FTEPS

(Fuel Tanks Explosion Protection System), based on

OBIGGS

(On Board Inert Gas Generating System)

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AVIATION SAFETY FACILITATORS CORP.

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FTEPS – PRESENTATION ROADMAP

- *Application Scenario in Military and Civil Fields*

- *Evaluation of Technology Background and Trends*

- *Alenia C-27J Aircraft Experience*

- *Summary and Conclusions*

NEED ANALYSIS AND MARKET REPLY

- **Fuel Tanks Protection**

  The prevention of the aircraft fuel tanks explosion has been pursued since a long time for safety and security reasons. Several solutions have been adopted to protect fuel tanks, such as nets, foam, pressurized nitrogen and so on, but they resulted to be not fully satisfactory on the following issues:

  - reduction of fuel load capability
  - penalties on aircraft performance and effectiveness (weight, fuel contamination, interference with other onboard equipment, retrofit capability)
  - repercussion on aircraft lifecycle (aircraft operability, maintenance tasks and support equipment)

- **Fuel Tanks Inerting**

  The inertization of fuel tanks through On Board Inert Gas Generating System (OBIGGS) is considered the most suitable solution for the protection against explosion.

MILITARY AND CIVIL APPLICATION

- **Military Field**

  The first need came form the Military Customer in order to prevent explosion of the aircraft fuel tanks following attacks in hostile regions missions. The increasing attention to the aircraft safety is even pushing this implementation for the additional prevention against fuel tanks explosion following failures (heating sources or electrical sparks in fuel zones).

- **Civil Field**

  Some occurred accidents revealed the pressing need to protect the fuel tanks against explosion following failure (heating sources or electrical sparks in fuel zones). The increasing attention to the security issues is even pushing this implementation for the additional prevention against terrorist attacks, such as manpads and small arm fire.

MILITARY REQUIREMENTS

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- **United States Air Force (USAF)**

  The fuel tanks inerting systems were already implemented on Boeing C-17, C-5, F-22 and others. A recent further requirement addresses the introduction of oxygen sensor to monitor the fuel tank inertization.

- **Italian Air Force (IAF)**

  “...to protect fuel tanks against risks of fire and explosion caused by projectiles, sparking, etc., and to assure protection from the threat of small fire from ground during operation in hostile regions”.

- **Royal Air Force (RAF)**

  “…the most likely cause of C-130K Hercules loss in Iraq (January 2005) was the ignition of a fuel\air mix in the space above the fuel... The fitting of a fuel tank suppression for C-130 should be considered… A more reliable and timely system should be developed to ensure aircrew are kept updated with relevant time sensitive information…” and they are still pursuing this application

CIVIL REQUIREMENTS

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- **Background:**

  On July 17, 1996, TWA Flight 800 disintegrated after taking off from New York. The investigation concluded that a center fuel tank explosion destroyed the aircraft in flight.

  Since 1959, 17 fuel tank ignition events have occurred and previous regulations did not prevent fuel tank explosions.

- **FAA and EASA harmonization:**

  Since the mishap, numerous airworthiness directives have been published and several others are proposed to reduce possible ignition sources and thereby reduce the risk of another fuel tank explosion.

CIVIL REGULATION UPDATING

- **SFAR 88 and INT/POL/25/12 (2001-2002)**

  Coming from the consideration of the previously existing FAR/JAR 25.1309 that requires 10^{-9} risk protection, the FAA Special Federal Aviation Regulation (SFAR) 88 and JAA Interim Policy INT/POL/25/12 (now AMC 25.981) issue tasked aircraft manufacturer to perform a safety analysis of each of their transport models. But this compliance seems not to be enough (B-727, Bangalore - India, May 4th 2006).

- **FAA and EASA trend**

  The trend more and more implies the fuel tanks inerting system implementation. New aircrafts (Boeing 787, Airbus A350) foresee this feature on the basic configuration and several in-service aircraft are likely to be retrofitted.

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PERFORMANCE REQUIREMENTS

- **Security Reason**

  Based on USAF studies, ullage oxygen concentration less then 9% avoids the risk of fuel vapor burn (fuel type JP-4, JP-5, JP-8), consequently obtaining the fuel tanks protection from explosions caused by projectiles 50 cal. API-M8 or 20 mm HEI-M97

- **Safety Reason**

  Several test campaigns carried out by Civil Certification Authorities are confirming that the oxygen concentration less than 12% is able to prevent fuel vapor ignition by electrical spark and hot sources

ALENIA EXPERIENCE

- **Background**
  - To fulfill Customer requirements, Alenia designed and developed a Fuel Tank Explosion Protection System (FTEPS), able to generate and maintain an atmosphere less than 9% of oxygen content in the A/C Fuel Tanks ullage.
  - FTEPS architecture developed for G 222-3A was the first application on turboprop aircraft.
- **G222-3A and C-27J Applications Highlights**
  - Proved capability to design, develop and certify the system integration
  - Optimization balance between system performance requirements and repercussion on the aircraft:
    - minimized air consumption to ensure inertization
    - negligible penalties on engine, air bleed, pressurization and ECS

TECHNOLOGY LEVEL APPRAISAL

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- **Design Constraint**
  - The pressurized air is processed by an On Board Inert Gas Generating System (OBIGGS) obtaining the Nitrogen Enriched Air (NEA)
  - The NEA is distributed in the fuel tank ullage in accordance with the existing venting system and the aircraft wing structure
  - Climb and dive features to ensure aircraft protection during tactical missions with high rate climb and descent
- **Aircraft Certification**
  - The G222-3A FTEPS was qualified by IAF in October 2001, after completion of ground and flight test program (Certificate N. 12572 issued by IAF)
  - C-27J FTEPS has been qualified by IAF in July 2006, after completion of ground and flight test program
  - The C-27J aircraft embodied a Flight Instrumentation System based on optical sensors to monitor the oxygen concentration in the fuel tanks (*first industrial application in aerospace field)*
- **Future Technology Target**
  - Possible implementation of optical sensors monitoring system to provide the crew with actual fuel tanks inertization. During the recent certification meeting, IAF also highlighted the importance of this upgrading.

