce:  
**4 \* 3 \* 400 = 4800**  
(8,900,000 flights planned *into* context, using >15k CPU hours...)

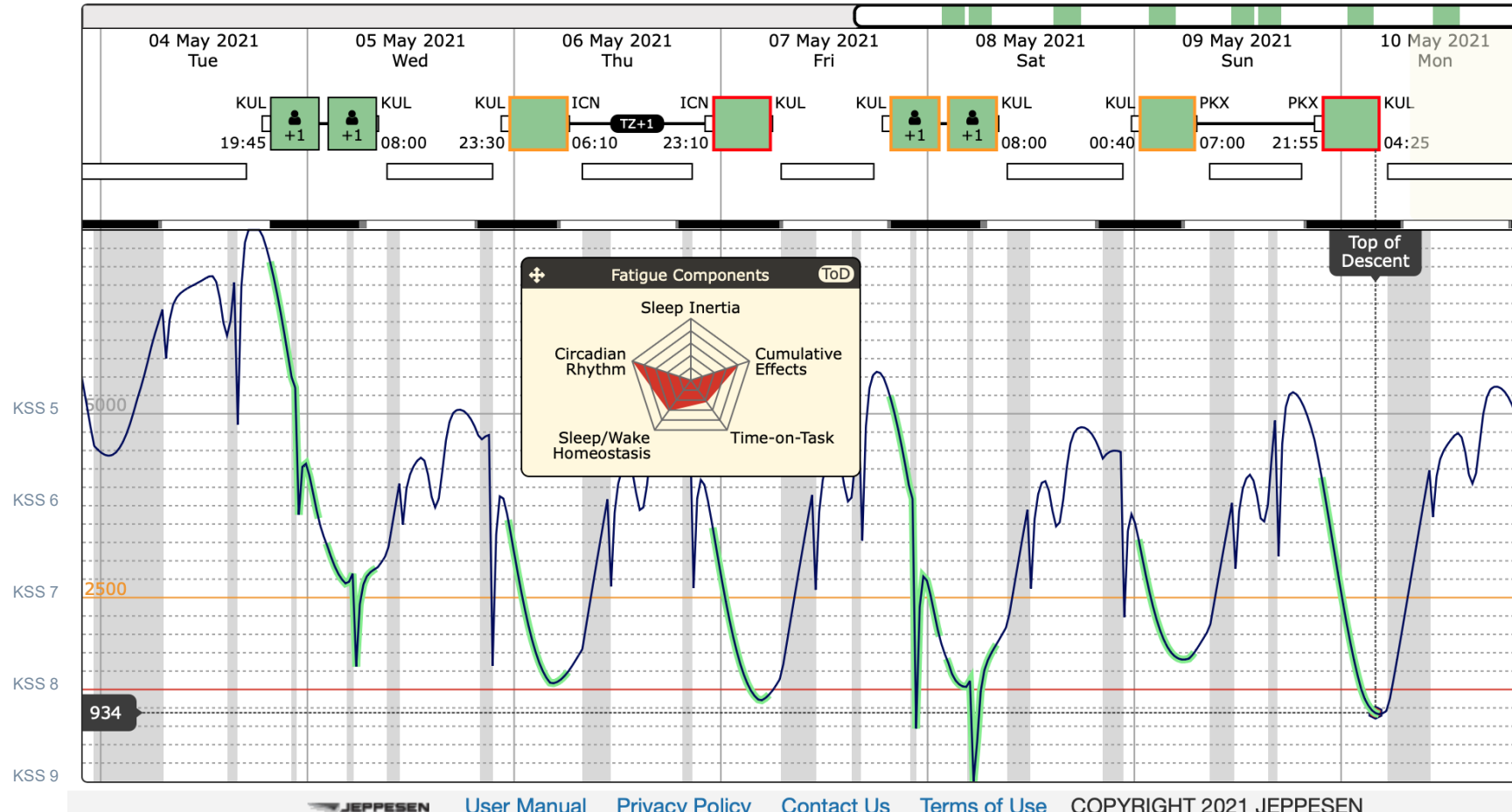


'Roll out' and load into a BI-solution



# Example of a pattern produced

Model: bam\_3.1.103 ⓘ All timings shown in timebase above unless stated differently.

