Turboprop Engine Nacelle Optimization for Flight Increased Safety and Pollution Reduction

Cristian DOROBAT*,1, Gheorghe MOCA[1], Elena PRESURA[1]

*Corresponding author
[1]COMOTI Romanian Research and Development Institute for Gas Turbines,
220D Iuliu Maniu Ave., 061126, Bucharest, Romania,
cristian.dorobat@comoti.ro*

DOI: 10.13111/2066-8201.2018.10.1.6

Received: 16 November 2017/ Accepted: 17 January 2018/ Published: March 2018

***Aerospace Europe CEAS 2017 Conference**,*
16th-20th October 2017, Palace of the Parliament, Bucharest, Romania
Technical session Aircraft and Spacecraft Design I

Abstract: *Commuter airplanes defined in CS-23 as being propeller driven, twin-engine, nineteen seats and maximum certified take-off weight of 8618 Kg had lately a special development due to advantages of turboprop engine compared with piston or jet engines. Nacelle optimization implies a sound and vibrations proof engine frame, engine fuel consumption reduction (through smaller nacelle drag and weight, better lift, better pressure recovery in air induction system, smaller drag of exhaust nozzles, engine cooling and nacelle ventilation more efficient, composite nacelle fairings with noise reduction properties, etc.). Nacelle aerodynamic experimental model, air induction experimental model and other nacelle experimental systems tested independently allow construction efficiency due to minimizing modifications on nacelle assembly and more safety in operation [1].*

***Key Words**: nacelle, optimization, commuter, experimental model*

1. INTRODUCTION

One COMMUTER aircraft will be certified in the CS 23 / FAR23 [2] Commuter category. It shall be powered by two Pratt & Whitney Canada PT6A-65B engines flat rated, to provide adequate performances under hot and high conditions, matching with HARTZELL Propeller HC-B5MP-3. As an alternative, PT6A-67D engine may be considered, with minimum design modifications for engine installation and nacelle arrangement. The engines will be enclosed in nacelles and supported by engine mounting structure (frame) attached to the wing box. Engine installation and nacelle arrangement are based upon CS 23 requirements, Pratt & Whitney Installation Manual and Engine Installation Drawings, Pratt & Whitney Specific Operations Instructions, design requirements and experience gained in PT6A engine installation on other airplanes.

2. NACELLE PREZENTATION

The PT6A-65B (digital mock-up in Fig. 1) is a lightweight free turbine engine certified on the basis of FAR 33 and having Transport Canada Type Approval. It has a four stage axial, single-stage centrifugal compressor driven by a single-stage reaction turbine. Another two-stage reaction turbine, counter-rotating with the first, drives the output shaft. Fuel is sprayed in the annular combustion chamber by fourteen individually removable fuel nozzles mounted around the gas generator case. A high energy unit and two spark igniter plugs are used to start combustion. A hydro pneumatic fuel control schedules fuel flow to maintain the power set by the gas generator power control lever. Propeller speed remains constant at any selected propeller control lever position through the action of a propeller governor, except in the BETA range where the maximum propeller speed is controlled by the BETA VALVE section of the propeller governor. A spray ring is provided for washing the compressor. A compressor blow off valve compensate for excess air flow at low rpm for easy starting.