AERONAUTIC SECTOR COMPARISON

- **FTEPS characteristics are in accordance with requirement trends**
  - Non intrusive system (no reduction of fuel tanks useful volume)
  - Low weight increase (less than 60 kg on G222/C-27J)
  - No logistic support required on ground (no need of pressurized nitrogen storage)

- **FTEPS features exploit previous experience and comply with future similar applications**
  - Previous operative experience on aircraft (L-159, Eurotiger, G222-3A, F-22)
  - Recent (C-27J) and future introduction (C-17, B787, A350)

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FTEPS ARCHITECTURE

- The Fuel Tank Explosion Protection System (FTEPS) can be split in the following subsystems:
  - **Bleed Air Temperature Control System (BATCS)** interfaced with aircraft pneumatic sources and aimed at the temperature control of the air supply to OBIGGS
  - **On Board Inert Gas Generating System (OBIGGS)** aimed at the inert gas generation and delivery to the fuel tanks
  - **Nitrogen Enriched Air Distribution and Control** for fuel tanks

FTEPS FUNCTION AND PERFORMANCE

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The OBIGGS, main component of Fuel Tank Explosion Protection System (FTEPS), is an equipment that produces NEA with an oxygen content down to 1% when fed in design conditions:

- Feed air temperature = 72 ± 6 °C
- Feed air pressure = 20 Psig
- Feed air consumption = Less than 2.8 Kg/min

The machine is provided with two Air Separation Modules (ASM), made of Hollow Fiber Membranes that separate nitrogen from air.

FTEPS COVERAGE OF AIRCRAFT MISSION

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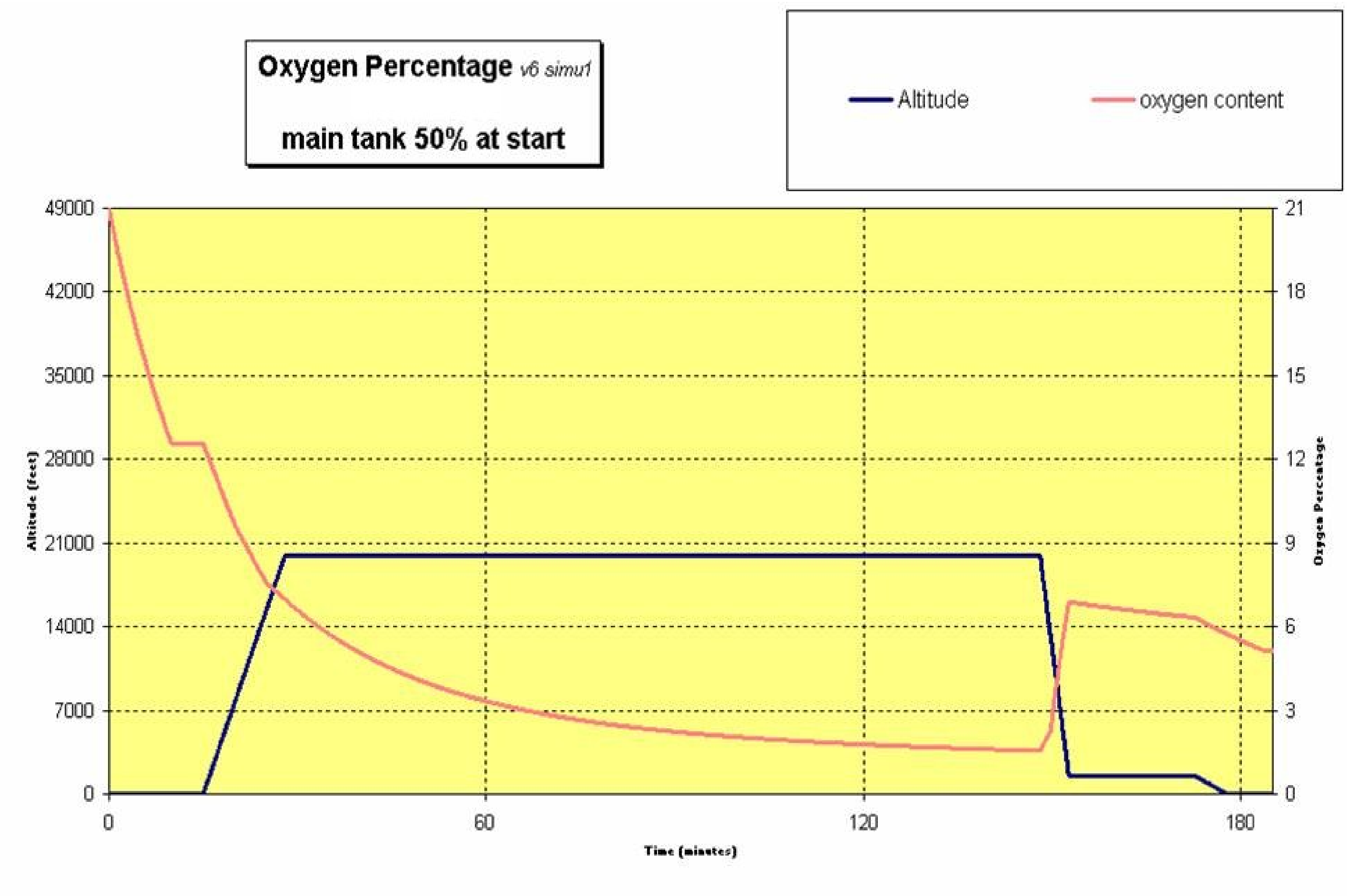
INERTIZING FUEL TANK - GROUND/FLIGHT - BLEED ON – NORMAL AND DESCENT MODE (IN HIGH DESCENT PHASE)



