Using CO_2 Sensors for Aircraft In-Cabin Interior Air Quality Monitoring

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INTRODUCTION

GSS has designed a new CO_2 sensor suitable for in-cabin commercial aircraft deployment. The sensors can be used to optimise in-cabin air quality by monitoring CO_2 levels in near real-time.

With the support of the UK Aerospace Technology Institute, GSS was a part of a British consortium consisting of several major aerospace companies, and National Physical Laboratory in a project titled U-CAIR (UK ATI Cabin AIR) to develop the technology needed to improve in-cabin air quality whilst reducing airline operating costs. The sensor was designed to be incorporated into an adaptive aircraft **E**nvironmental **C**ontrol **S**ystem (ECS). Information from an array of the sensors can be used to adjust incoming fresh air to improve aircraft efficiency and reduce the impact of airborne pathogens like COVID-19.

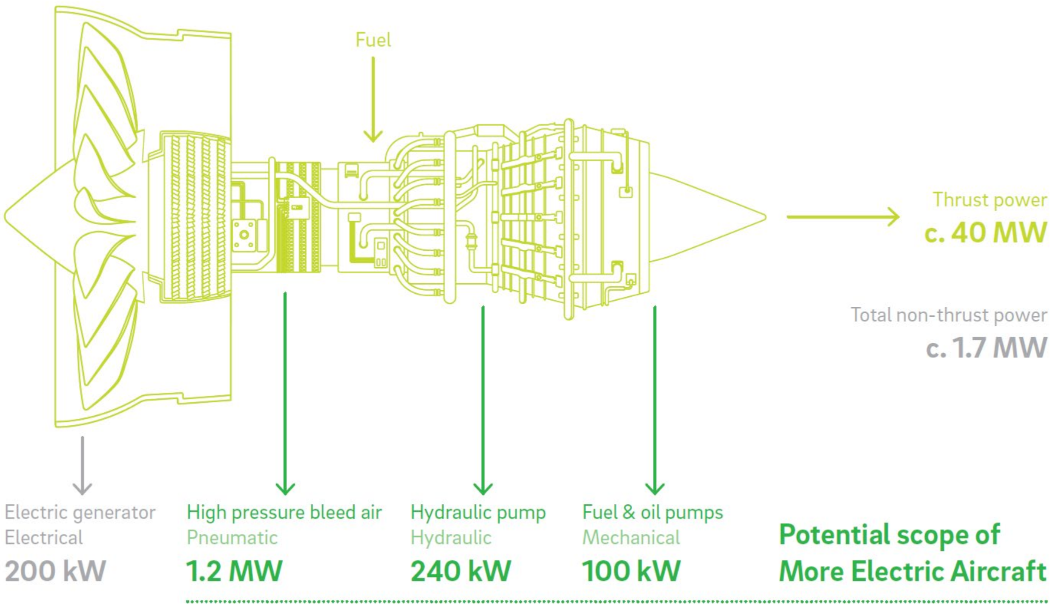
AIRCRAFT INTERIOR ENVIRONMENT CONTROL SYSTEM

The purpose of an aircraft ECS is to provide protection, comfort, and life support for passengers from the hostile external environment during flight. Although the ECS covers in-cabin conditioning, water and sanitation, food and waste management, and noise control, this white paper will focus solely on in-cabin conditioning. In-cabin conditioning encompasses any environmental facet that affects the passenger, such as cabin pressure, temperature, ventilation, humidity, and fire protection.

Cabin air conditioning must provide the passenger with an environment that is acceptable in normal flight conditions. It must provide heating and cooling control within tight temperature limits, it must maintain cabin air pressure to specification regardless of flight level, it must humidify or dehumidify the atmosphere, and more importantly than ever, it is responsible for disinfecting the air.

The ECS is a complicated system, one that is integral to the structure of the aircraft. However, this sophistication and complexity comes at a cost. The ECS is the second largest consumer of power in the aircraft after propulsion, with a typical system using about 1kW per passenger. A typical Airbus A320 consumes about 40MW in the engines, with 200kW for the ECS, and all the rest no more than a few tens of kW.

Fuel represents one of the most significant costs of running an aircraft. Commercial airlines are spending small fortunes investing in more fuel-efficient aircraft. Most of these efficiency gains are due to the installation of new engines. However, there are other potential efficiency gains to be made by reducing the power consumption of other aircraft sub-systems. The ECS is an obvious candidate for investigation as it has the largest power consumption budget after the engines.



GSS has been part of a consortium of companies looking at developing a system to help reduce the operational costs of an aircraft whilst improving in-cabin air quality by utilising an adaptive ECS. The objective of the project was to develop a system for monitoring cabin air quality and using the information from an array of carbon dioxide (CO_2) sensors to adjust the supply of fresh air from outside, to ensure energy is not wasted drawing more air than is needed and provide the ability to optimise in-cabin air quality for the benefit of passengers on a near real-time basis.