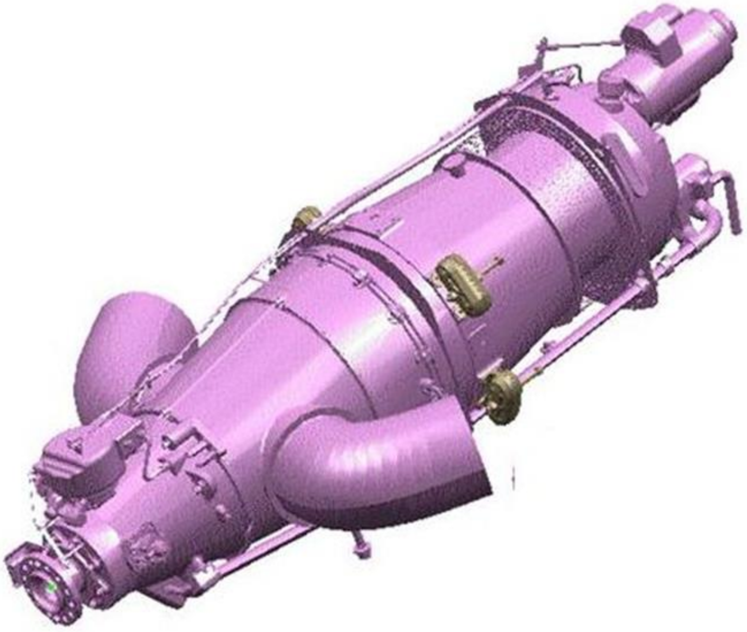

Fig. 1 – The PT6A-65B

Engine performances are presented in Table 1.

Table 1 – Engine PT6A-65B performances

Rating	Output Shaft Speed Nprop rpm	Min. power SHP	Max. ambient ºC	Max. SFC lbs/SHPhr.
Take-off	1700	1173	43.6	.561
Max. Continuous	1700	1173	38.3	.561

The Hartzell Propeller HC-B5MP-3 data:

- Aircraft……………………………………………COMMUTER
- Engine ……………………………………………PT6A-65B
- Propeller…………………...……………………HC-B5MP-3( )
- Blade………………………………………………M10876ANS (K)
- Spinner……………………………………………D-3434-8P
- Number of blades………………………………Five (four as alternative)
- Propeller Diameter……………………………...2824.48 mm

- Spinner Diameter………………………………495.3 mm
- Spinner Length…………………………………531.37 mm
- Hub Material……………………………………Steel
- Blade Material…………………………………Aluminum
- Activity Factor Per Blade………………………89
- Lift Coefficient (Cl¡) Per Blade……………….. 0.472
- Airfoil Section Type……………………………Hartzell Modified NACA 65 Series

In Fig. 2 is presented digital mock-up of power plant equipped with Hartzell propeller HC-B5MP-3.

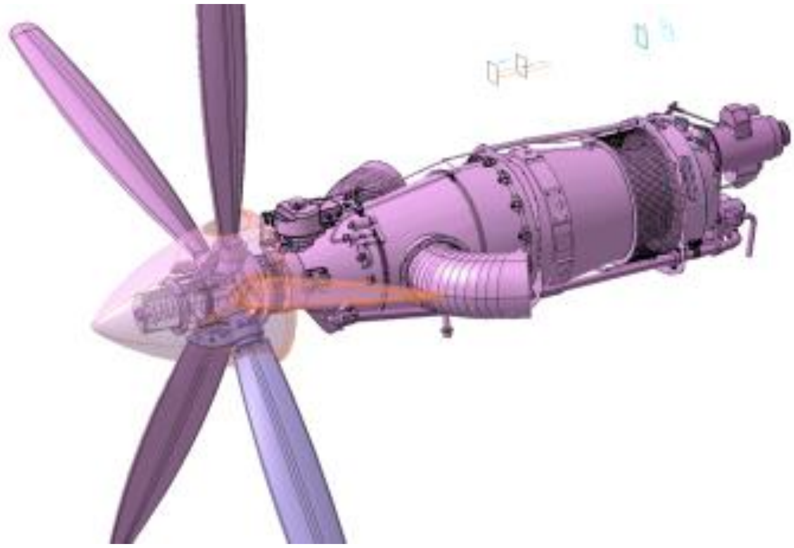

Fig. 2 – Digital mock-up of power plant

The nacelle assembly consists of a completely dressed engine readily to be installed or removed from the engine frame attached to wing, cowlings and systems which connects engine to aircraft systems.