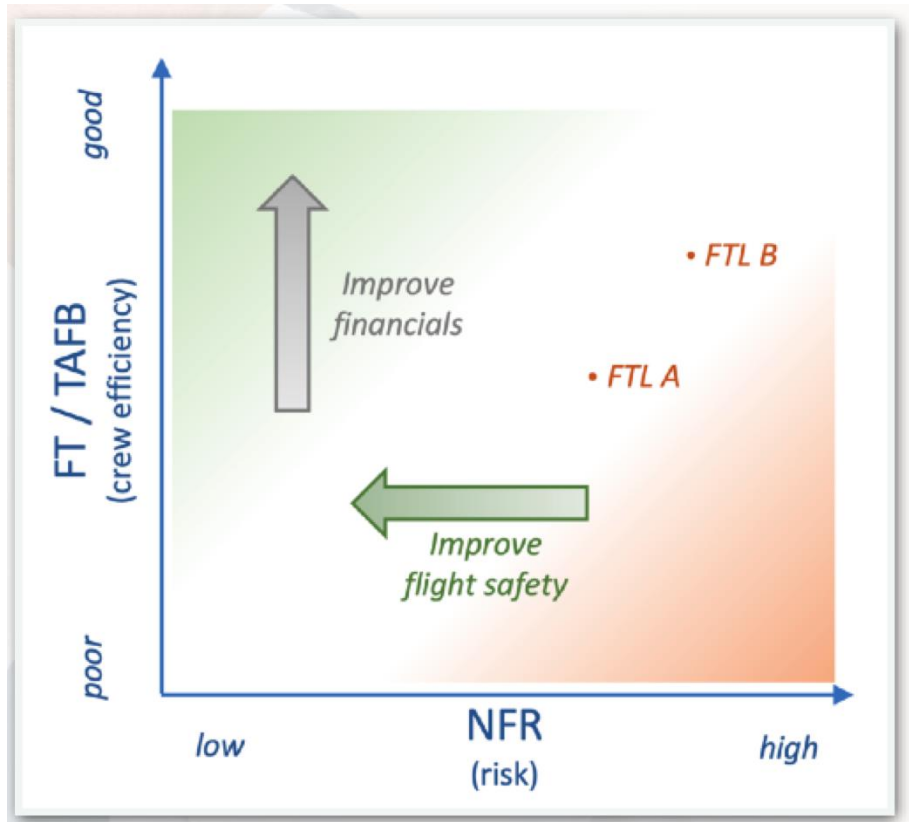


- MH 330
- Planned only using the EASA FTLs
- Six consecutive nights disrupted
- [NOT how they operate, but how they would be allowed to operate]

# The metrics

**FTL Effectiveness:**

The ability of a regulatory flight and duty time ruleset to limit fatigue risk while allowing for crew efficiency.



### A Best Practice for Quantification of Fatigue Risk

Understanding and improving upon the situation for crew fatigue risk in an operation is of course greatly simplified with a well thought-through way of quantifying this risk. To some extent one can use fatigue reports, collected data and crew feedback, after-the-fact, but what is the best practice metric for the fatigue risk in upcoming crew pairings and rosters to operate next month?

**Defining Fatigue Risk**  
There is no formal definition of fatigue risk set by ICAO or IATA. A proven useful definition when planning crew members is: the risk of crew performing a lapse, slip, mistake or violation, negatively impacting flight safety, as an effect of low levels of alertness.

With this definition, the focus thus lies on flight safety and human error primary among pilots on active flights, rather than crew comfort or sleepiness during commute, ground duties or a deadhead flight.

**A metric for one flight**  
Looking at a single flight it is clear that the potential for human error negatively impacting flight safety is greatly elevated during approach and landing, which is the phase of flying most taxing on pilot capabilities. During this time, the workload is normally at its highest and there is little margin for slowing down or double checking oneself or a colleague in order to reduce risk. The consequence of a slip, lapse, mistake or violation is also potentially disastrous. A vast majority of fatigue-related accidents in aviation are related to human error during this phase of flying.

For these reasons it makes sense to focus a metric on estimating fatigue risk primarily using the predicted level of alertness (or sleepiness) close to the end of active flights. An often used point in time for collecting data is close to top of descent (TOD), making it a good choice for predicted alertness level to represent a flight.

**Risk vs. Sleepiness**  
The risk of a lapse, slip, mistake or violation for an individual has been shown to accelerate as sleepiness increases. Figure 1 illustrates the development in the probability of an accident (dotted line) in a driving simulator where an inflection point is seen just above where subjects are experiencing KSS 8.

However, when predicting future sleepiness, a fatigue model will have limited accuracy for one individual, due to a number of reasons: the models are not perfect, models are under-informed, and there are significant inter and intra individual differences among crew. Figure 2 illustrates how the odds-ratio for an actual accident develops as a function of predicted sleepiness from a bio-mathematical model.

The conclusion to draw is that a predictive metric capturing fatigue risk should also include a risk contribution from much lower levels of predicted sleepiness than those close to, or passing KSS 8. Human physiology, when being predicted into the future, does not have any sharp 'thresholds' separating safe from unsafe. The probability of an accident accelerates more slowly, and from lower levels, when sleepiness is predicted, compared to the risk development observed for self-assessed sleepiness. Figure 3, further below, based on FDM data, tells a similar story.

**A metric for a set of flights**  
The focus of fatigue risk management when scheduling crew should of course be to reduce the overall risk for the operator to suffer an incident or accident.

