LEONARDO

Flight test process
for the cooling of a reciprocating engine
on a Remotely Piloted Aircraft System

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Electronics

Helicopters

Aircraft

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Overview of the presentation

- **Introduction**
- **Cooling Design and integration**
  - Overview of the aircraft and engine
  - Cooling system characteristics
  - The engine cooling improvement
- **Preparation of the flight test campaign**
  - Objectives and campaign requirements
  - Flight Test Instrumentation
  - Safety assessment and risk reduction
- **Execution of the flight test campaign**
  - Personnel involved
  - Overview of the flight tests
  - Flight Test Process
  - The Test Card
- **Achievements of the Campaign**
- **Conclusions**

Introduction

Falco XN Tactical RPAS
(gasoline engine)

During 2010s

Falco Evo RPAS
(diesel turbocharged engine)

- 650 kg MTOW
- 12.7 m wingspan
- Multi payload
- 20+ hours mission

Continuous full rate of climb in hot climates

Upgrade of the standard engine cooling system

Cooling Design and integration

Overview of the aircraft and engine

- **Thr aircraft (air vehicle)**
  - Short-fuselage type
  - pusher propeller
  - high gull wing
  - boom-mounted empennages
  - Belly-mounted turret

- **The engine (propulsion system)**
  - heavy-fuel
  - four-stroke
  - three-cylinders in line
  - direct injection
  - liquid cooling

Cooling Design and integration

Cooling system characteristics

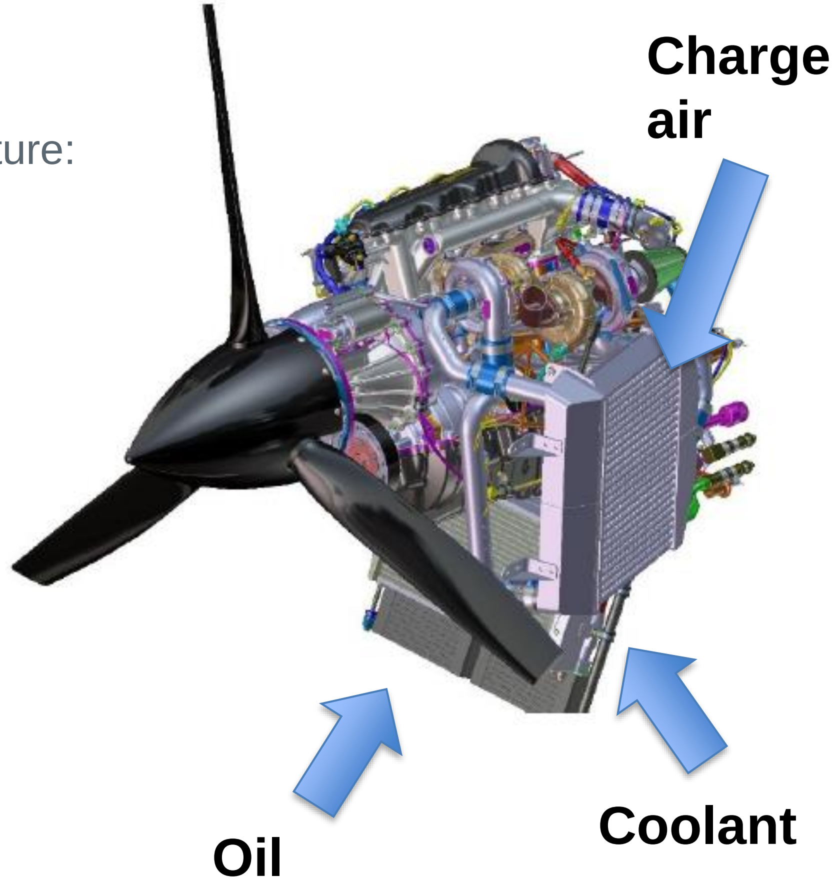
- **Fluids: Oil, Coolant, Charge air (turbocharging system)**

- Ideally, the three cooling fluids should reach their maximum operating temperature:
    - Simultaneously
    - At maximum engine power
    - In the desired operating condition

- In the reality, the design needs to achieve a trade-off between:
    - cooling performances on three fluids
    - engine maximum performance

- Key factors in the design:
    - weight
    - cooling drag

  They go in the direction of reducing the aircraft endurance.