The main requirement for nacelle design is that it must be constructed and supported so that it can resist any vibration, inertia and air loads to which it may be subjected in operation. Also, nacelle design have to assure easy cowling removal and installation, access to engine equipments for maintenance and overhaul and assure engine ventilation and fire protection requirements.

Nacelle external shape is a surface resulting from the following conditions:

- matching with propeller spinner, wing and flap
- matching with designed air inlet system and oil cooler duct
- to be outside nominal engine envelope (where no airframe equipment or attachment may be located)
- to assure a minimum frontal area for minimum drag

Nacelle compartments are defined starting from fire protection requirements (i.e. engine firewalls position), air inlet system and engine inertial separator design. Nacelle panel's position must assure easy access to engine accessories.

Nacelle configuration (exploded) is presented in Fig. 3.

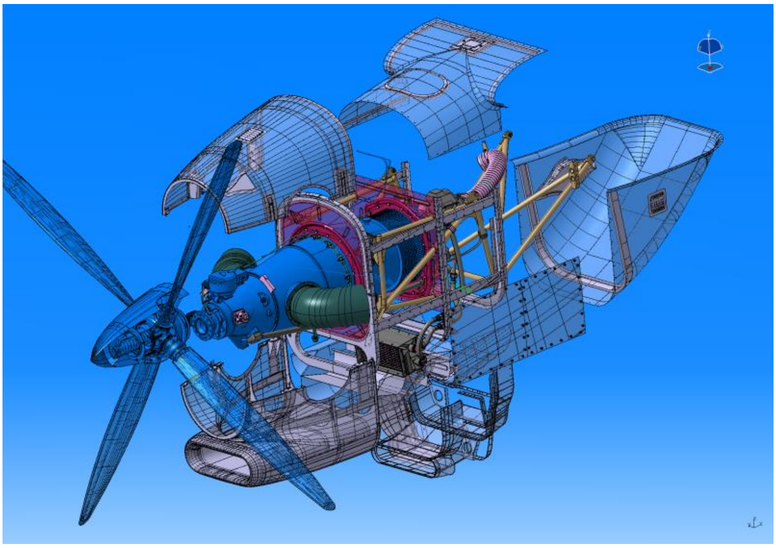

Fig. 3 – Nacelle configuration

A satisfactory installation requires careful attention to the detailed design of all features affecting the operation, maintenance and durability of the engine. Requirements are prescribed to ensure that the engine will not experience detrimental effects under the normal use to which the engine and aircraft may be subject within the engine power range. The engine mounting system (Fig. 4) must protect the airframe from any undesirable power plant-generated vibrations.

The engine is mounted on four pads located symmetrical on the diffuser case in engine mounting plane, and bolted to engine mounting frame. Mount reaction must be pure shear; loads due to airframe structure deformation must not be transferred to the engine. Engine mount pads are located in the engine inlet plenum. This provides adequate airflow for cooling the pads.

The mounting system uses four Berry Mounts vibration isolators and prevents excessive displacement.

Engine installation drawings give all necessary data for installing the engine, like:

- engine accessories, their mounting pads and connectors locations
- engine dimensions and nominal engine envelope
- engine installation pads, flanges
- center of gravity
- engine systems data and connections (oil, fuel, air, drains, electrical, instrumentation, compressor wash)
- engine firewalls /fire seals position & dimensions
- engine controls

Engine mounting design requirements are fully detailed in [5].

Engine frame is a high resistant (4130), welded steel tubes (1.25 in diameter, thk .065) assembly attached to the wing with four bolted attachments. The front U tube of the frame has four bushes welded on brackets which accommodate vibration isolator’s bolts, which in turn are bolted to engine mounting pads. Also, the front U tube has four front brackets to which nacelle mounting structure is attached with 12 bolts. Six mid brackets welded on tubes allow rear fire seal to be attached.