**Figure 1:** Probability of an accident as a function of self-assessed KSS [1]

**Figure 2:** Odds ratio for an actual crash as a function of predicted KSS [2]

**Figure 3:** The same shape of acceleration in risk, or decrement in human performance, observed in FDM data (rate of low speed events) when correlating with predicted alertness for almost 10,000 flights

**Figure 4:** Scenario A (top) and scenario B (bottom) with the same set of flights planned in two different ways (top crew roster)

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The overall risk metric has been named AFR, for **Absolute Fatigue Risk**, and serves as a proxy for the overall probability of an incident or accident. The higher the number, the higher the risk.

$$AFR = \frac{1}{100} \sum_{i=1}^n \frac{1}{1 + e^{-x_i}}$$

where  $x_i$  is the predicted alertness in CAS divided by 100

**Using AFR**  
AFR is now our best practice metric reflecting overall fatigue risk in a set of flights. It takes both frequency (number of flights) and the severity into account and can be used in a number of helpful ways when planning crew:

- Quantify the 'system response'. In our example, will the shortening of maximum duty time result in overall lower risk? Do we also need to limit consecutive night duties?
- Suppress risk during crew pairing and roster optimization by allowing AFR to feed into the objective function.
- Distribute fatigue risk among crew, sharing the burden.
- Track the risk development over time.
- Direct focus to the right part of the operation.
- Use as a risk 'proxy' by dividing AFR over the number of flights, a metric named NFR (Normalised Fatigue Risk).

Figure 4 shows how the same set of flights have been planned in two different scenarios but with a clear difference in risk. Both scenarios respect the same planning rules but we can, by just looking at the distributions, quickly confirm that scenario B is to prefer as it contains much lower risk. (Fewer flights in the left tail of the distribution). Our AFR and NFR metrics are confirming the same thing but also quantifying that the risk has been reduced by 45%.

The AFR/NFR approach described is today used by a large number of Jeppesen customers to control and reduce overall fatigue risk and is an already established best practice, allowing them

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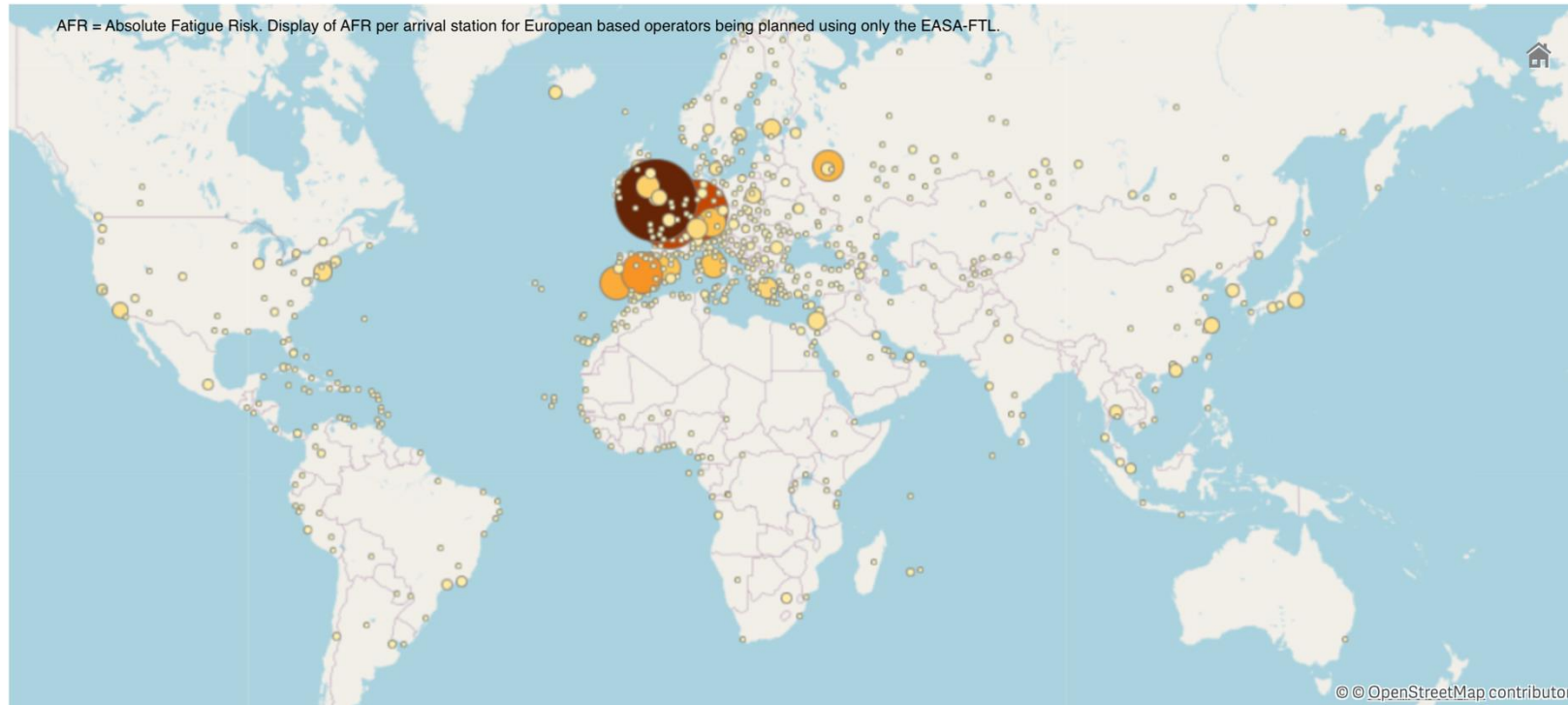
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*--- Results ---*