IN-CABIN AIR SUPPLY

The air inside an aircraft is a combination of outside air and re-cycled air. Fresh air is ultimately brought in from outside into the aircraft cabin. Most aircraft including very modern ones such as the Airbus A350 use so-called bleed air, where air is bled from the main engine compressors, and into the ECS where it is compressed, humidity and temperature are controlled and then mixed with re-cycled inside air prior to re-entering the cabin. The exception to this architecture is the Boeing 787, which does not use bleed air from the engines but electrically pumped air. Thereafter, it works in a similar manner to other ECS setups. The balance between outside air and re-cycled air is normally approximately equal but can vary depending upon the flight altitude and power settings.

The ECS is designed to manage temperature and humidity, with pressure, ventilation, particulates and contaminant control, and air-flow rates normally designed-in based on the requirements of each section of the aircraft.

IN-CABIN AIR QUALITY

The Federal Aviation Administration lays down the rules for certification of aircraft in the US. The Code of Federal Regulations (CFR) Title 14, Aeronautics and Space, Chapter 1, Subchapter C, part 25.831 and 25.832 describe aircraft ventilation and heating requirements. The regulations say the ventilation system must be designed to provide each occupant with an airflow containing at least 0.55 pounds of fresh air per minute with carbon dioxide (CO_2) concentrations of less than 0.5% by volume (<5,000ppm) @ sea level, carbon monoxide (CO) less than 1 part in 20,000 parts of air and maintain cabin ozone concentrations at or below 0.25 parts per million by volume, sea level equivalent, at any time above flight level 320; and below 0.1 parts per million by volume, sea level equivalent, time-weighted average during any 3-hour interval above flight level 270.

Bleed air is naturally free from contaminants at flight level altitudes, but re-cycled and bleed air are passed through HEPA and carbon filters to remove particulates and other small contaminants. Most commercial aircraft use High Efficiency Particulate Arrestors (HEPA) filters, which are said to remove >99.9% of particulate material. There has also been recent research to show a standard HEPA filter is effective at preventing the re-circulation of the SARS COVID-19 virus.

The ECS ensures the airflow inside the cabin is constantly circulating from the top of the cabin down through the floor at approximately one meter per second. In a modern aircraft, the airflow is also optimised to reduce longitudinal movement so there is no spread between adjacent seat rows. Typically, aeroplane manufacturers ensure the air is renewed every 2-3 minutes.

THE IMPORTANCE OF MEASURING CO_2 LEVELS

Notwithstanding the certification requirements to keep in-cabin CO_2 levels below 5,000ppm, the established benchmark test to assess air quality is to measure CO_2 levels. Ignoring particulate matter, VOCs, and other contaminants, it is generally understood that indoor CO_2 levels are a good proxy for the amount of pollutant dilution in densely occupied spaces and can therefore be used as a good indicator for fresh air.

The background level of CO_2 is generally considered to be in the range of 350-450 parts per million (ppm). CO_2 is a by-product of normal human activity and is removed from the body via the lungs in the exhaled air. Unless the aircraft cabin is adequately ventilated, CO_2 will naturally build up over time. Above 1,000ppm and most people will begin to complain about the stuffy atmosphere or poor air quality. High levels of CO_2 indoors are also associated with headaches, sleepiness, poor concentration and cognition, loss of attention and in extremely high concentrations, CO_2 is harmful to life due to oxygen deprivation. CO_2 levels in a well manged indoor space are generally 350-1,000ppm.

Assuming monitoring of CO_2 levels is a good proxy for fresh air, CO_2 sensors can be used to check if there is enough ventilation in the aircraft and if not, to trigger a response. According to The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), acceptable interior air quality is where there are no known harmful contaminants in harmful concentrations, and whilst the general principles of mitigating these are sound, except for setting upper limits on CO_2, CO, and ozone, there is a total absence of parametric guidance.

Reducing CO_2 levels to natural ambient levels sounds compelling. It is likely to aid passenger well-being, improves aircrew cognition, ensures the in-cabin atmosphere is well ventilated, and reduces the level of pollutants and viruses, something that is of huge concern as the world learns to deal with COVID-19. However, drawing in outside air raises fuel consumption, and therefore it would seem airlines have an incentive to allow CO_2 levels to rise whilst still maintaining crew safety and ensuring the aircraft meets legislative standards.

There is obviously a balance to be trodden between these competing forces. The starting point to address the problem is to be able to assess CO_2 levels at various points around the aircraft cabin. To deliver this capability, GSS has developed a CO_2 sensor capable of withstanding the rigours of real-world flight conditions.

SENSOR CHALLENGES

The ability to manage in-cabin local CO_2 levels using an adaptive environmental control system requires high quality, cost-effective flight proven sensors. GSS non-dispersive infra-red (NDIR) sensors work by measuring the amount of IR light absorbed by CO_2 gas in an optical chamber. Gas concentration is proportional to the amount of light absorbed as it passes through the gas.

The amount of light absorbed by the target gas, and hence measurement accuracy, is influenced by external environmental factors. The absorption of IR light is dependent on the number of gas molecules present in the optical chamber. There are many factors that influence the number of molecules, the size of the optical chamber, the gas concentration, humidity, temperature and barometric pressure. To accurately measure gas concentration, it is therefore important to understand these effects and then design a sensor system that is either robust to the impact of these external factors or is sufficiently well behaved that their impact can be corrected in a systematic fashion.

