PART I

High Temperature Electronics Background

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High Temperature Electronics for Aviation Applications

Aviation is a dynamic industry that continuously adapts to various market forces. The aviation market doubles in size, every 10 to 15 years, so there will be a greater need in the future for large aircrafts.

Key market forces that impact the airline industry are fuel prices, economic growth and development, environmental regulations, infrastructure, market liberalization, airplane capabilities, other modes of transport, business models, and emerging markets [1]. Each of these forces can have both positive and negative impacts on the industry.

While the world economy GDP is expected to grow by 3.2% between 2012 to 2032, the number of airline passengers and airline traffic is expected to grow by 4.1% and 5%, respectively in the same interval.

The fleet size is expected to roughly double from 2013 to 2032 [1]. A long-term demand of 35280 new airplanes, valued at $4.8 trillion is forecasted [1]. 14350 of them will replace older, less efficient airplanes, reducing the cost of air travel and decreasing carbon emissions.

Europe is forecasted to be second largest market in the world by 2032 [1]. As shown in one of following section, from 2008 EU has already started to address and shape future aviation needs in Clean Sky and Clean Sky2 programs.

1.1 Value Story

Air traffic contributes today about 3% to global greenhouse gas emissions, and it is expected to triple by 2050 [2]. Although, other sectors are more polluting (electricity and heating produces 32% of greenhouse gases), pollution from air traffic is released high in the atmosphere where the impact is much greater. Meeting the climate and energy objectives will require reducing drastically the sector's environmental impact by reducing its emissions. Maximizing fuel efficiency to use less to go farther is also a key cost-cutting factor in a very competitive industry – and as air traffic increases, better noise reduction technologies are needed. Game-changing innovation in Aviation is risky, complex and expensive, and requires long-term commitment. This is why all relevant aviation stakeholders must work together to develop proof-of-concept demonstrators.

1.2 Fuel Prices Are Challenging the Airliners Profitability

Volatile oil prices have been the greatest challenge to airline profitability apart from the weak economy. *Fuel costs have surpassed labor as the largest segment of airline operating cost [1].* Fuel costs, approximately 13 percent of total costs in 2002, are closer to 34 percent today. After spiking in early 2012, oil prices have decreased in 2015. On the demand side, the weak economic outlook has moderated near-term growth projections. On the supply side, rising shale oil production in the United States is moderating near-term price projections. Lower jet fuel prices, are bolstering near-term airline profitability as shown in Figure 4 of [3]. However, long term projections for jet fuel are indicating a significant price increase [4], from approximately $60/barrel in 2015 to $90/barrel in 2020, $142/barrel in 2030 and $229/barrel in 2040. Jet fuel price is growing faster than other goods and services.

Therefore, there is a strong need for long term investment in the development of low consumption technologies for jet engines.

1.3 Growing Fuel Efficiency

Fuel costs have nearly doubled over the past 10 years. ***Fuel represents up to 30 percent of total operating cost for single-aisle airplanes and up to 50 percent for widebody airplanes [1]***. Fuel saving is a constant research topic of airplane manufacturers [5, 6], as this has a direct impact on costs. The main ways to save fuel for aero engines are presented in Figure 1.1 [5–7]. They must be balanced against all the costs and can only be realized when the initiative is fully deployed and sustained.

Airlines can improve their fuel efficiency in different ways [5–7]:

1. Deploying more fuel-efficient engines: replace older, less efficient airplanes with new-technology airplanes, such as the Boeing 787 or Airbus350 XWB. Weight reduction can be achieved by using composites and advanced avionics. Airbus has reported an 11% fuel burn improvement of A330neo versus current A330 at powerplant level [6].