C-27J EXPERIMENTAL CAMPAIGN

Instrumented Prototype Testing

TEST PROGRAM

Ground Session:

- Main and Auxiliary Tanks loaded at 25% and fuel consumption allowed in the acquisition tanks only (most critical condition due to the big empty ullage to be inertized)
- APU run feeding OBIGGS
- First Test in NORM Mode
- Second Test in NORM and DESC Mode combination

Flight Session:

- Main Tank Loaded at 50% and Auxiliary tank Loaded at 25%
- Climb up to maximum ceiling (30,000 ft) with APU run (extreme condition for system integration)
- High Rate (2000 ft/min vertical speed) Descent (most critical condition due to the fuel tanks venting inflow)

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OXYGEN CONCENTRATION MEASUREMENT SYSTEM

Operating Principle

The operational principle is based on the fluorescence of a ruthenium complex in a solgel to measure the partial pressure of oxygen.

System Architecture:

- 3 electronic boxes
- 3 computer boxes
- 10 oxygen probes
- a thermocouple wire and an optical fiber from each probe up to the boxes

Qualification

In the frame of the development, the equipment were qualified in accordance with Alenia General Environmental Requirements for C-27J aircraft document that is based on RTCA DO-160C reference.

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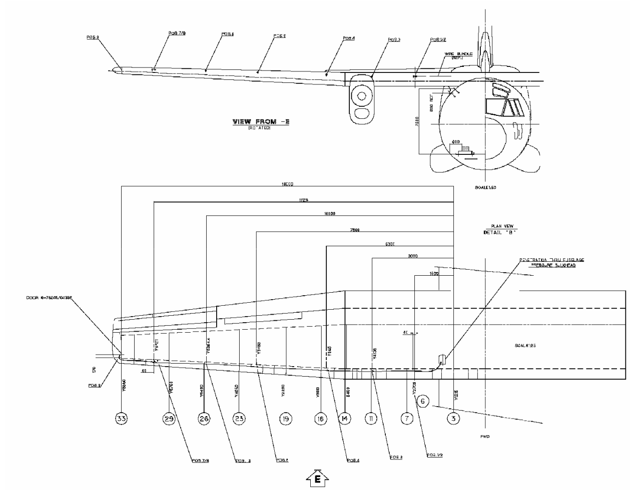
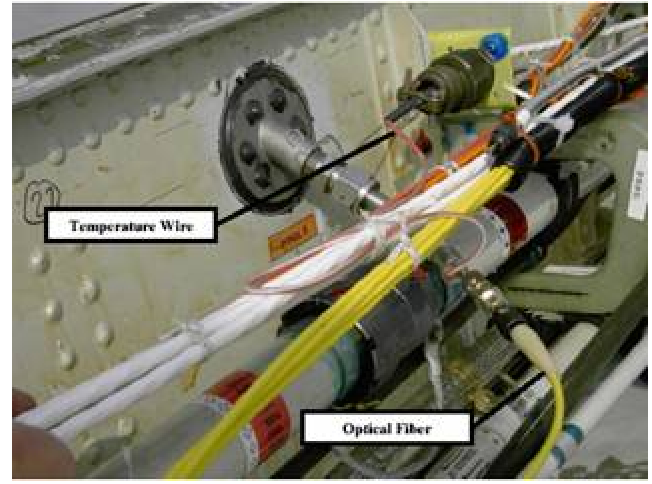
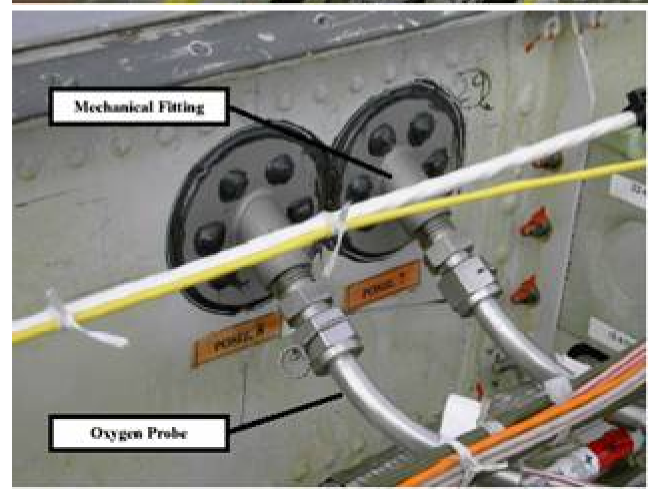
OXYGEN CONCENTRATION MEASUREMENT SYSTEM

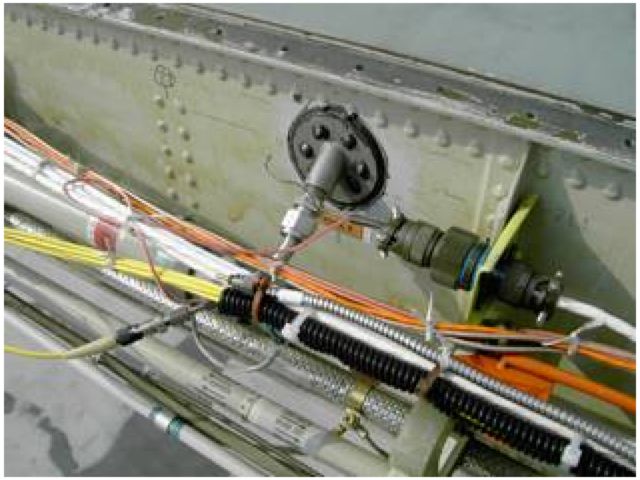






9 Probes along the right wingspan (3 in the auxiliary tank and 5 in the main tank, 1 in the fuel venting line) and 1 in the inerting line