# EASA and European-based operators

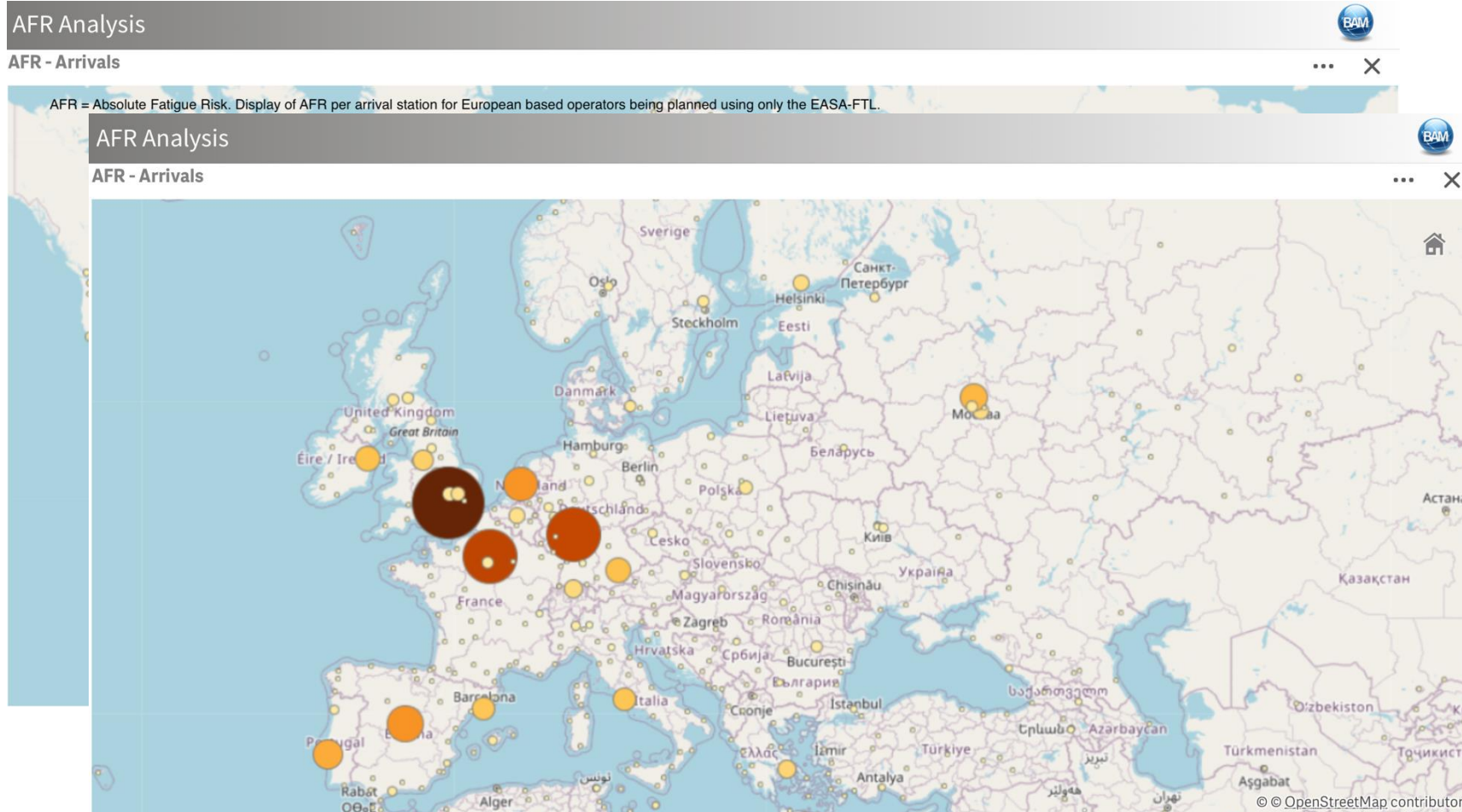
AFR Analysis

AFR - Arrivals



- European-based operators
- AFR: volume & severity, proxy for the probability
- Planned with current EASA FTLs only
- [NOT how they operate, but how they would be allowed to operate]

