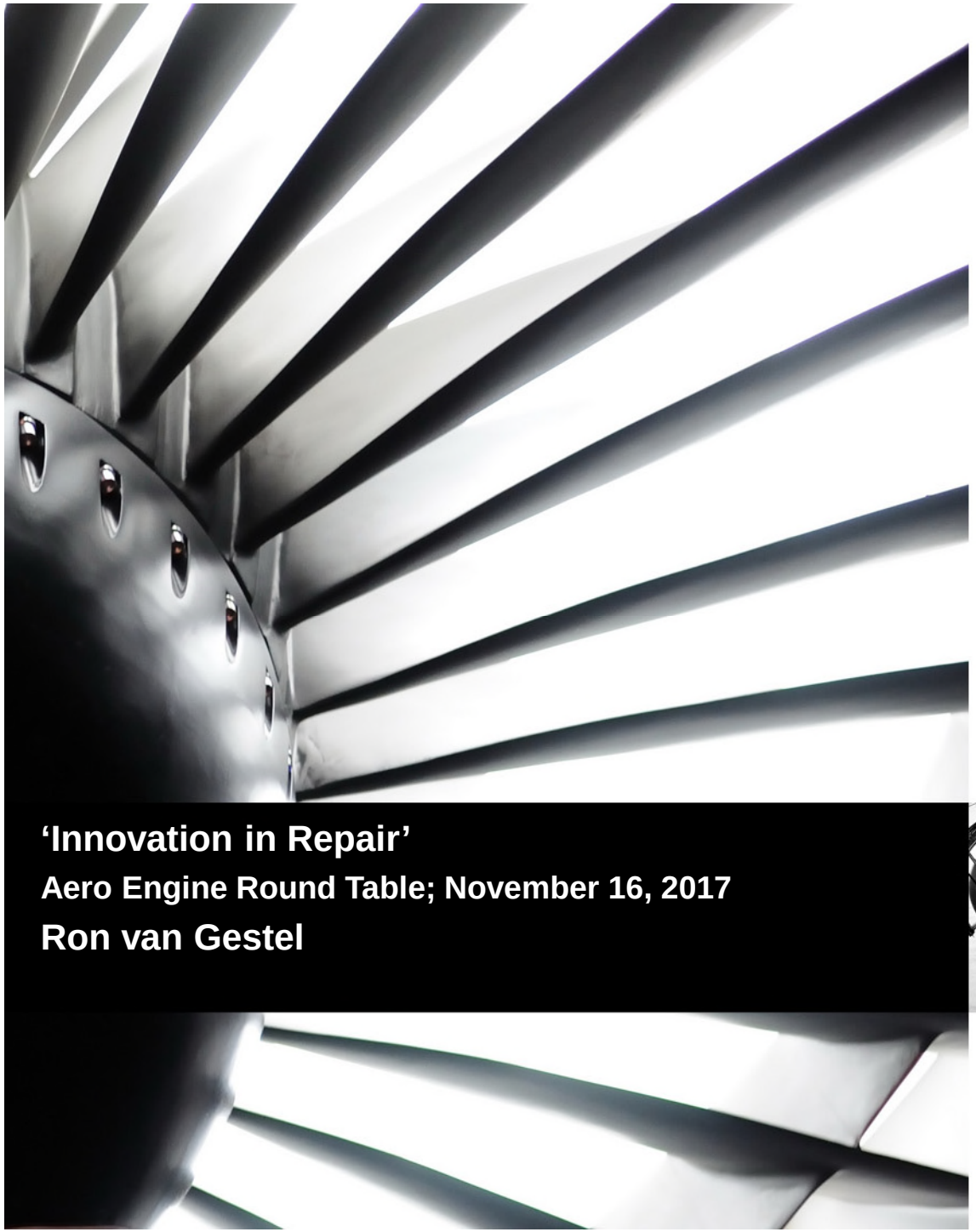


CHROMALLOY

‘Innovation in Repair’

Aero Engine Round Table; November 16, 2017

Ron van Gestel

Long live your engine.

LoC

- Playing field
- Cost drivers
- Future perspectives
- New generation engines
- New technologies & new material choices
- Innovation in repairs

Aero-Engine Component Repairs

Drivers

- Alternative to replacement
- Increases availability of parts
- Reduces overall maintenance costs
- Positively influences raw material usage – sustainability
- ….
- ….
- ….

Technical data

OEM solution

- Book repairs
- R(epair) S(ource) S(ubstantiation)
- Send to OEM affiliation

Alternative approaches

- FAA D(esignated) E(ngineering) R(epresentative)
- EASA D(esign) O(rganization) A(uthorization)

Marketing strategies - I

General Electric	TrueChoice
CFMi	TRUEngine
Pratt&Whitney	Enginewise
Rolls-Royce	Total Care

TotalCare®

Rolls-Royce

Marketing strategies - II

- An engine qualified for the TRUEngine™ program is one which has been maintained in accordance with CFM manuals and recommendations. These engines contain TRUEngine LLP (Life-Limited Parts), which are rotating critical parts that have always operated in CFM-approved configurations
- The principal advantage of TotalCare programs is to provide the most cost effective, risk-mitigated engine maintenance plan through Rolls-Royce's Network
- EngineWise represents a commitment to share intelligence with you to develop the best solutions together. From a single engine overhaul to comprehensive fleet management, we are delivering straightforward solutions to reduce total cost of ownership and optimize fleet availability
- A TRUEngine is an engine which has been maintained to GE or CFM manuals and recommendations. A TRUEngine contains TRUEngine LLP, which are life-limited parts (LLP) that have always operated in GE- or CFM- approved configurations. When rotating LLP and their associated critical influencing parts and all other internal engine parts are confirmed for GE- or CFM-approved configuration, the engine is eligible for TRUEngine status.