Temperature Effects

Changes in temperature effect sensor accuracy in several different ways. As well as those effects that can be described by simple gas laws, the LED and photo-diode, the electronics and the mechanical parts of the sensor will be all be affected by temperature. There are several methods to mitigate the effects of temperature on sensor accuracy. Sensor accuracy variations due to changes in temperature can be characterised and corrected.

At GSS, each sensor has built-in temperature correction based on characterisation of its behaviour over temperature and gas concentration during factory calibration.

Mitigating the Effects of Vibration

Changes to the sensor caused by mechanical vibration cannot easily be corrected, and thus the sensor needs to have an intrinsic immunity to being placed in a noisy and stressful environment. The international gold standard used to define the environmental test conditions, applicable test procedures and criteria for avionics equipment is DO-160**,** Environmental Conditions and Test Procedures for Airborne Equipment**,** published by RTCA (Radio Technical Commission for Aeronautics). All manufacturers of aeronautic products must meet the requirements of this standard to ensure that their equipment will operate correctly when airborne.

The GSS sensor works by analysing the amount of light absorbed by the target gas. The sensor is characterised and tested using high accuracy calibrated gases. This reference data is stored on-board the sensor and used to calculate real-time CO_2 levels. Mechanical stress on the sensor can cause minute changes in the optical path. As part of the sensor development, the GSS team undertook Finite Element Analysis (FEA) to determine any likely mechanical stress and vibration would not compromise sensor accuracy.

The new GSS CO_2 sensor was designed to meet the full extent of DO-160 and passed all applicable tests when incorporated into the appropriate airborne setup.

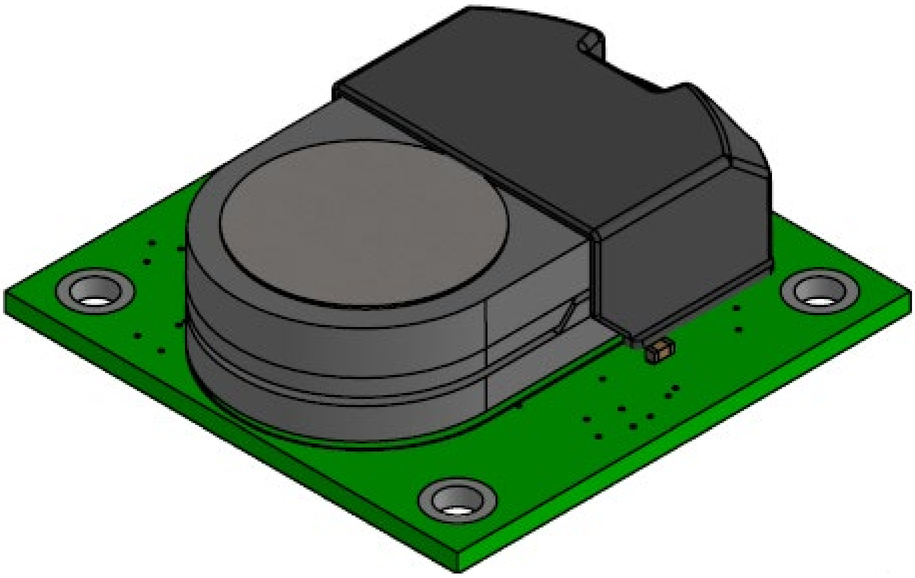
Pressure Compensation

Absorption of IR light in the sensor is affected by pressure changes mainly caused by variations in the number of molecule collisions in the optical chamber. Unless corrected, the accuracy of CO_2 measurements will be compromised by the effects of these ambient pressure changes. As air-cabin pressure increases, so do the number of collisions due to the higher density of molecules present, and as CO_2 has a higher density than air, there is also an effect driven by CO_2 concentration. This effect is non-linear and therefore to correct the CO_2 reading from the sensor, the ambient pressure must be known.

The GSS sensor system measures the ambient barometric pressure level in real-time and this measurement data is fed back to the CO_2 sensor. A pressure compensation algorithm was developed to work within the operating flight level envelope of the aircraft. On-board the sensor, each CO_2 reading is adjusted using this algorithm in real-time to provide pressure adjusted CO_2 measurements.

Sensor Performance

The GSS sensor was tested in a variety of flight conditions including exposure to different levels of CO_2 over pressure, humidity and atmospheric pressure, and in the presence of other contaminant gases such as ozone and VOCs.



Conclusions

The GSS sensors were used to obtain real-world data on in-cabin air quality for multiple flight profiles, the first time this data has been gathered. The project team was able to demonstrate that real-time CO_2 data can be used to enable effective adaption of the ECS to dynamically adjust the balance between flight efficiency, cognitive impairment, and passenger well-being. Installation of such systems by commercial airlines will give them the ability to balance these competing forces based on their own policy stance.

To learn more about how GSS CO_2 sensors, visit our website today.
https://www.gassensing.co.uk/products

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