Cooling Design and integration

The engine cooling improvement

Design

- **Input**: maximum off-ISA temperature to be reached at Take-Off Power
- **Activity**
- **Output**: installation with new ducted coolers

Bench Testing on prototype engine

- representative of mission conditions
- verify materials, mechanical strength and cooling performance
- update of the engine thermodynamic model

Predict the expected behaviour in flight

Integration on the aircraft

- physical checks
- functional tests

Preparation of the flight test campaign

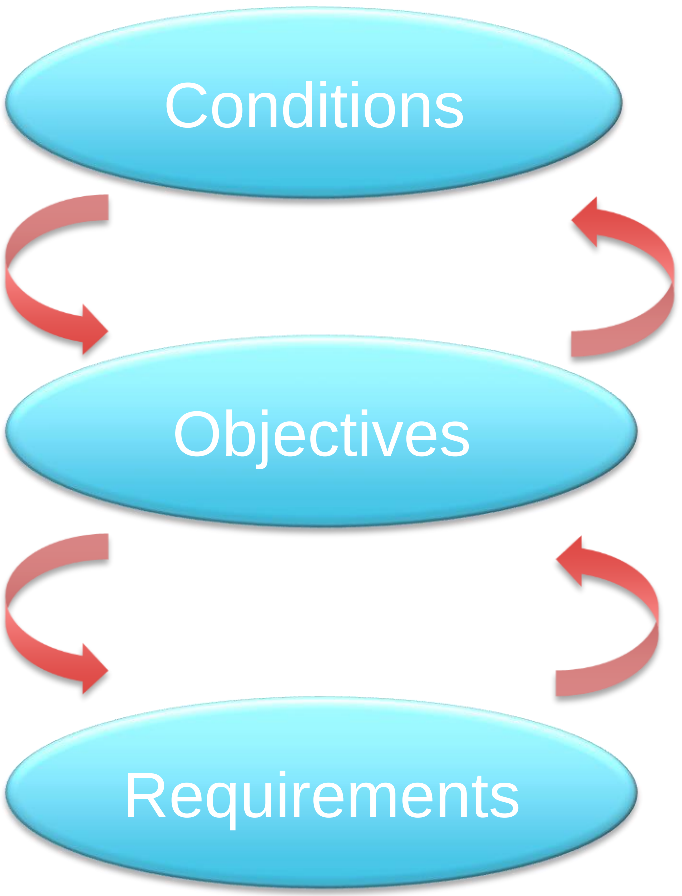
Objectives and campaign requirements

- **Conditions**:
  - technical requirements
  - safety aspects related to the test area
  - budget and time

- **Objectives**:
  - verify air vehicle performances and rate of climb in TOGA and MCP, plus rate of descent
  - environmental conditions as hot as possible
  - configuration representative of ISR mission (under-belly 16'' EO/IR turret)

- **Requirements:**
  - Airworthiness-based (AEP-4671 - USAR 1043 (Cooling test) and USAR 1047 (Cooling test procedures))
  - Performance-based: quantified performance objectives

    Example: «*Take-off power shall allow to comply with the expected rate-of-climb in ISA+30 ° C, in known flight envelope, with 16'' under-belly turret installed*»