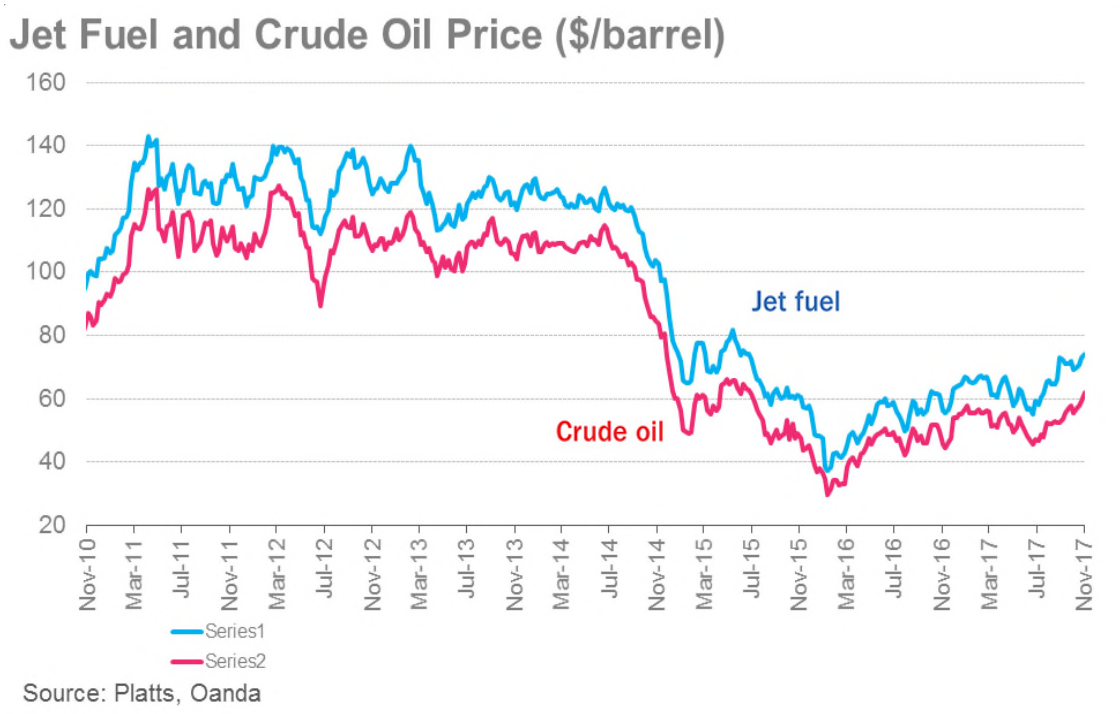
Effect/Consequences for the after market

- Manipulation on liability responsibility
- Increased pressure on rule making
- Operators rely more on the OEM solution
- Limited need/demand to develop alternative solutions (like repairs, PMA's)
- More rigid regulations lead to increased development effort (time & costs)
- Less 'independent' vendors available
- Limited interest from operators to 'commit'
- Need driven repairs delayed by OEM priority setting
- Increased pricing – 'monopoly'-situation
- Focus on replacement instead of repairs

But, is this MAIN

THE COST DRIVER?

Price-of-Fuel

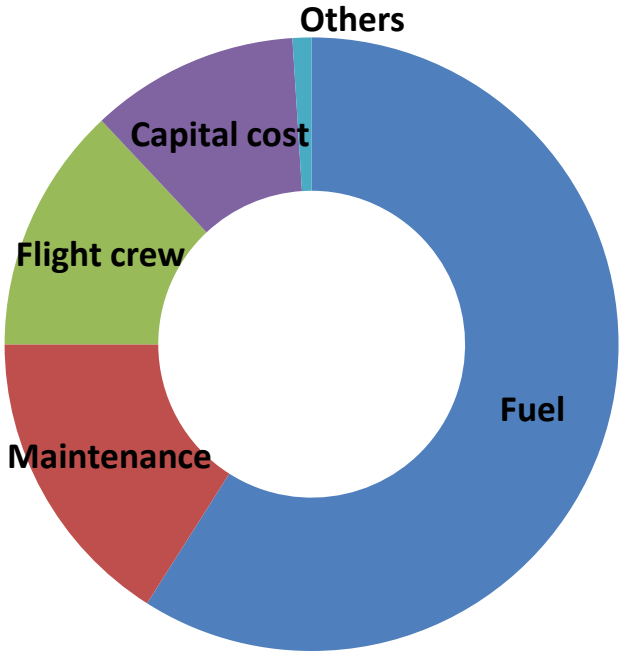


Price-of-Fuel

New economics are tilting fleet decisions toward new aircraft for some models

Airline Operating Costs

(averaged over all aircraft types)



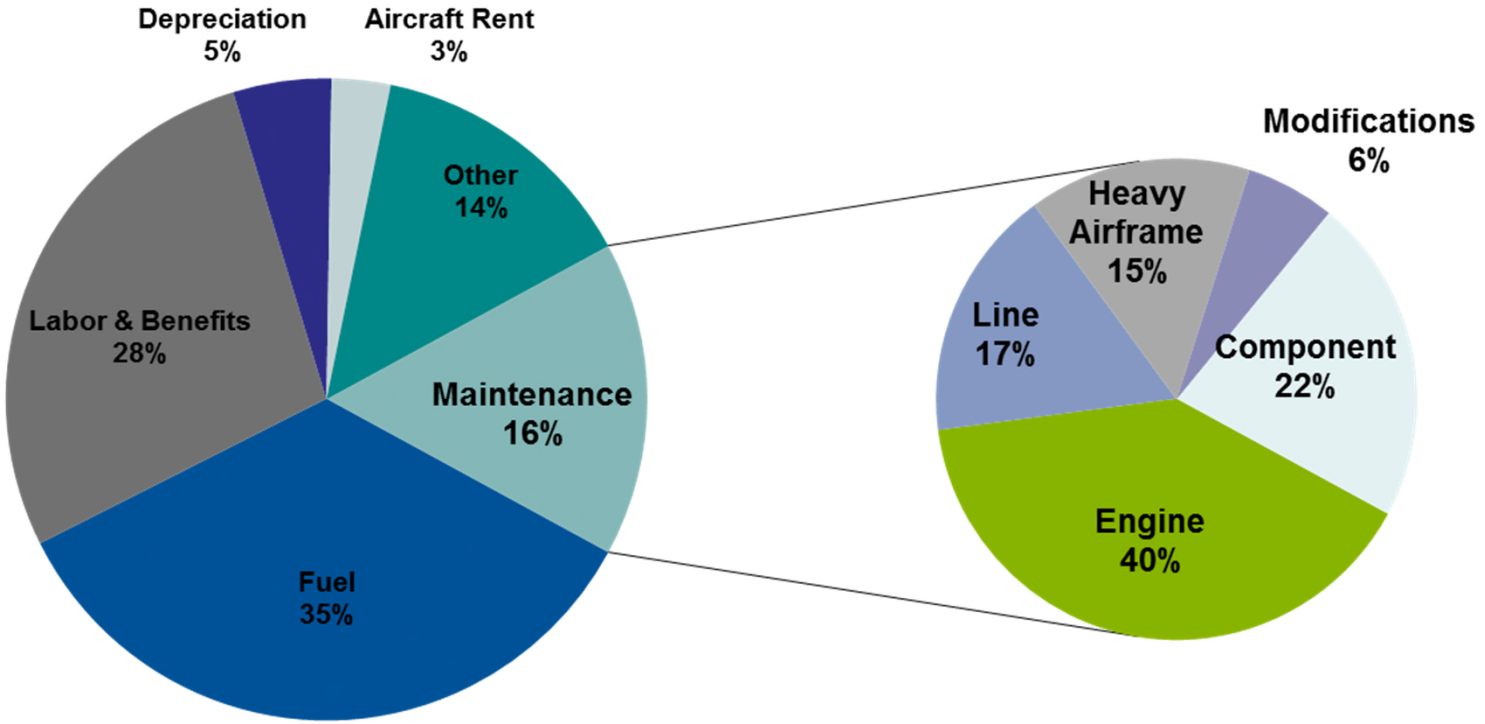
Costs	New 737-700	Old 737-300
Fuel @ 93$/bbl WTI	3.24	3.80
Other costs excl. maintenance	2.46	3.49
Maintenance costs	0.10	0.24
Total other costs	3.21	3.73
Cost of buying new @ 7% interest rate / Gain from selling @ 1% cash return	1.11	
Total costs	**6.90**	**7.53**