OXYGEN PROBES INSTALLATION



Right Wing Front Spar

Key Issues:

- Probes body bending for optical fibers clearance
- Passing through mechanical fittings
- Probe inclination for sensing element exposure to ullage
- Optical fibers routing and protection for bending limit
- Cross reference for temperature measurement

OXYGEN PROBES INSTALLATION PICTURES

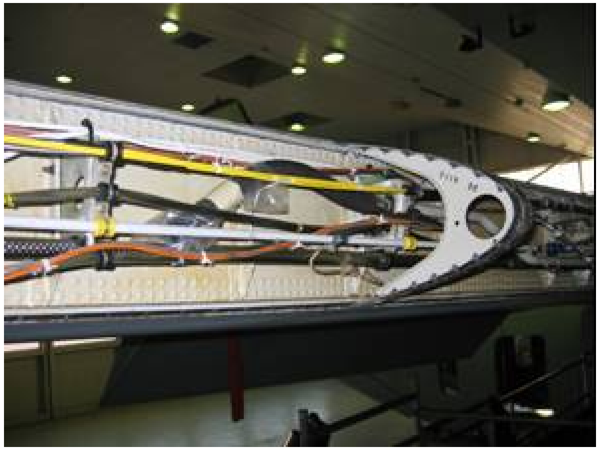
Inerting Distribution Line Probe

Fuel Venting Box

Temperature Wires Connectors

Wire Fuselage Passage

Fuel Venting Box Probe

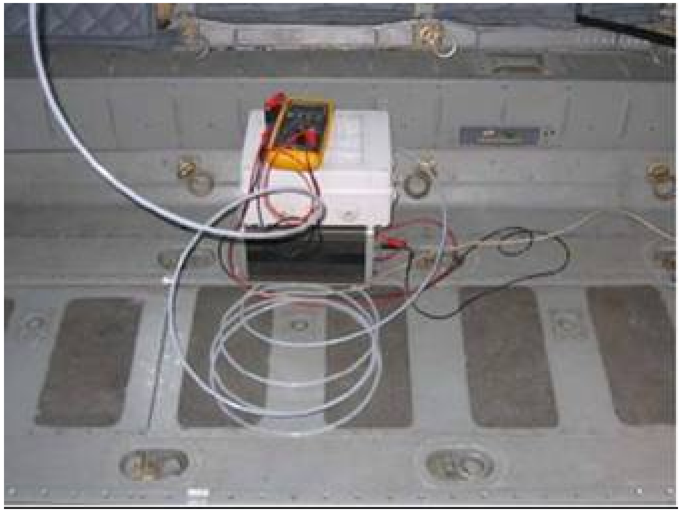


Installation Cables Routing

TEST INSTRUMENTATION

Main Measurement Parameters:

- Pneumatic (pressure, flow and temperature) from and to OBIGGS
- Environmental Condition (Temperature and Pressure) in Aircraft Outside Ambient and Installation Compartments
- Fuel Tanks Conditions (fuel quantity, pressure, temperature)
- Oxygen Concentration Analyzer (pick-up connection to dedicated ports)



