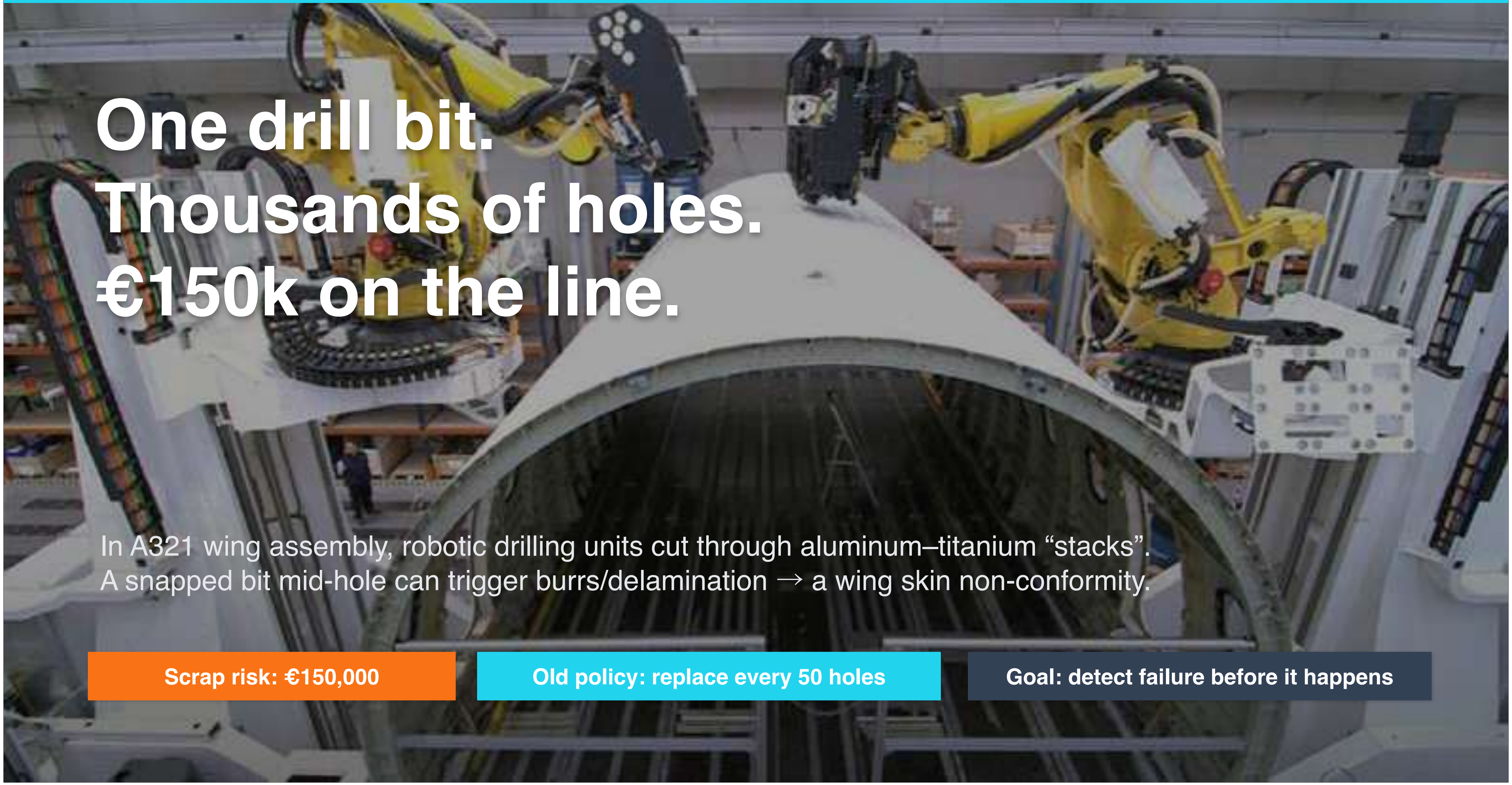
Case study: Physics-Informed Condition-Based Maintenance (CBM) for A321 wing drilling



One drill bit.
Thousands of holes.
€150k on the line.

In A321 wing assembly, robotic drilling units cut through aluminum–titanium “stacks”.
A snapped bit mid-hole can trigger burrs/delamination → a wing skin non-conformity.

Scrap risk: €150,000

Old policy: replace every 50 holes

Goal: detect failure before it happens

Time-based maintenance looked safe…

…but it created two expensive failure modes:

- 30% of bits replaced early
- 5% failed prematurely (material hardness variation)
- A mid-hole snap can cascade into interlayer burrs / delamination

The pivot: measure “wasted energy” in the cut

Specific Cutting Energy (u)

$$u = (\tau \cdot \omega) / MRR$$

As wear increases friction, more spindle power turns into heat instead of clean shearing — u spikes before failure.

Stack drill bits (example)

Digital twin (for drilling):

a live data model that mirrors each tool, regime, and hole — and forecasts risk.