Sources: [29271]

Airline Operating Cost

Typical Airline Operating Costs 2013
US$ 380B

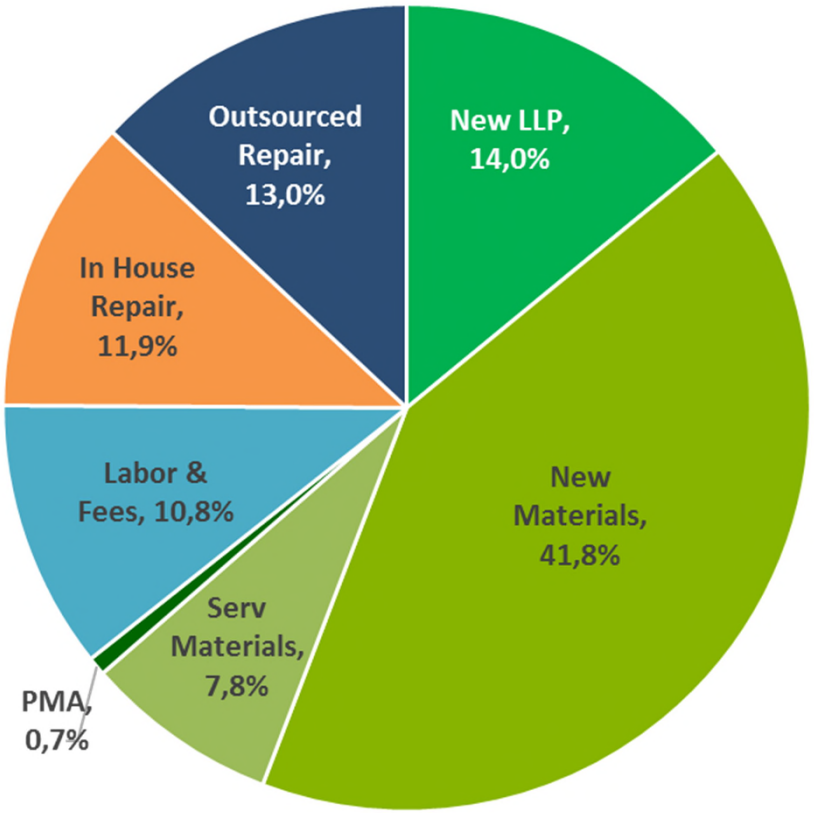
Typical Airline Maintenance Costs 2013
US$ 60B



Source: ICF SH&E

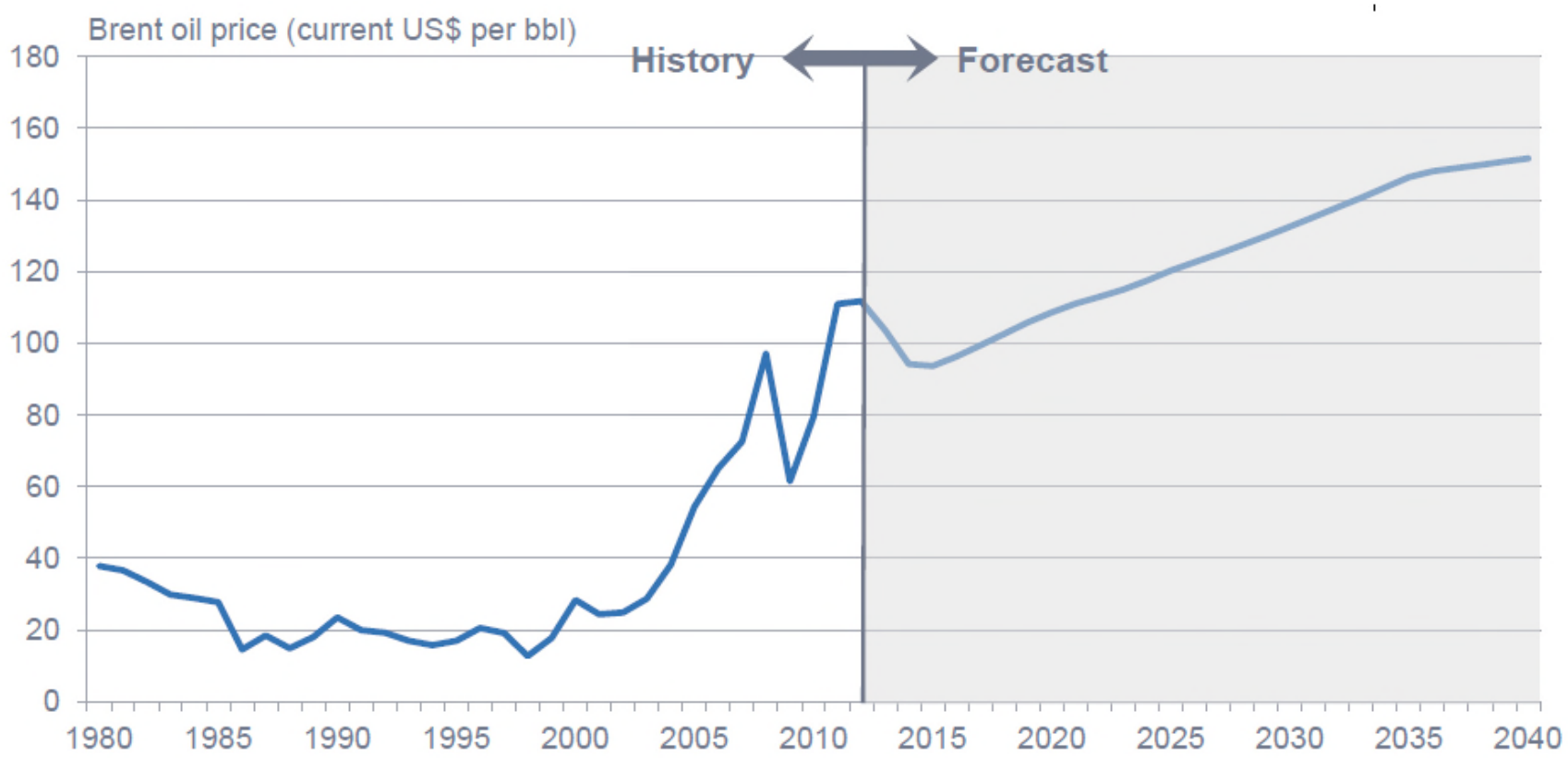
Understanding the magnitude of the maintenance costs within the airline operating costs, make airlines more cost-aware