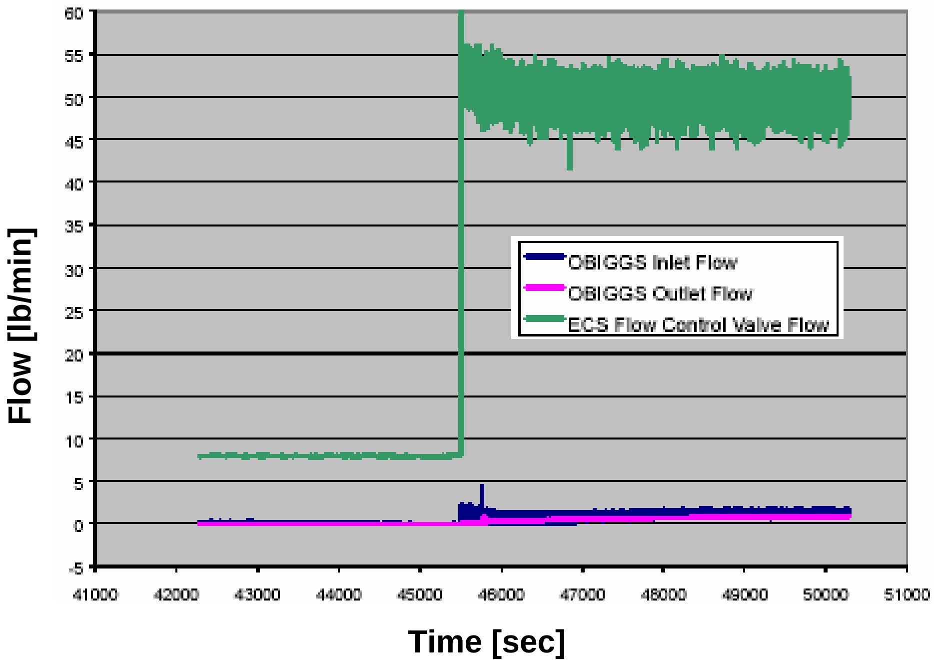
Oxygen Analyzer

Oxygen Measurement Ports

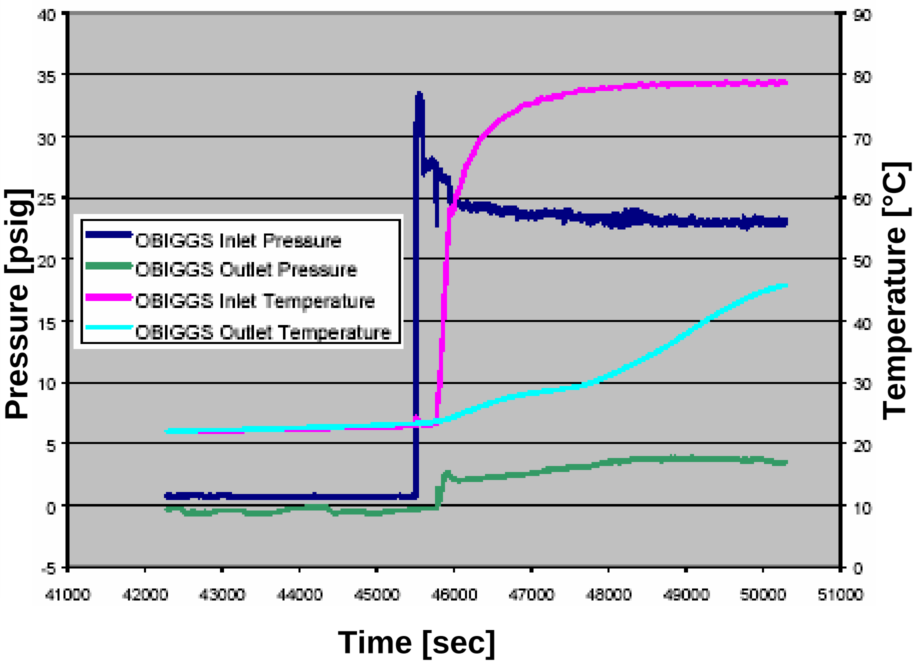
FTEPS EXPERIMENTAL CAMPAIGN

GROUND SESSION – FIRST TEST RESULTS

Airflow Consumption



OBIGGS inlet Pneumatic Conditions



Flow Comparison of OBIGGS and ECS needs:

☺ **No jeopardizing of Air Conditioning and Cabin Pressurization Systems Performance**

OBIGGS Pneumatic Conditions:

☺ **Proper supply and delivery in accordance with interface requirements**

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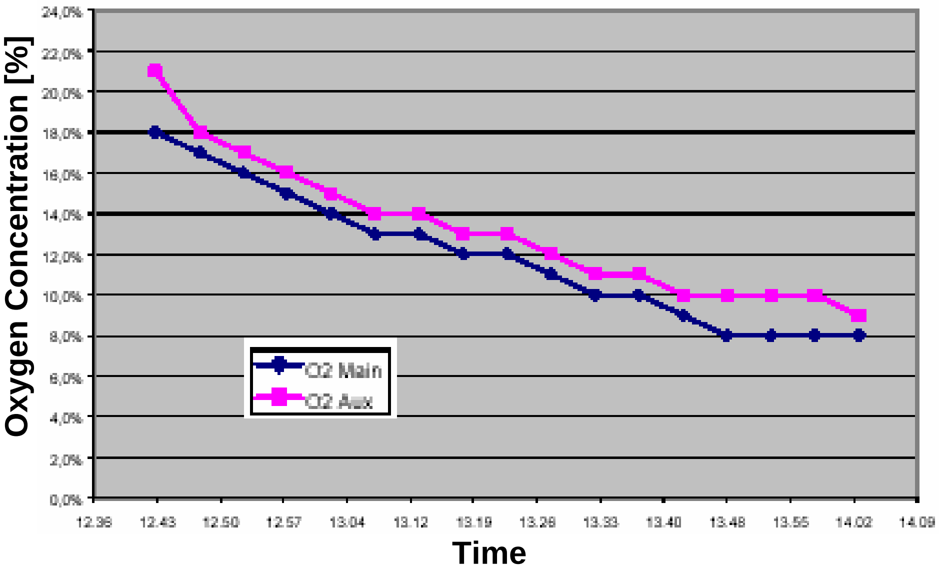
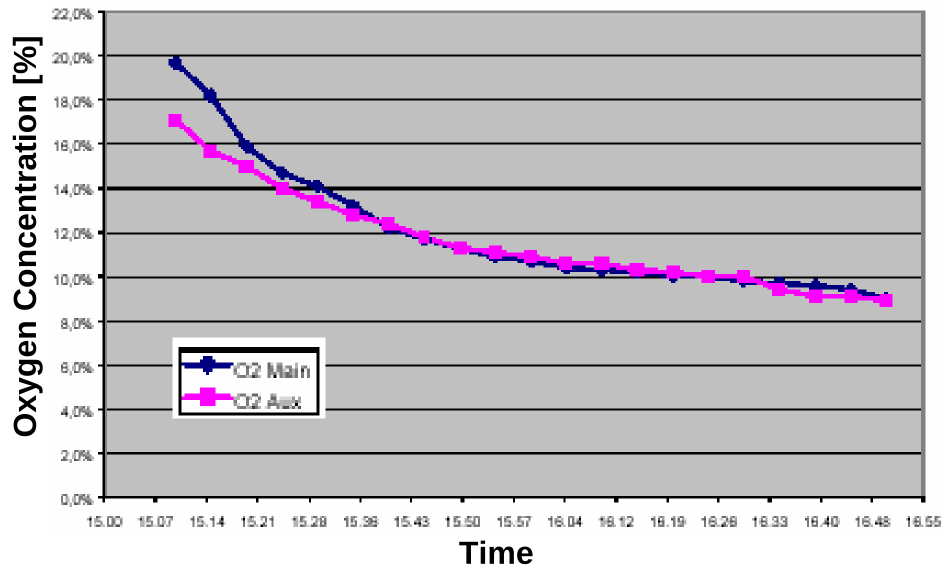
GROUND SESSION – FUEL TANKS OXYGEN CONCENTRATION