# EASA and European-based operators

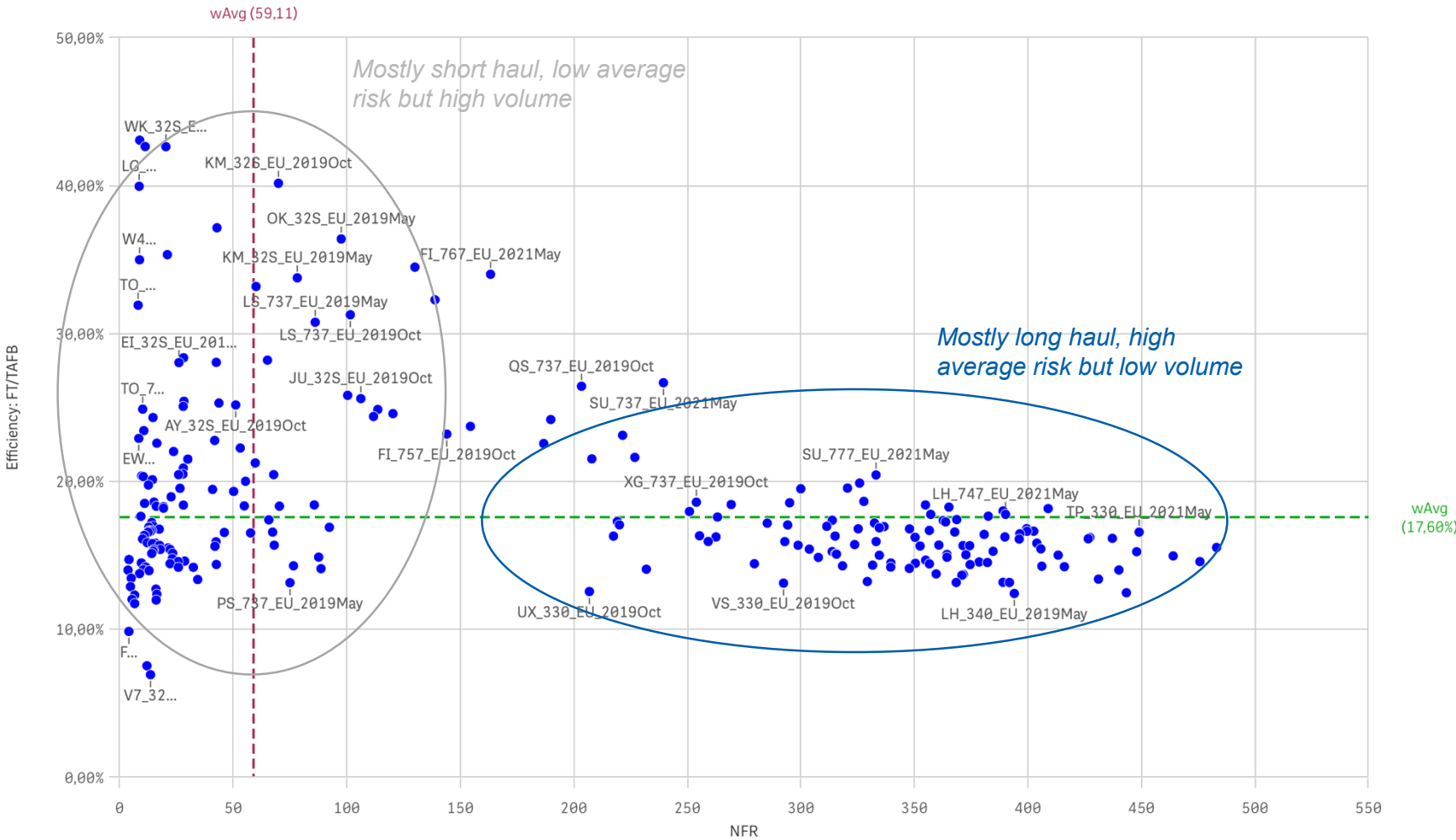


- European-based operators
- AFR: volume & severity, proxy for the probability
- Planned with current EASA FTLs only
- [NOT how they operate, but how they would be allowed to operate]