Cost distribution engine only



FUTURE PERSPECTIVE

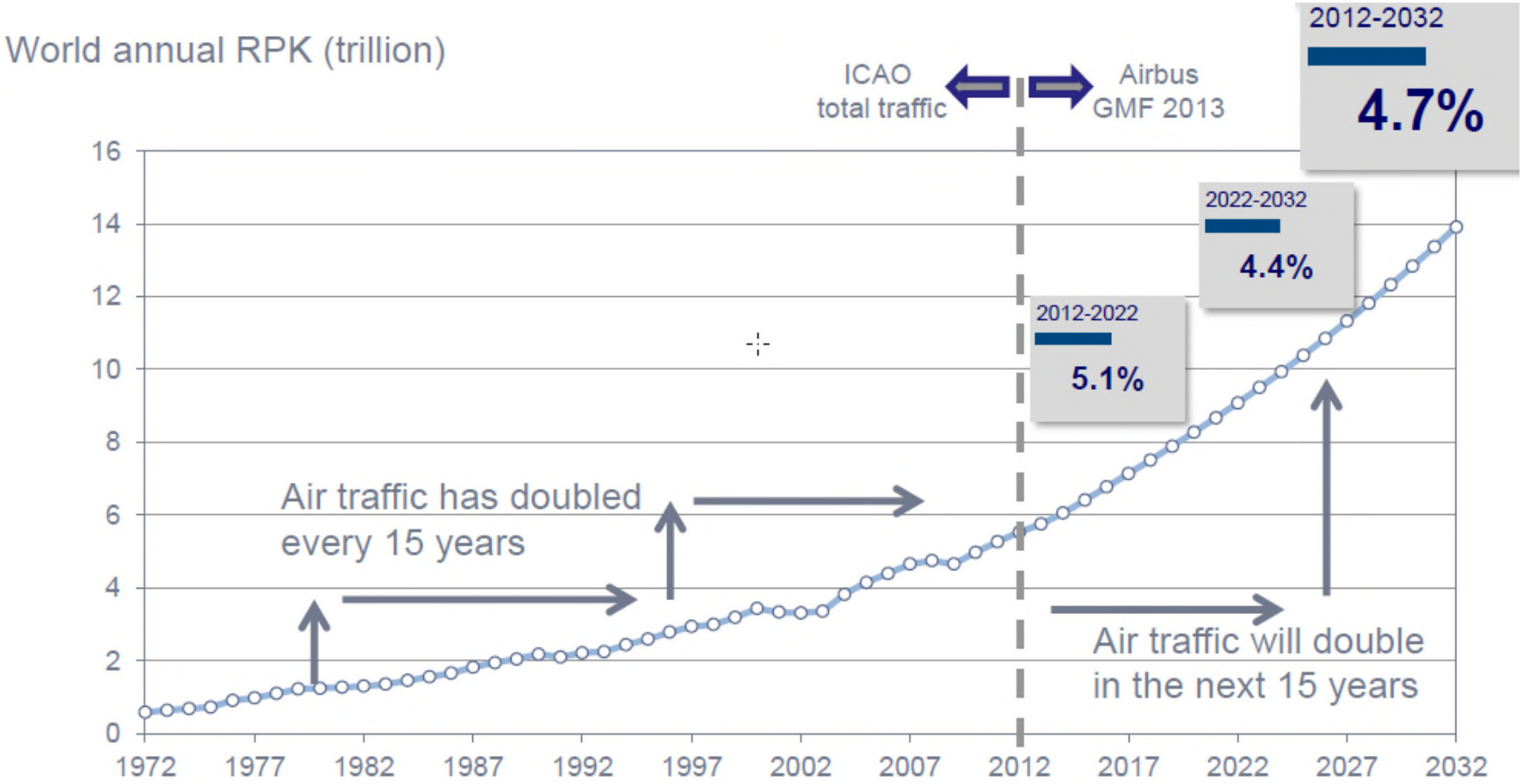
Demand for fuel-efficient engines driven by fuel prices



Source: EIA, IHS CERA, Airbus

Fuel costs are expected to increase and maintain to be a significant cost for the Airlines