Asset & Job

MSDR/Flextrack
+ wing station

→

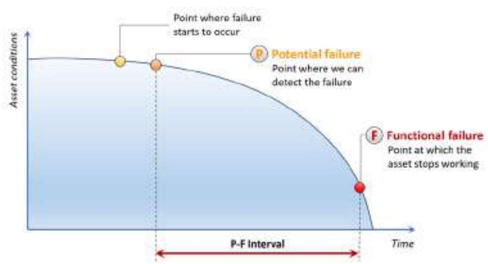
Sensor stream

Torque, ω, vib, feed
+ regime tags

→

Feature model

u, vibration score
+ anomaly score



Reliability view: P-F interval

How "P" is detected

1. Regime normalization

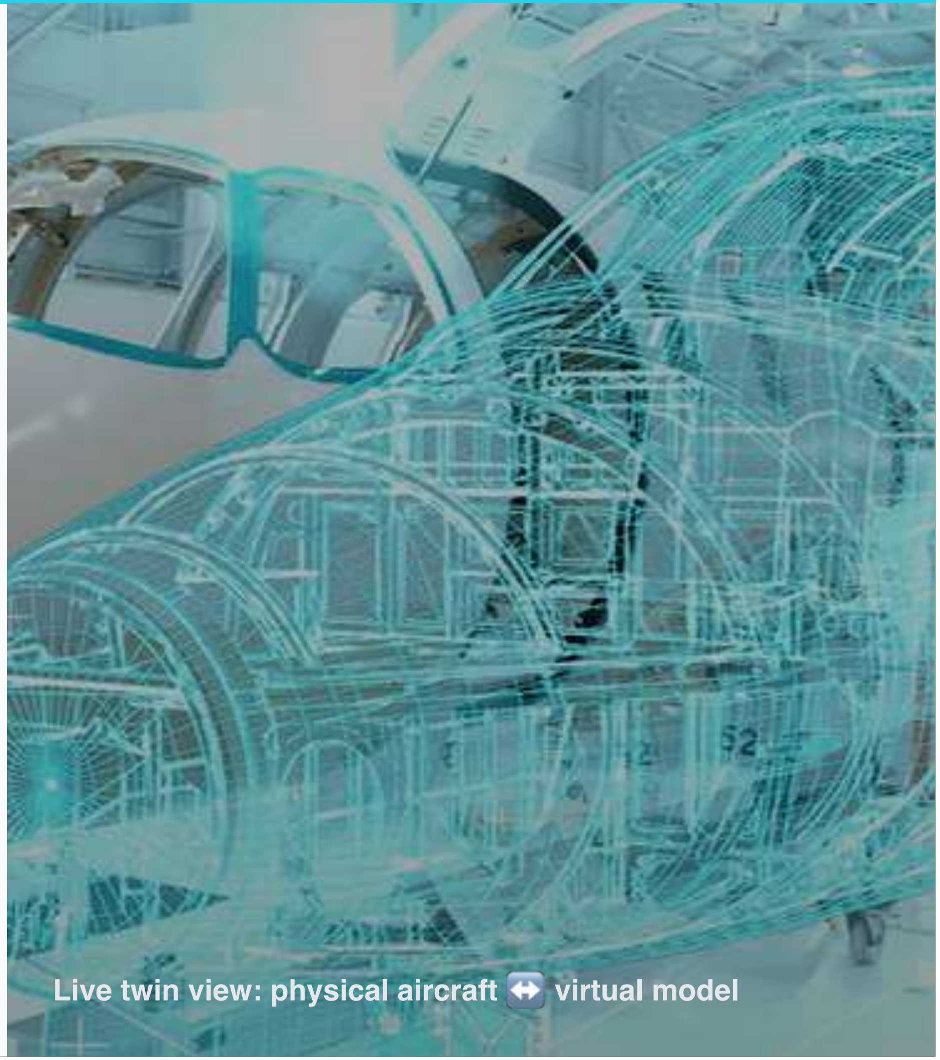
Compare like-for-like: Titanium vs Aluminum cutting regimes.

2. Anomaly isolation

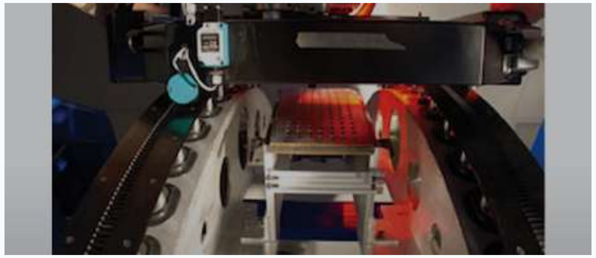
Isolation Forest scores deviations from healthy behavior.

3. Alert persistence

Trigger only if 6 of 12 consecutive samples are anomalous.



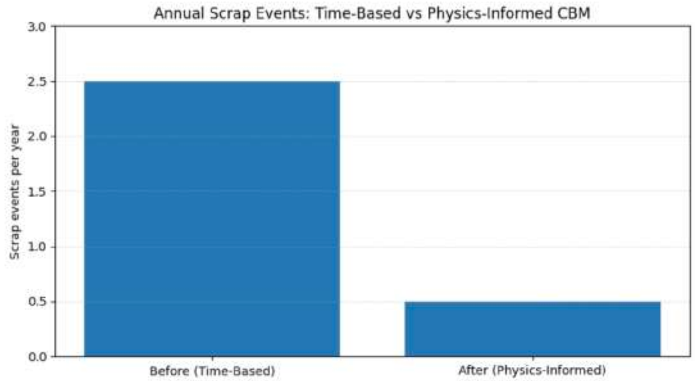
Live twin view: physical aircraft ↔ virtual model



Condition-based decisions — synchronized with the process (not the calendar).

Operational shift: reactive/static → proactive/dynamic (≈2-hour lead time at Point P)

Scrap events (wing skin)



Avg. net savings ≈ €138k per prevented failure