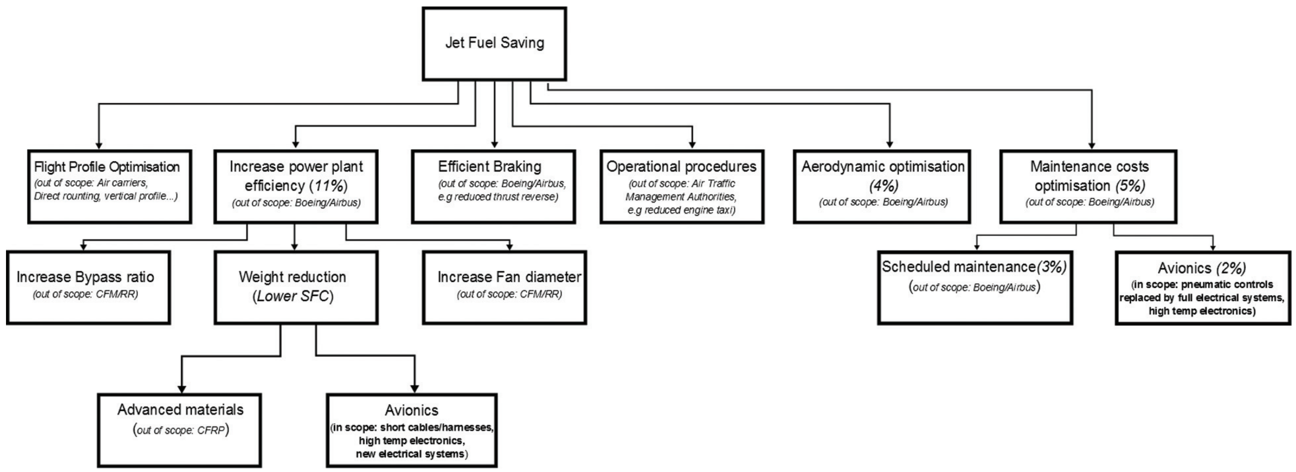

Figure 1.1 Aero engine fuel saving scheme based on [5, 6].

2. Improving operational procedures. Airlines can optimize fuel efficiency by making changes in operations, such as reducing the engine taxi time and the use of Auxiliary Power Unit (APU). Air carriers are also keen on raising the load factors on flights, which means making sure flights are close to or at aircraft capacity (all the seats are filled) [5].
3. Increasing braking efficiency by reducing the flap approach and a reduced thrust reverse [5].
4. Optimization of flight profile includes the optimum cruise altitude, the optimum climb/descent and the optimization of the cruising speed [5].
5. Optimization of aerodynamics & weight body shape by using of sharklets at the tips of the wings and the use of light composite materials. Airbus has reported an 4% fuel burn improvement of A330neo versus current A330 [6].
6. Maintenance costs optimization: Airbus has reported a 5% fuel burn improvement of A330neo versus current A330 due to lower direct maintenance costs [6]. This was achieved with longer maintenance intervals and by replacing the pneumatic controls with an electrical bleed air system.

The scope of current project is to focus on improving jet fuel saving by increasing the engine efficiency through a reduction of its weight which can be achieved with high temperature electronics placed closer to the engine such shortening the length of cables and harnesses. Further possible applications of high temp electronics, includes the replacement of pneumatic/mechanical controls with full electrical systems.

Benefits for high temperature electronics for aero-engines: By placing the electronics near to the sensor, the weight will also be reduced since the physical length between terminals will be minimized while the cost will be reduced since fewer cables will be needed, and the associated time to mount them on the engine will be also reduced. The fault rate will decrease as the signal is digitized before transmission and cables length is reduced. Sensor accuracy is improved as signal is digitized on the spot, also as cables length is minimized there is less noise coupling area to the signals. As the components are operational at higher temperatures there will be a reduced need for cooling. The flexibility of the system is increased as the components may be now placed in hot areas, which were previously inaccessible.

1.4 Clean Sky Initiative

The EU has taken a lead in green aviation technologies through Clean Sky1 and Clean Sky2 [8].

The Clean Sky Joint Technology Initiave started in 2008, and constitutes an industry wide, coherent program totaling €1.6 bn, equally shared by the EU and the European Aeronautical Industry.

Clean Sky2 is a natural continuation to progress achieved in Clean Sky1 (which has ended).

Clean Sky1 and Clean Sky2 are targeting very significant environmental gains, as shown in Table 1.1 [8].

By 2050, 75% of the world's fleet now in service (or on order) will be replaced by aircraft that can deploy Clean Sky2 technologies. Based on the same methodology applied in the Clean Sky1 economic case in 2007, the market opportunity related to these programes is estimated at ∼€2000 bn. The direct economic benefit is estimated at ∼€350–€400 bn and the associated spill-over is of the order of €400 bn.