Preparation of the flight test campaign

Flight Test Instrumentation

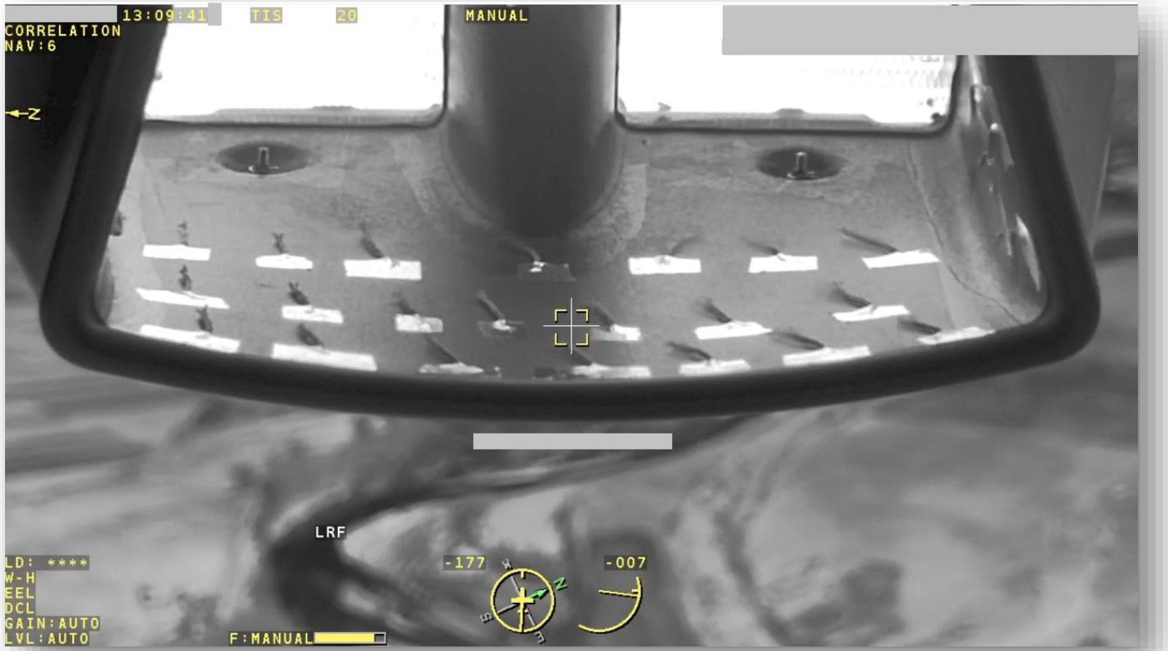
- The preparatory bench tests and related engine modelling allowed an immediate understanding of:
  - relevant temperature and pressure trends
  - possible criticalities

  by means of the **standard engine sensors suite**.

- Flight Test Instrumentation was almost eliminated

- Engine sensors were acquired through the standard engine monitoring unit, routed to the GCS via the RPAS Data Link.

- The impact of the turret on the oil and coolant radiators was to be confirmed in flight:
  - tufts were positioned in the coolant and oil inlet duct
  - turret **IR sensor** used to monitor the relevant area