# EASA FTLs, NFR per fleet

## IPA2 Absolute Numbers



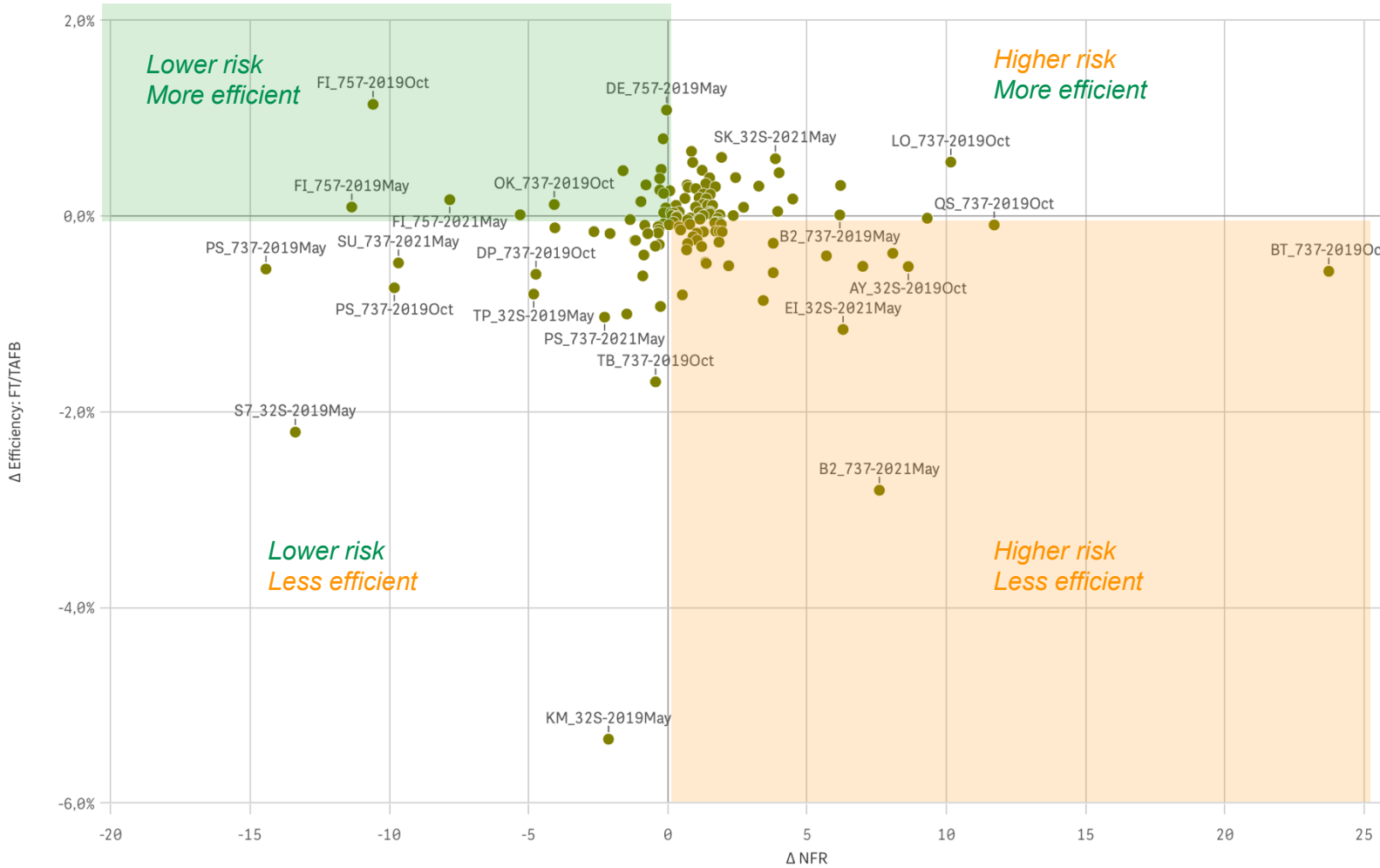
Risk of a fatigue-related incident/accident:

**47/53%**

Short haul/long haul

# Shift in Efficiency and Risk

## Subpart Q → EASA FTLs



## Short-haul (Europe)

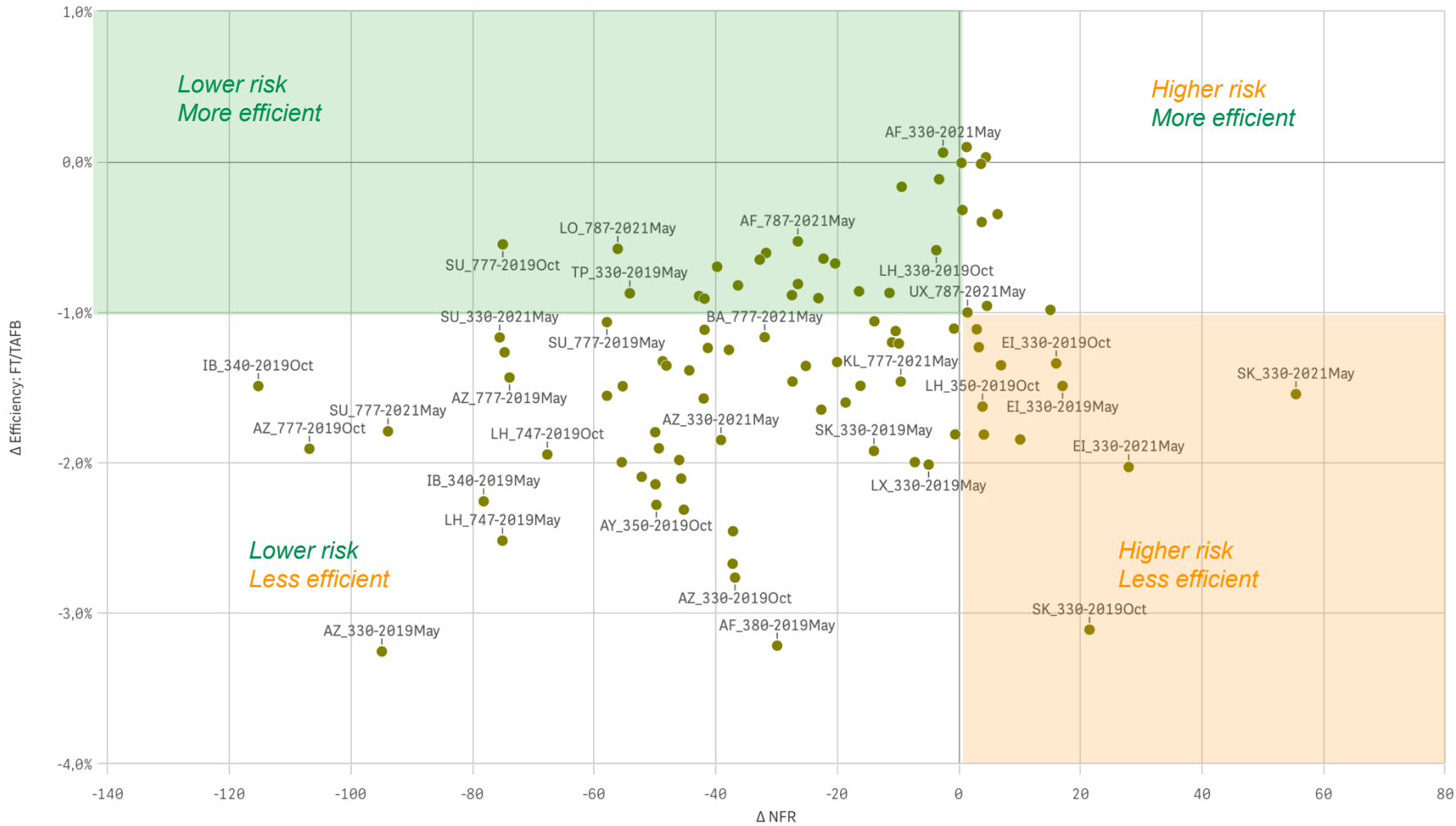
Subpart Q → EASA FTLs

NFR: 29.82 → 30.77 (+3.2%)

FT/TAFB: 17.70% → 17.60% (0.6%)

Elasticity? (small push using BAM, Subpart Q, 2019Oct)

	AF320	LH320	KLM737	Sun Express737
Ref NFR	20	26	10	242
NFR w/ penalty	11 (-45%)	17 (-34%)	5 (-50%)	223 (-7.9%)
[FT/TAFB change]	-0.25%	-1.2%	-0.13%	-1.2%
NFR w/ award	25 (+25%)	33 (+27%)	16 (+60%)	249 (+2.9%)



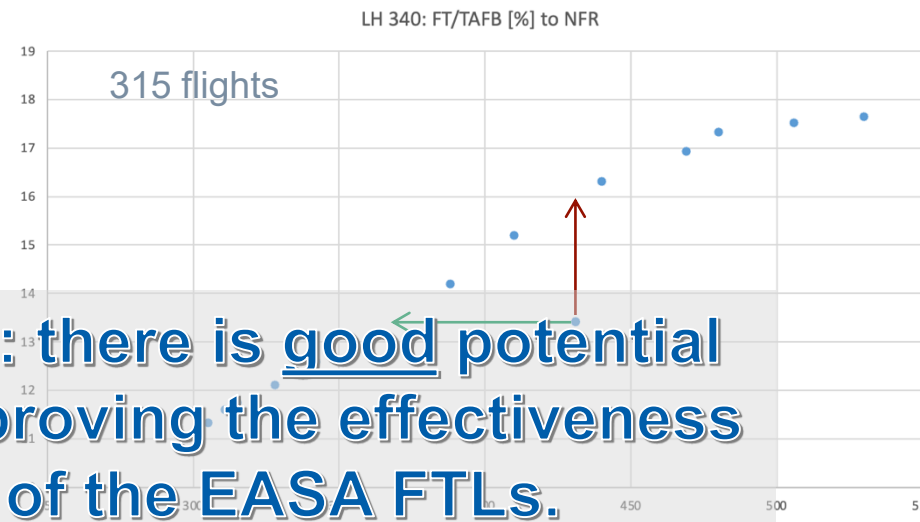
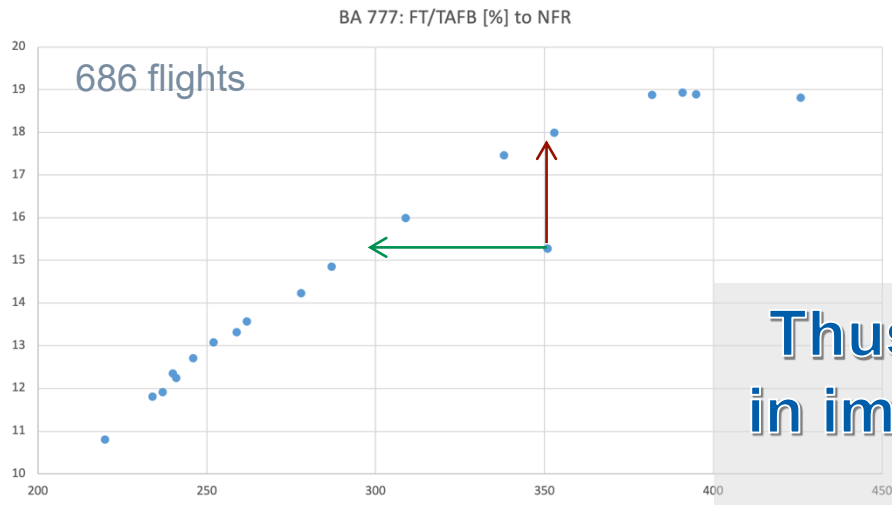
## Long-haul (Europe)