The environmental case for continuing Clean Sky1 is even more compelling with an estimate of the CO_2 saving potential of 4 billion tones through Clean Sky2. These 4 billion tones of CO_2 to be saved from 2020 to 2050 will be additive to the approximately 3 billion tones achievable as a consequence of the Clean Sky Program.

GE was represented in Clean Sky1 by GE Aviation Systems (UK) & GE Global Research Munich as participants in High Temperature Survival Electronic Devices for Engine Control Systems (HIGHTECS) project no. 255749 working with Oxford University Materials.

1.4.1 Benefits of High Temperature Electronics for Jet Engine Controls and Health Monitoring

Environmental benefits: lower emissions – CO_2 reduction by 15–20%

For the aero-engine market, the extended high temperature electronics capability will facilitate the implementation of distributed architectures, where smart actuators and sensors can replace (or off-load) the centralised control

Table 1.1 Clean Sky1 and Clean Sky2 targets

	Clean Sky1*	Clean Sky2*
CO_2 and Fuel Burn	–20% to –40% (2020)	–20% to –30% (2025/2035)
NO_x	60% (2050)	–20% to –40% (2025/2035)
Population exposed to noise/Noise footprint impact	10dB to 20dB less noise (2020)	Up to –75% (2035)

* = Baseline for Clean Sky1 and Clean Sky2 figures are best available performance in 2000 and 2014, respectively.

electronics. Up to 500 conductors are currently used for interfacing between jet engine sensors, actuators, flight control computers and the centralised FADEC. The application of distributed architectures could reduce the conductor count from 500 to 8 for duplex control, offering cable and harness weight saving, connector pin reduction, fault reduction and a simpler FADEC [9]. This type of electronic unit would be installed inside the actuator or sensor housing and would consist of the sensor signal conditioning electronics, A/D converters, multiplexers and a serial interface bus [9].

At present, long, high-temperature mineral insulated (MI) or fibre-optic cable is required to connect the sensor to the electronics located in a more benign region of the gas turbine. Electronics co-located with the sensor will lead to a reduction in associated cabling, connectors, and terminals leading to reductions in weight and parts count (hence cost). The development of MEMS sensors with electronics integrated onto a multi-chip module could also lead to significant enhancement of performance at reduced costs. Moreover, the ability to perform signal handling/conditioning prior to engine control unit (ECU) will have benefits in terms of enhancing the data available for engine health monitoring. For example, temperature signals from thermocouple arrays must be averaged prior to sending the signal to the ECU as weight restrictions do not allow for individual cables from each thermocouple to be relayed to the ECU. The use of a multiplexing systems that can withstand engine casing temperatures ($\sim$250°C) would allow individual thermocouple signals to be analyzed by the ECU off a single cable harness. This could permit the detection of engine hotspots, radial distortions in temperature and condition monitoring of individual thermocouples.

Managing engine performance is receiving a greater amount of attention for safety, reliability and fuel burning savings [10]. Advances in heat resisting sensors and the desire to use full authority digital control electronics (FADEC) and engine health monitoring systems (EHMS) near to the sensing element is accelerating the interest in the use of high temperature electronics. This is leading to the development of “intelligent sensors”, which incorporate high temperature electronics in the sensor itself and have the capability to perform self-diagnosis of their health. The output of the “intelligent sensor” will be a digital signal which is then fed into the FADEC. The reduced need for processing of analogue signals within the FADEC unit can increase the capacity for incorporating the EHMS within the same unit, saving weight, space and costs.

For the aerospace market, improved sensor technology will have significant benefits in a number of areas. Firstly, although sensor weight may be small relative to the total weight of the aircraft, any improvements that could be achieved through reductions in lead-outs, terminals, connectors, etc. can still have a tangible impact on fuel consumption and running costs. For example, weight savings of even a few kilos can result in hundreds of thousands of pounds in annual fuel saving. Secondly, improved engine monitoring capability should result in engines being run at conditions for more optimal thermodynamic efficiency, resulting in reduced fuel consumptions (and engine emissions) and potentially increased component life. Moreover, improved sensor performance could lead to a reduction in maintenance costs through "smart scheduling" of servicing and overhaul based on reliable and indicative sensor data and not on fixed flight hour intervals.

References

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