Preparation of the flight test campaign

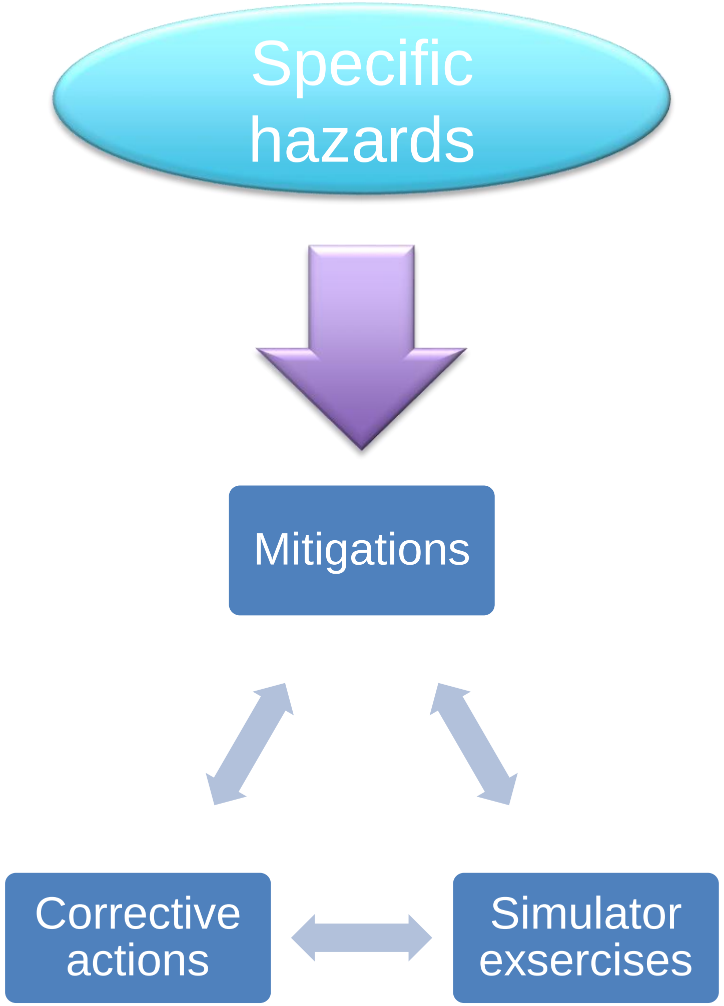
Safety assessment and risk reduction

- **Hazards specific to the flight campaign**:
  - engine overheat during takeoffs and climbs, with engine loss of power and possible flameout
  - exceeding exhaust gas temperature (EGT) lower limit, with possible flameout

- **Mitigations**:
  - **Build-up approach**: higher to lower airspeeds
  - Distance from the airbase and flight test altitude guarantee a **glide back**
  - **Knock-it-Off** (KIO) defined, for parameters featuring dynamic and fast variations (ex. EGT)
  - live monitoring in the **Control Room**, with a real-time prediction for the critical parameters

- **Corrective actions**:
  - **takeoff abort modes and escape maneuver** after takeoff (teardrop landing)
  - **power reduction procedure** and relevant power and altitude settings during climb
  - **parachute recovery** in case of an unsafe aircraft behavior

- **The Flight Crew exercised at simulator**:
  - possible **failures**, both in calm air and with light wind and turbulence
  - **takeoff abort** maneuver
  - procedure to manage the **engine out pattern**.



Execution of the flight test campaign

Personnel involved

- 8 people directly involved
- the **Flight Crew**, in the Ground Control Station:
  - Test Pilot;
  - Lead Flight Test Engineer
  - Data Link / GCS technician.
- the standard **Ground Crew**, for maintenance and pre/post-flight ramp activities:
  - mechanic technician
  - avionics technician.
- the **Test Personnel** in the Control Room:
  - the Test Director, in charge of clearing test points and communicating with the Flight Crew.
  - two specialists one from Leonardo engineering, the second from the engine manufacturer

Execution of the flight test campaign

Overview of the flight tests

- Two aircraft configurations: clean and ISR (belly-mounted EO/IR turret).
- Minimum and maximum take-off weight
- Four flights, maximum 90 minutes each

- Worst test conditions achievable in summer at the test site:
  - low altitude
  - ISA + 25 °C

  adequate to allow post-processing for requirements verification

- Test approach:
  - Takeoffs cleared by a number of high speed taxi sessions, up to rotation speed.
  - Climb and cooling performances investigated for different speeds with Wide-Open Throttle (WOT)
  - Descents at different throttle settings.

- Between each session:
  - inspection of critical components
  - preliminary data processing, to understand if data collected were usable

Execution of the flight test campaign

Flight Test Process

Request for Flight Test
- Objectives
- Requirements

Test Plan
- mid-level details
- overview of the campaign

Short Test Plan
- details the test plan
- data to issue the test cards

Experimental Flight Test Order
- configuration parameters,
- test limitations, normal procedures, exceptions
- test card

Test execution
- crew brief
- flight execution
- debrief (safety, data acceptability, remarks)