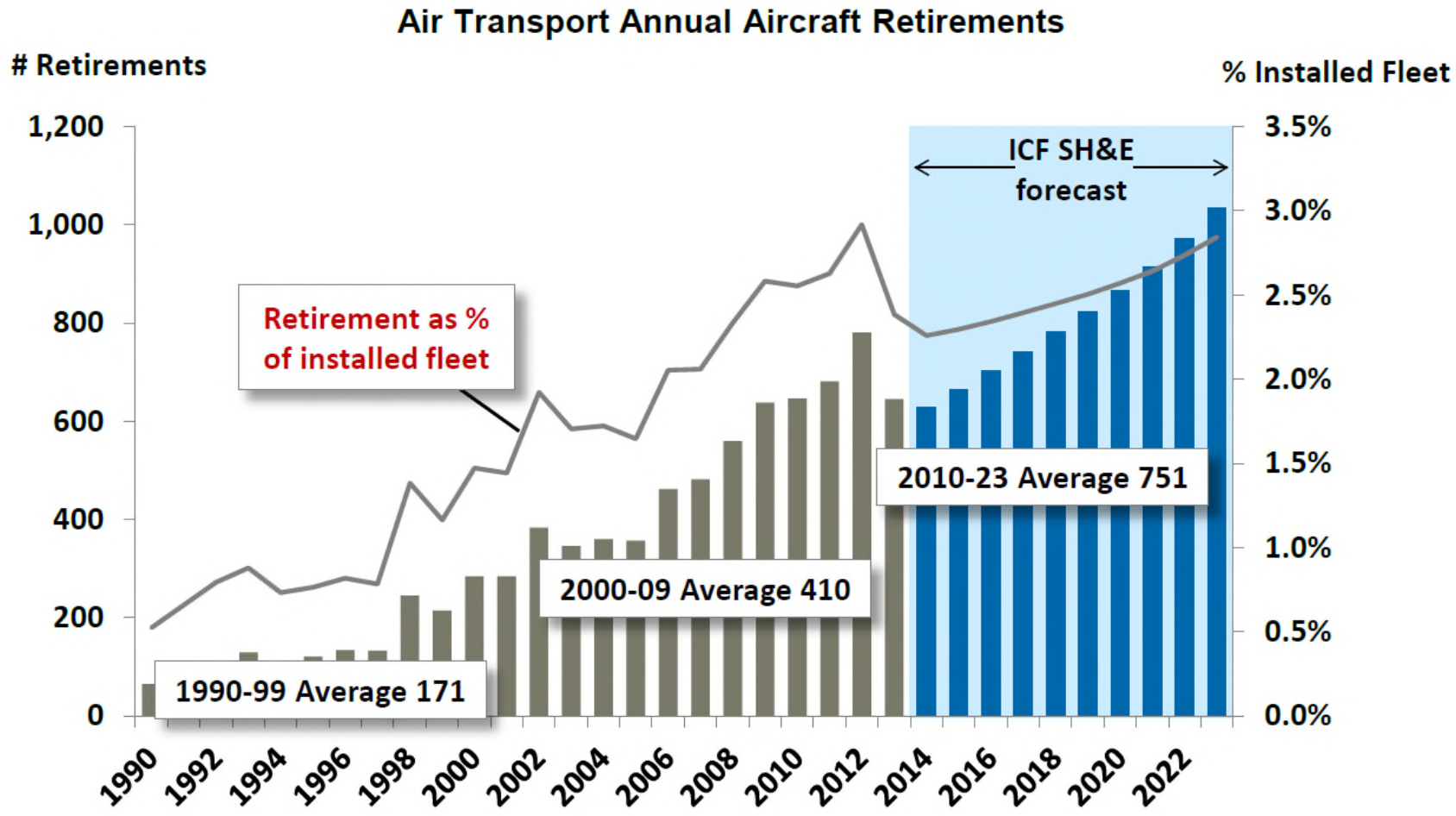
Air travel remains a growth market



Source: ICAO, Airbus

Air travel has proved to be resilient for economic uncertainties, such as oil crises, Gulf & Asian crisis, WTC attack, SARS and the financial crisis and has doubled every 15 years

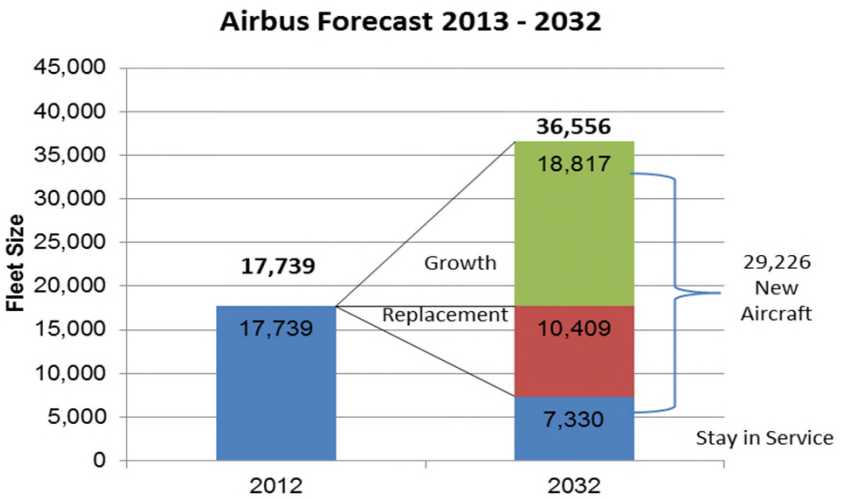
Significant reduction in Economic life of A/Cs

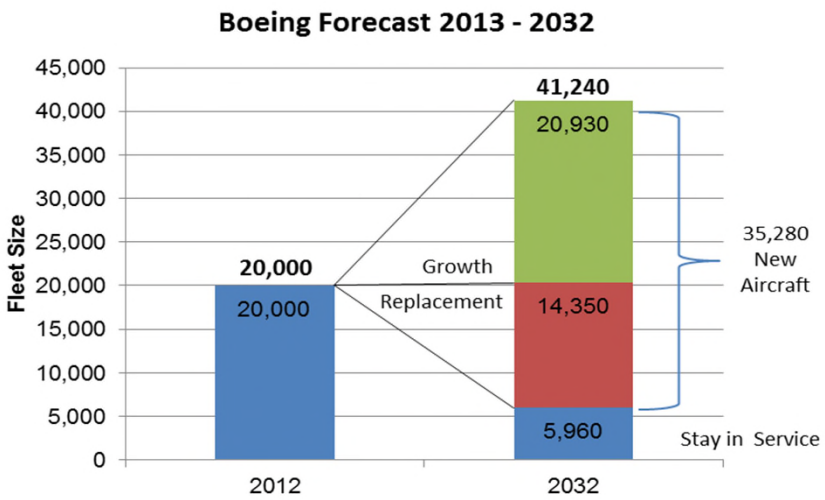


Source: Airline Monitor, ACAS, ICF SH&E

Decreasing the economic life of an A/C from 40 years to <25 years

2013 – 2032 Commercial Aero Aircraft Outlook





- **Replacement of less eco-efficient aircraft – 2/3 of existing fleet will be replaced**
- **Traffic will double in the next 15 years**
- **Air Transport is highest in expanding regions**
- **Market for new airplane deliveries set to become more geographically balanced**
- **Airbus & Boeing estimate that airlines will need nearly 65,000 new airplanes**