C-27J Fuel Tanks Inertization NORM MODE



C-27J Fuel Tanks Inertization DESC-NORM MODE



First Test in NORM Mode:

☺ **Agreement with numerical simulations**

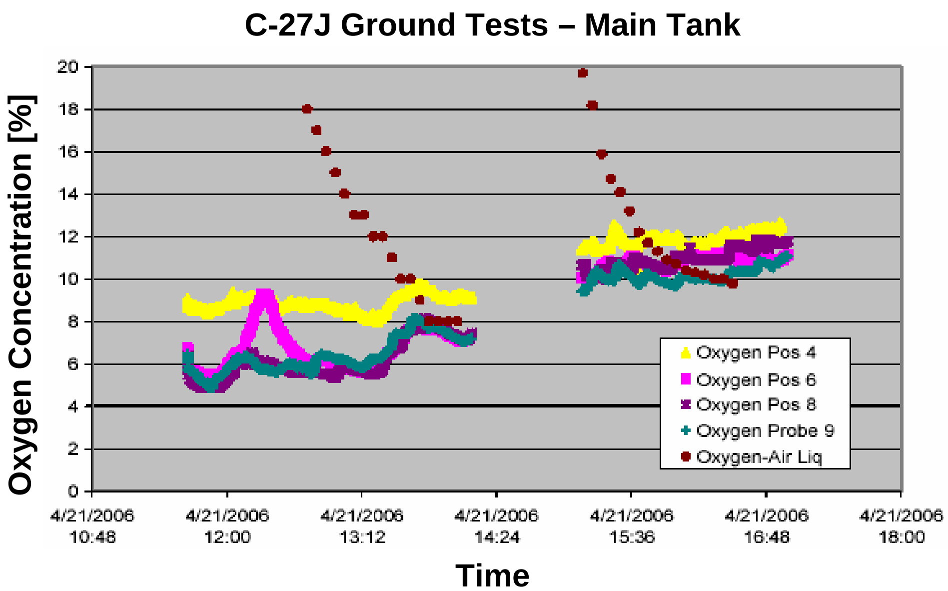
Second Test in NORM and DESC Mode combination:

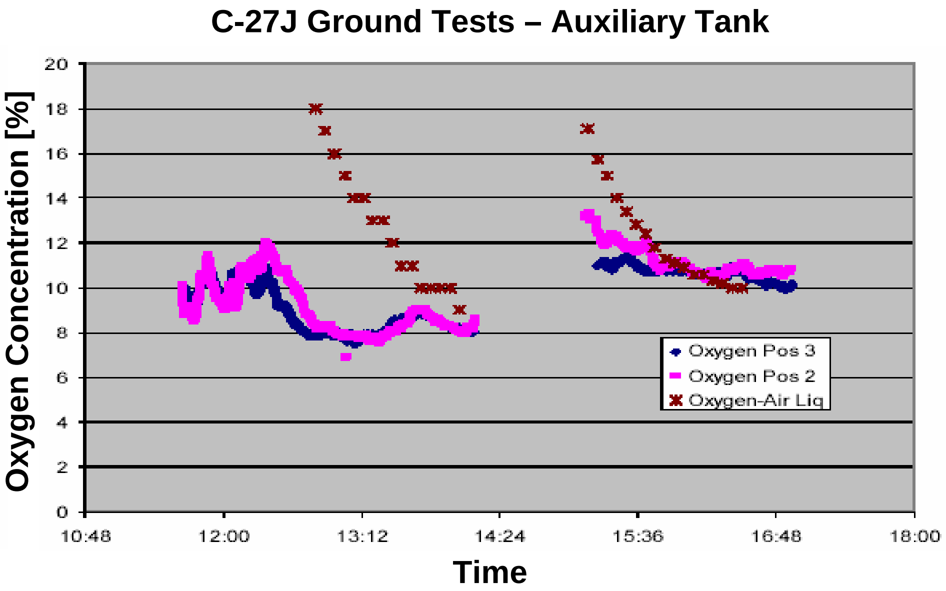
☺ **Agreement with numerical simulations**

Aircraft Operability Effectiveness Verification:

☺ **Oxygen concentration was checked again after 115 hours aircraft parking and no loss of inertization condition**

GROUND SESSION – FUEL TANKS OXYGEN CONCENTRATION





Main Tank in the First and Second Test:

☺ **Agreement with inertized condition measured by the oxygen analyzer**

Auxiliary Tank in the First and Second Test:

☺ **Agreement with inertized condition measured by the oxygen analyzer**

Optical Oxygen Probes:

☺ **Demonstration of proper operation and survivability on the aircraft (more than 5 month installation on the aircraft involved in ground and flight operations… and still working)**