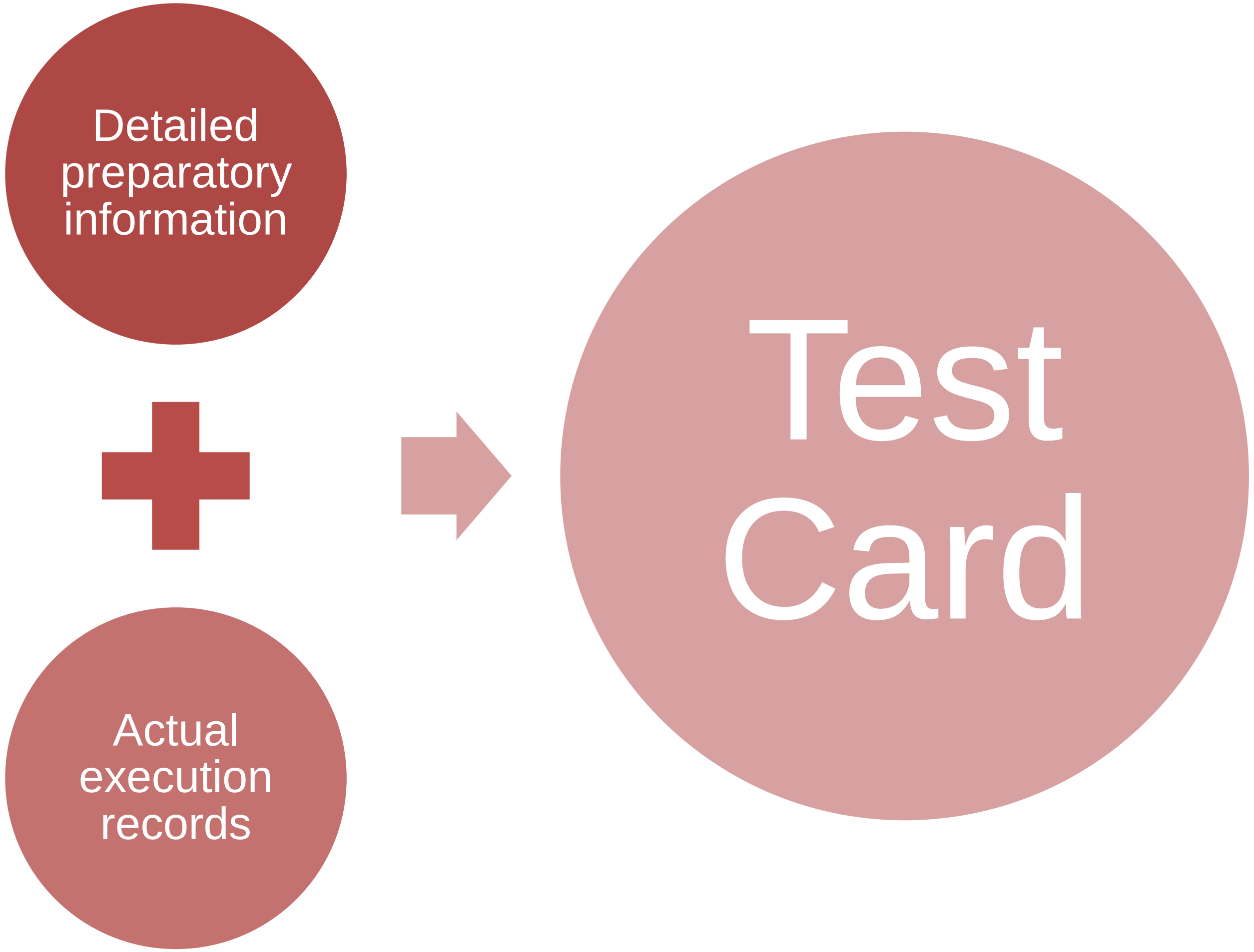
Post Flight Report
- activity executed
- deviations
- preliminary qualitative results

Output documentation

- Cooling effectiveness report
- Aircraft performance report
- Compliance matrixes
- Engine DDP

Execution of the flight test campaign

The Test Card



- Includes detailed test data, for preparation and execution
- handwritten data, useful to:
  - record aspect not immediately detectable through routine post processing
  - provide timing of events

Achievements of the Campaign

Main results

- Good exploitation of the time and resources available, thanks to preparation
- Post processing confirmed a climb performance in line with the expectations, also in hot climatic conditions
- Rate-of-climb limitation in hot climates was removed
- Slight reduction of endurance in line with the estimations
- Engine showed a responsiveness higher than expected; control laws were then tuned and tested

Conclusions

- Modelling and bench testing can reduce the number of flight test points
- Importance of clarification and the agreement of the objectives in advance
- “Waterfall-like" process, to keep track of the information during the entire campaign
- An effective RPAS flight campaign begins from the development phase, followed by accurate planning and tracking of information.

Accurate preparation and planning is a key to reach the RPAS flight campaign objectives, with an efficient use of resources.

Conclusions

“In omnibus autem negotiis, prius quam aggrediare, adhibenda est praeparatio diligens.”

“Before undertaking any enterprise, careful preparation must be made.”

M. Tullius Cicero. De Officiis.

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