Source: Airbus & Boeing

The next 20 years there is a requirement for over 35,000 aircraft, severely clogging the OEM supply chain

NEW GENERATION ENGINES

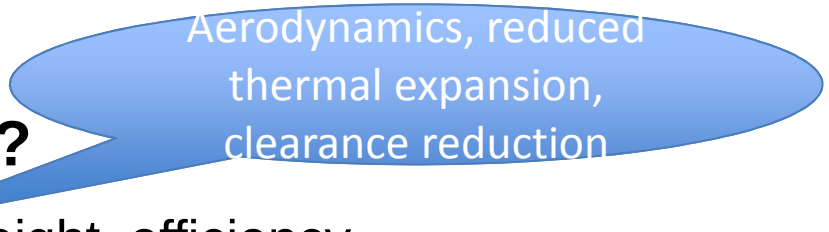
Strive to be ……

CLEANER,

QUIETER,

FASTER, (HOTTER)

MORE AFFORDABLE



How is one intending to do this?

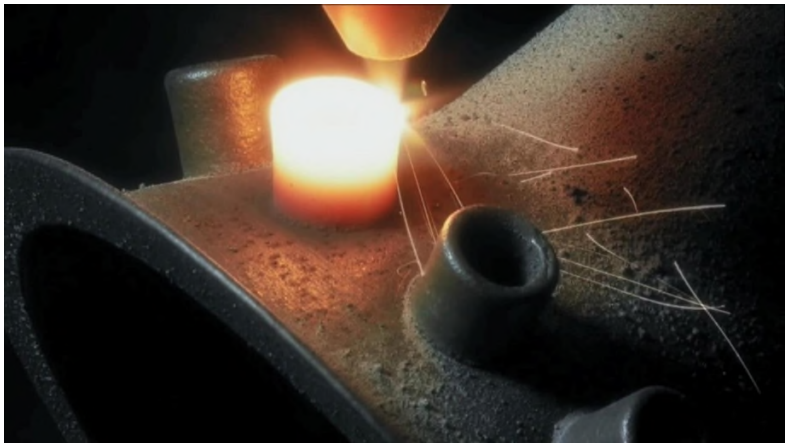
- Performance improved design, weight, efficiency
- Emissions emission reduction, alternative fuels, noise
- Reliability durability
- Costs of ownership fuel burn, maintenance costs

This can be reached by …..

NEW TECHNOLOGIES & NEW MATERIAL CHOICES

New technologies

- Additive manufacturing



New technologies

- Additive manufacturing
- Electrochemical machining

New technologies

- Additive manufacturing
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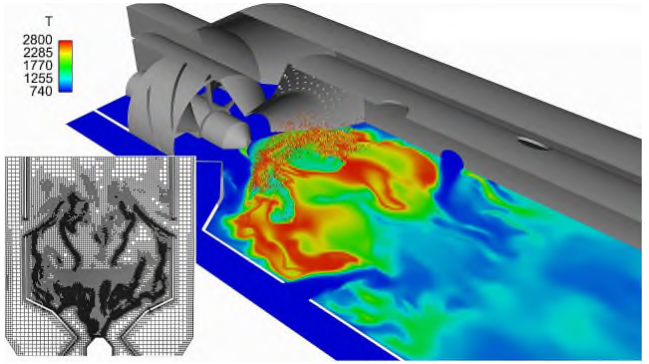
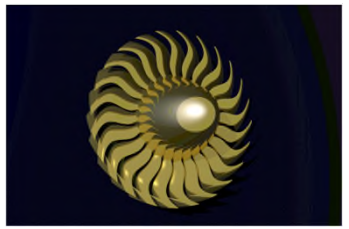
- Metal/Ceramic injection moulding

New technologies

- Additive manufacturing
- Electrochemical machining
- Metal/Ceramic injection moulding
- 3D aerodynamic design
- New generation cooling systems
- Combustion dynamics



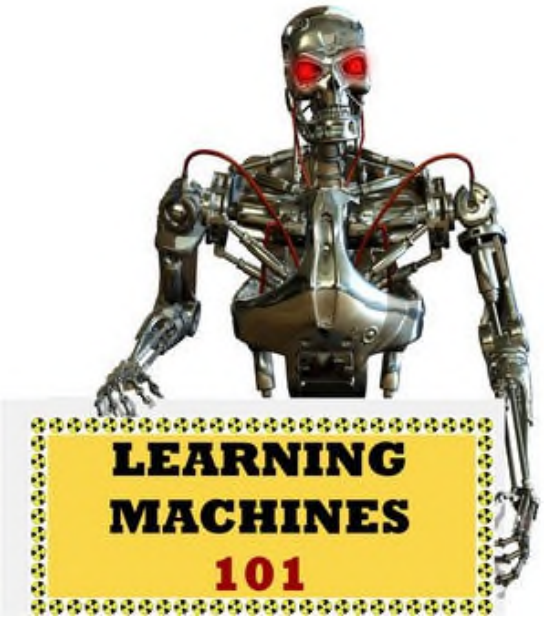


New technologies

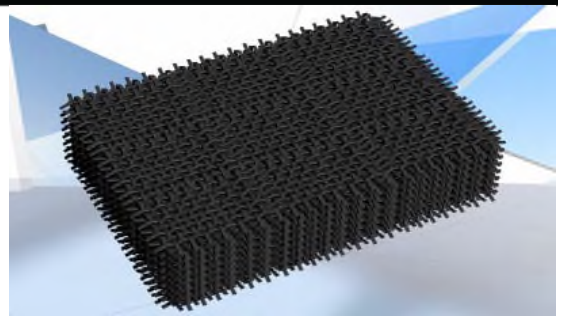
- Additive manufacturing
- Electrochemical machining
- Metal/Ceramic injection moulding
- 3D aerodynamic design
- New generation cooling systems
- Combustion dynamics
- Advanced LP turbine
- Blisks & impellers
- …