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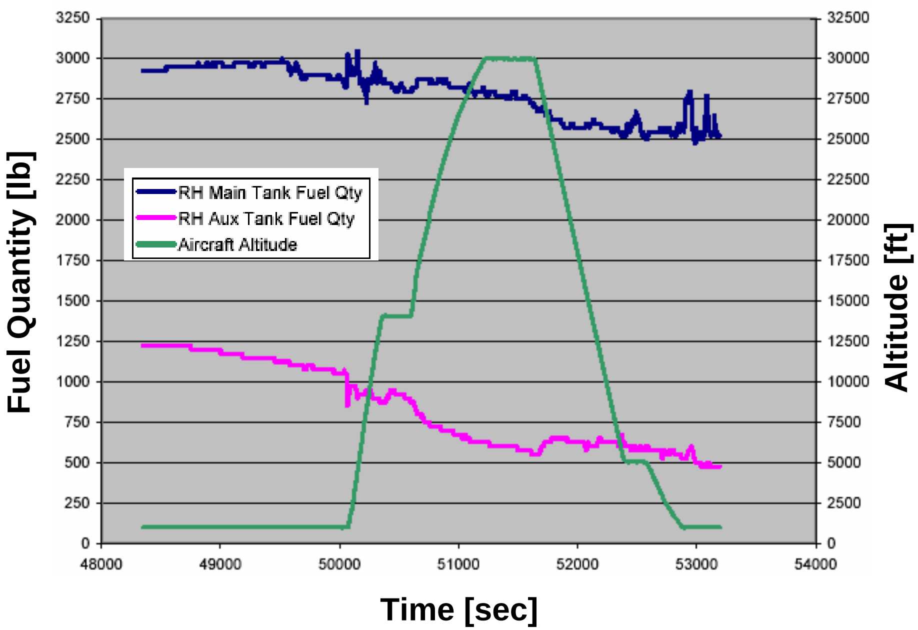
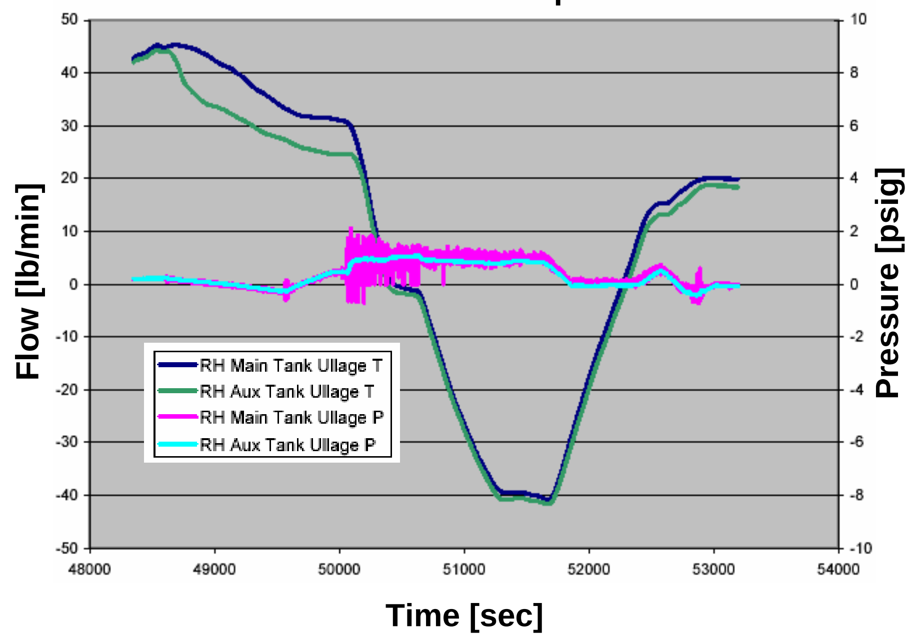
FLIGHT SESSION – FUEL TANKS CONDITIONS

Aircraft Fuel Tanks Conditions



Airflow Consumption



Aircraft Fuel Consumption:

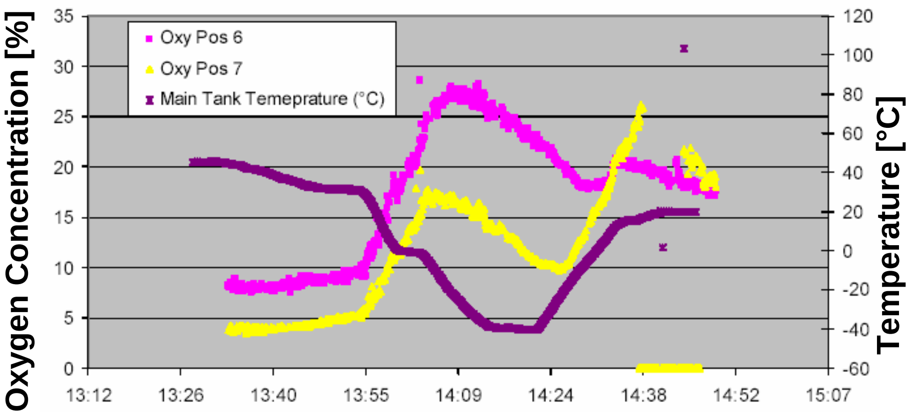
☺ Fuel consumption not affected by OBIGGS running

OBIGGS Pneumatic Conditions:

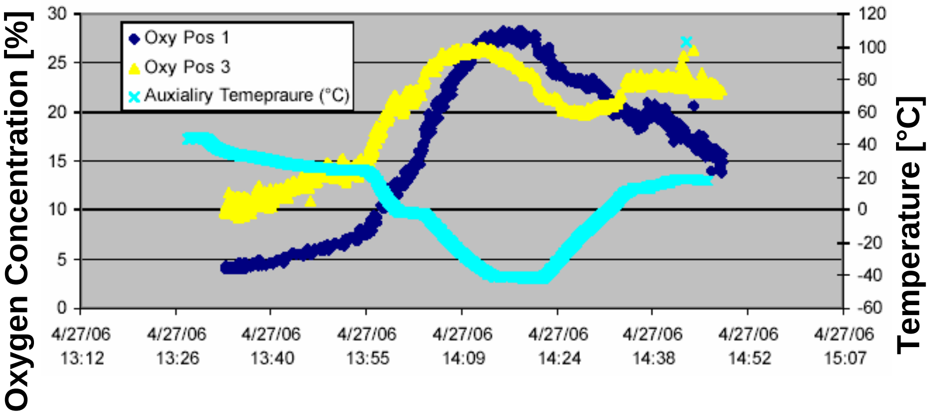
☺ Proper operation of fuel tanks venting in accordance with interface requirements