Subpart Q → EASA FTLs

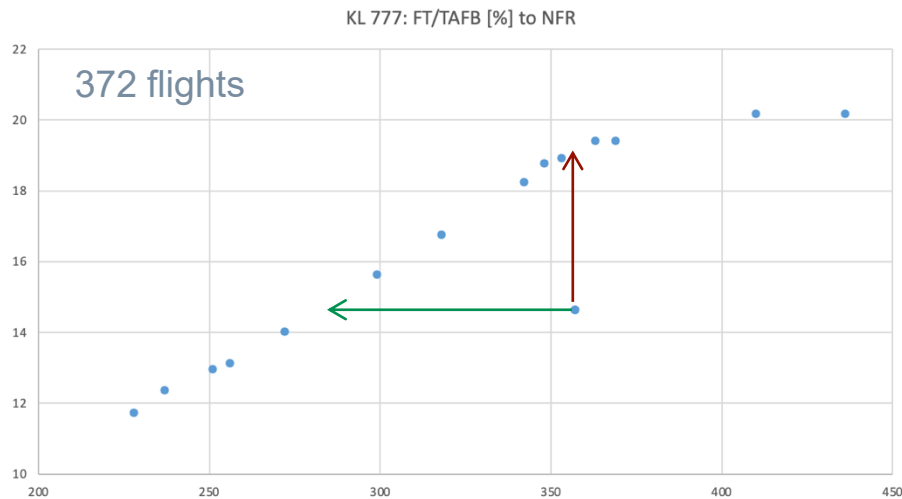
**NFR: 380.2 → 350.4 (-7.8%)**

**FT/TAFB: 17.30% → 16.10% (-7%)**

# Elasticity in long haul – it's there!



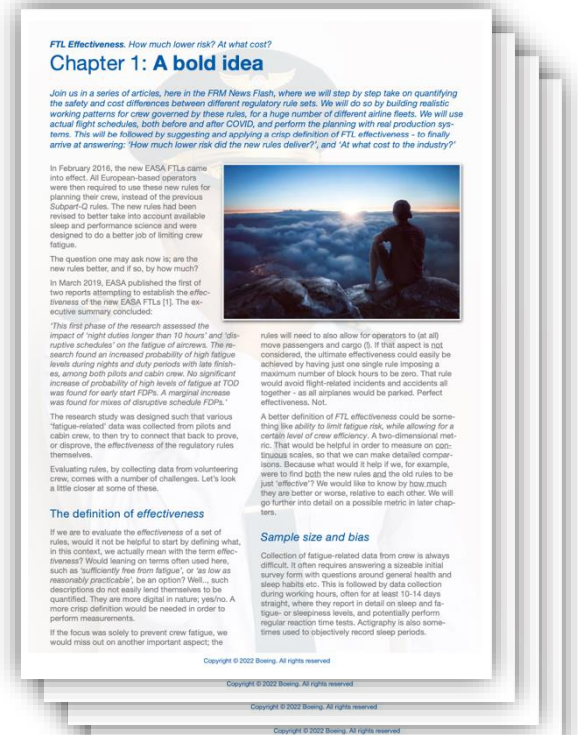
Thus: there is good potential  
in improving the effectiveness  
of the EASA FTLs.



- Weighted, remaining, potential in EASA FTL on these three fleets:
  - -16,1% fatigue risk, OR  
+18,0 % crew efficiency !!!
- ...to be compared with the overall change with Subpart Q → EASA FTL:
  - -7.8 % risk  
-7.0 % crew efficiency
- *[Note: The 16 & 18% are for only one (1) mechanism. Then there is acclimatisation, minimum rest...]*

# Discussion. Next steps?

- Hold here for a moment. Is anyone (at all) interested?
- Then:
  - What are the rules to praise/blame?
  - What can be learnt from FAR and CAAC?
  - Add CAP 371, CAO, CAR... and learn also from them?
  - Add more planning periods?
  - Measure with one more fatigue model?
  - Add also Embraer fleets?
  - *What-if* analysis to reformulate and improve the rules – on a few selected problems.
  - *Pressure-test* the rules? Direct the optimizer to produce the worst legal patterns allowed...



[Chapter 1 - a bold idea](#)

[Chapter 2 - the platform](#)

[Chapter 3 - the metrics](#)

[Chapter 4 – Had we not hoped for more?](#)

# Questions?



*Acknowledgements:*

- *Magnus Ek and Eduardo Furuzato, Jeppesen*
- *Joji Waites, BALPA*
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