New technologies

- Additive manufacturing
- Electrochemical machining
- Metal/Ceramic injection moulding
- 3D aerodynamic design
- New generation cooling systems
- Combustion dynamics
- Advanced LP turbine
- Blisks & impellers
- …
- Artificial intelligence (Adaptive machining)
- Robotics



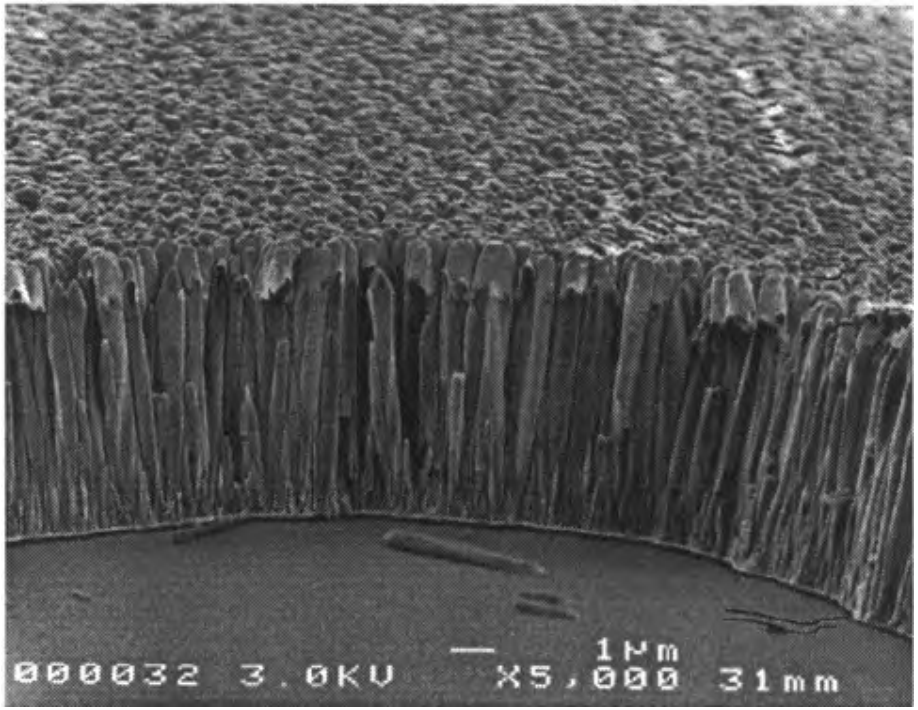
New material choices



- Composites (CFC, PMC, MMC, CMC)

New material choices

- Composites (CFC, PMC, MMC, CMC)
- Advanced coating systems
  - Compressor
  - Turbine



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New material choices

- Composites (CFC, PMC, MMC, CMC)
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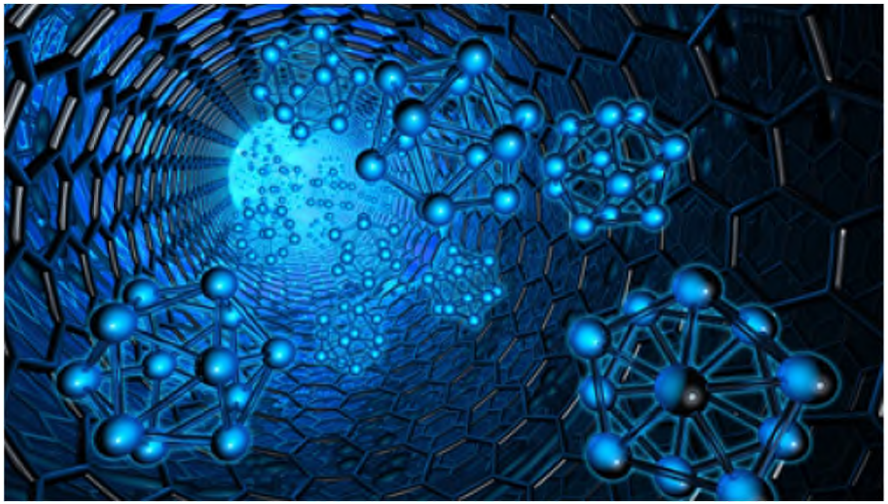
  - Compressor
  - Turbine
- Powder technology
- Nano technology



New material choices

- Composites (CFC, PMC, MMC, CMC)
- Advanced coating systems
  - Compressor
  - Turbine
- Powder technology
- Nano technology
- Titanium aluminides
- …..

INNOVATION IN REPAIRS

Legacy versus advanced engines

Technical data

- **Legacy engines**
  - Content OEM repair manuals reduces
    - more critical inspection criteria
    - more control of critical processes (RSS)
  - This results in some cases that repairs are no longer feasible → **consumable parts**
- **Advanced engines**
  - Limited content OEM repair manuals
  - (Detailed) technical data limited up to not available
  - Send back to OEM
    - → **Full control serviced parts!**