FLIGHT SESSION – FUEL TANKS OXYGEN CONCENTRATION

C-27J Flight Test – Main Tank



C-27J Flight Test – Auxiliary Tank



Main Tank in the Flight Test:

☺ **Agreement with cross reference temperature measurement**

Auxiliary Tank in the Flight Test:

☺ **Agreement with cross reference temperature measurement**

Optical Oxygen Probes:

☺ **First Industrial Application of Aircraft Fuel Tanks Inerting Continuous Measurement in Flight… and results evaluation still running**

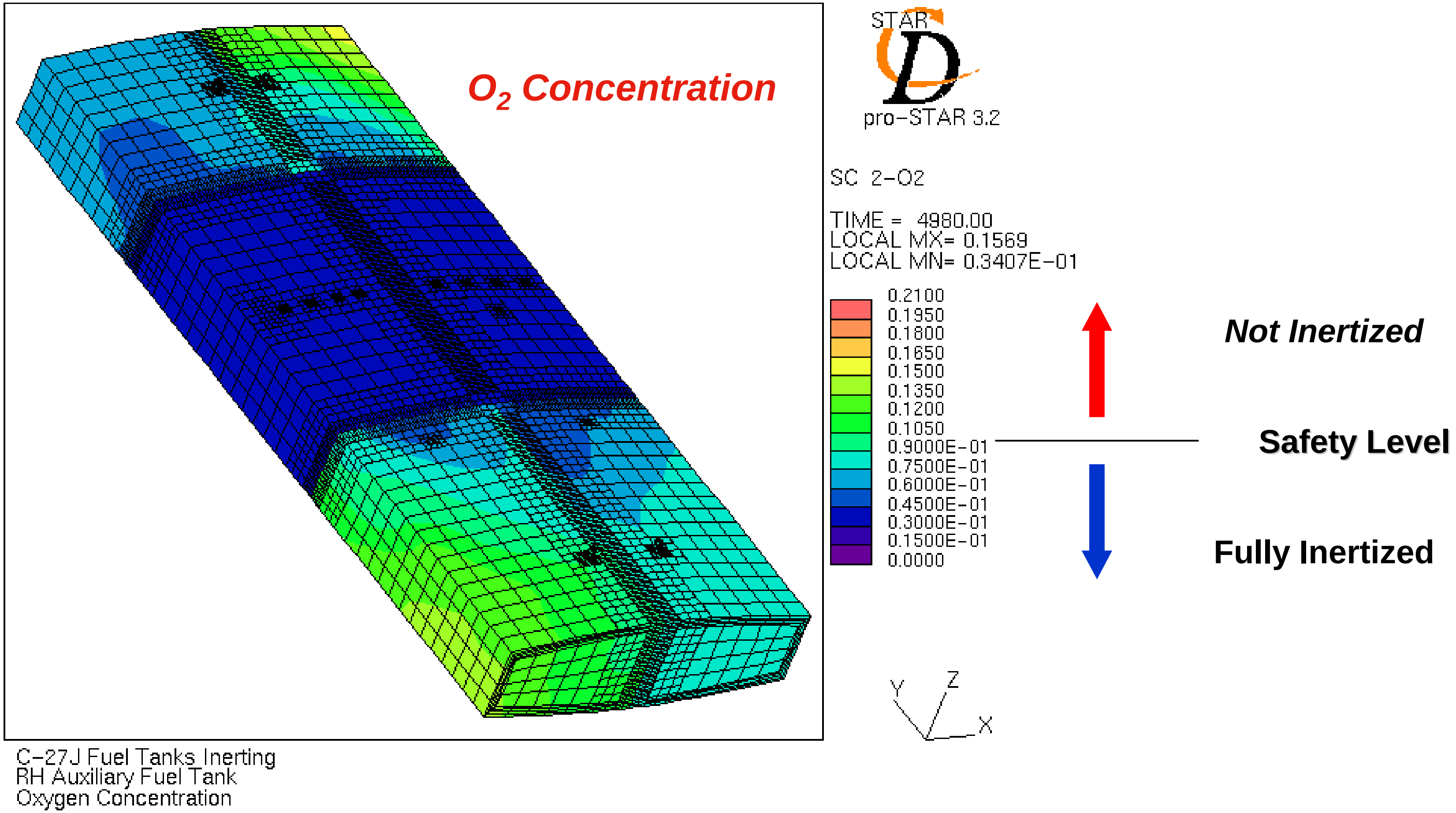
NEXT STEPS

WORK IN PROGRESS…

- **Integration of Pressure Sensor**
  - A fiber optic pressure sensor is going to be integrated in the oxygen probes for the actual oxygen concentration measurement
- **System Tailoring**
  - Electronics development in accordance with aircraft constraints
- **System Integration and Certification**
  - System integration with on board systems
  - System qualification and aircraft certification

FTEPS DESIGN AND VIRTUAL MOCK-UP

Computer Aided Engineering for Nitrogen Enriched Air (NEA) Distribution



Right Auxiliary Fuel Tank Oxygen Concentration

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SUMMARY AND CONCLUSIONS

- System design in accordance with both the current military requirements and the next evolution trends in civil market (Italian Air Force certified)
- System operation on flight crew activation upon aircraft mission needs; enhanced system control and monitoring features
- Deep integration in the aircraft ensuring compatibility with engine (low air consumption) and other on board systems (mainly air conditioning and cabin pressurization); no intrusive devices jeopardizing fuel tanks capability and operation
- System capability to retain fuel tanks inert condition after flight, shortening the time between consecutive missions with protection ensured
- Low impact on maintenance tasks (only a filter cartridge shall be replaced after 1000 operative hours) and no need of AGE
- Future trend to implement the fuel tanks oxygen concentration monitoring through integration of optical probes as derivation of the technology currently applied in the test campaign