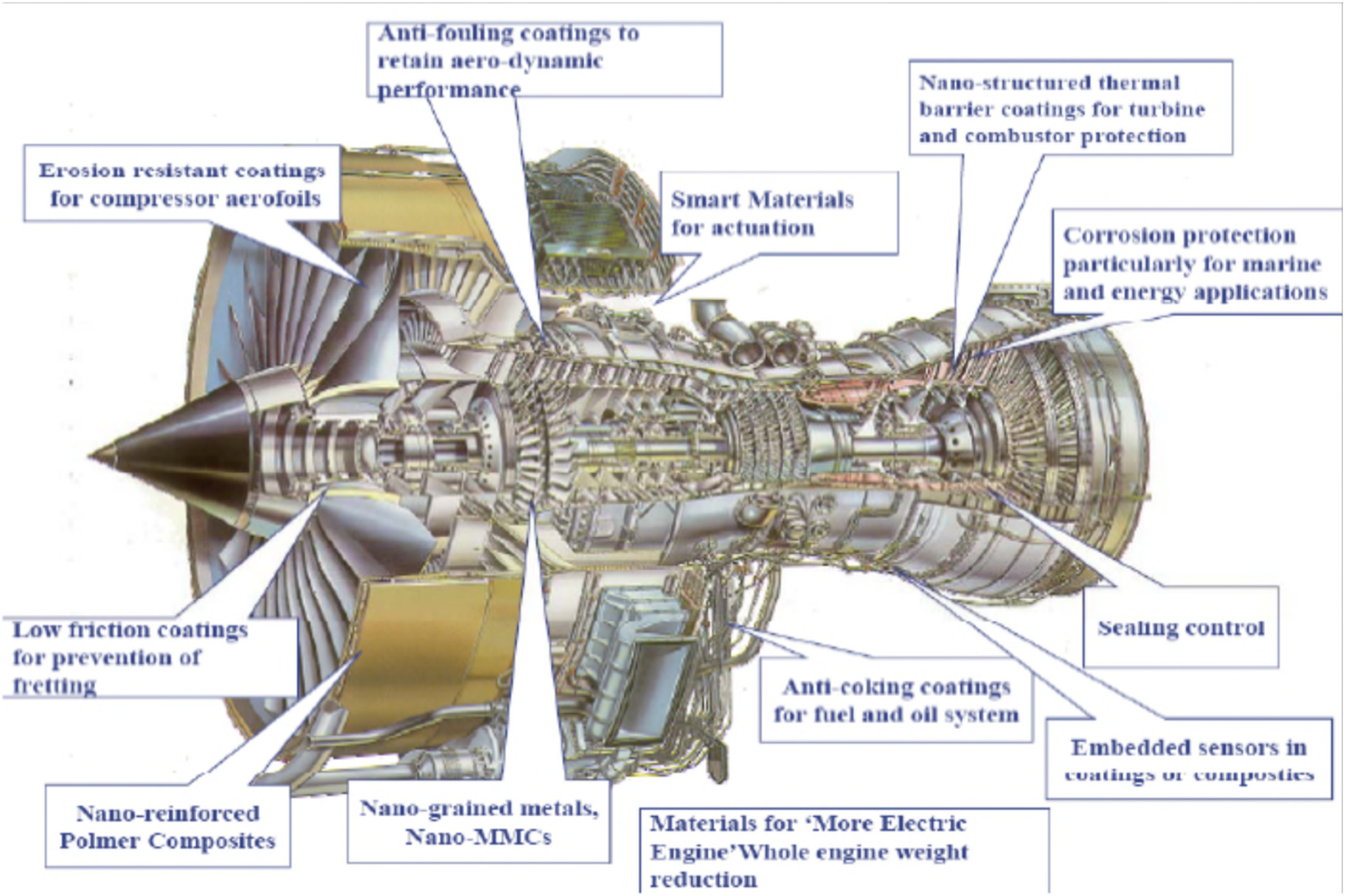
Complexity of developing alternative solutions

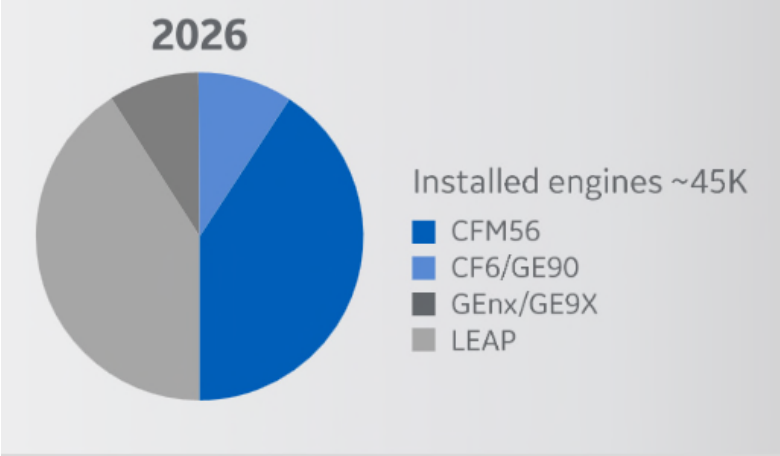
- More stringent regulations
- Increased data protection
  - ‘Software’
  - Hardware
- Patent infringement challenges
- Proprietary materials & coating systems
- Repair investments frequent design changes
- Operator committment

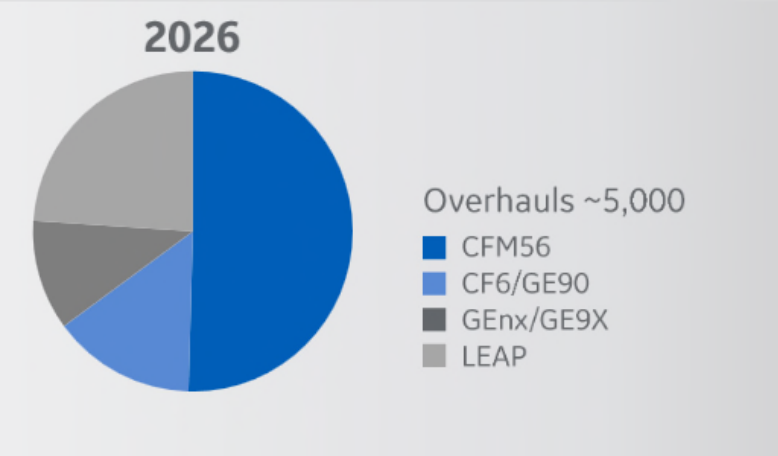
CHROMALLOY

Long live your engine.

BACKUP SLIDES


Anti-fouling coatings to retain aero-dynamic performance
Nano-structured thermal barrier coatings for turbine and combustor protection
Erosion resistant coatings for compressor aerofoils
Smart Materials for actuation
Corrosion protection particularly for marine and energy applications
Low friction coatings for prevention of fretting
Sealing control
Anti-coking coatings for fuel and oil system
Embedded sensors in
Nano-reinforced Polmer Composites
Nano-grained metals, Nano-MMCs
Materials for 'More Electric Engine'Whole engine weight reduction

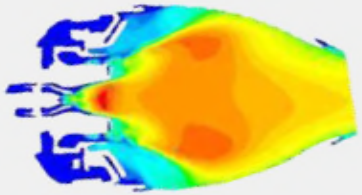




In 10 years the new technology engines will account for 50%+ of the fleet and about 1/3rd of the maintenance shop visits

Lean-burn combustion

Lean-burn combustor



Reduced hot spots

Improved durability … throughout hot section

Advanced materials

Ceramic Matrix Composite (CMC)

Combustor liner

1/3 weight

2x strength

Reduced cooling air

Advanced cooling

Similar metal temperatures with higher gas temperatures