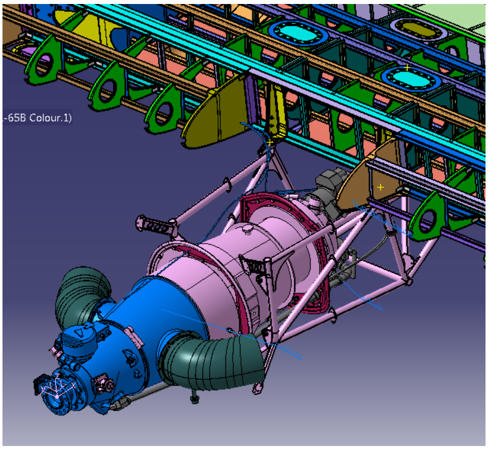

Fig. 4 – The engine mounting system

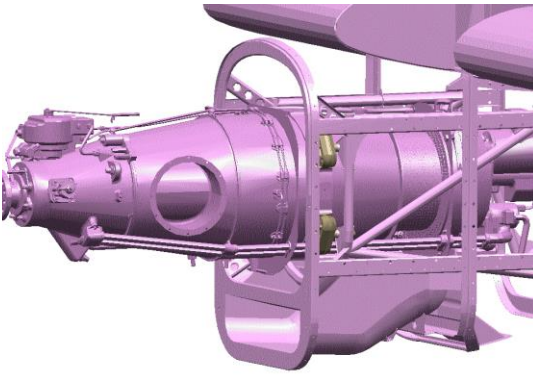

Fig. 5 – Nacelle supporting structure

A special technology using an inert gas pressure control inside the structure assures best fiability of engine frame.

A Nacelle supporting structure (Fig. 5) comprising welded inertial separator is bolted to engine frame.

The turboprop aircraft are required to be certified considering whirl flutter which may cause the propeller mounting unstable vibrations, even a failure of the engine, nacelle or whole wing.

Reference [6] details a method to assess whirl flutter of the power plant in case, using the diagram from Fig. 6.

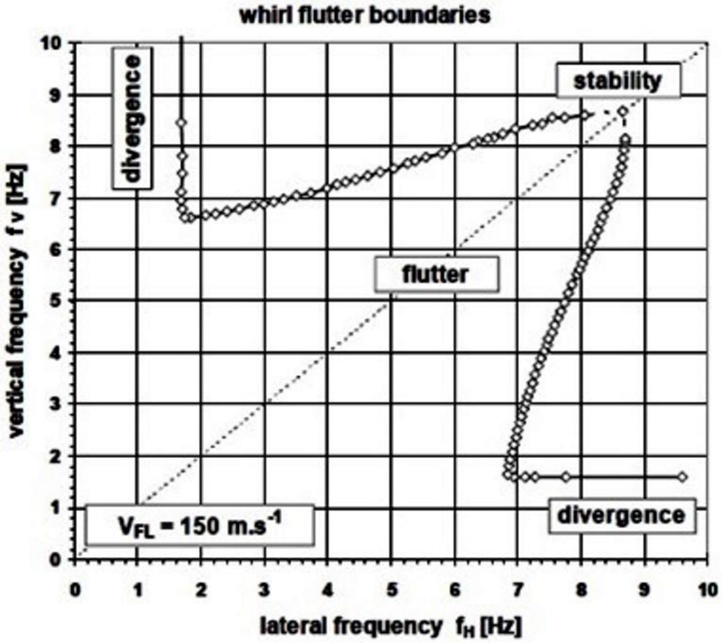

Fig. 6 – The diagram used to assess whirl flutter of the power plant

Nacelle reference surface comprising engine installation requirements and constraints is the basis of nacelle cowlings, air inlet system and inertial separator assy design.

Nacelle reference surface assure matching with propeller spinner and wing, matching with designed air inlet system and oil cooler duct, is to be outside nominal engine envelope (where no airframe equipment or attachment may be located), has to assure a minimum frontal area for minimum drag.

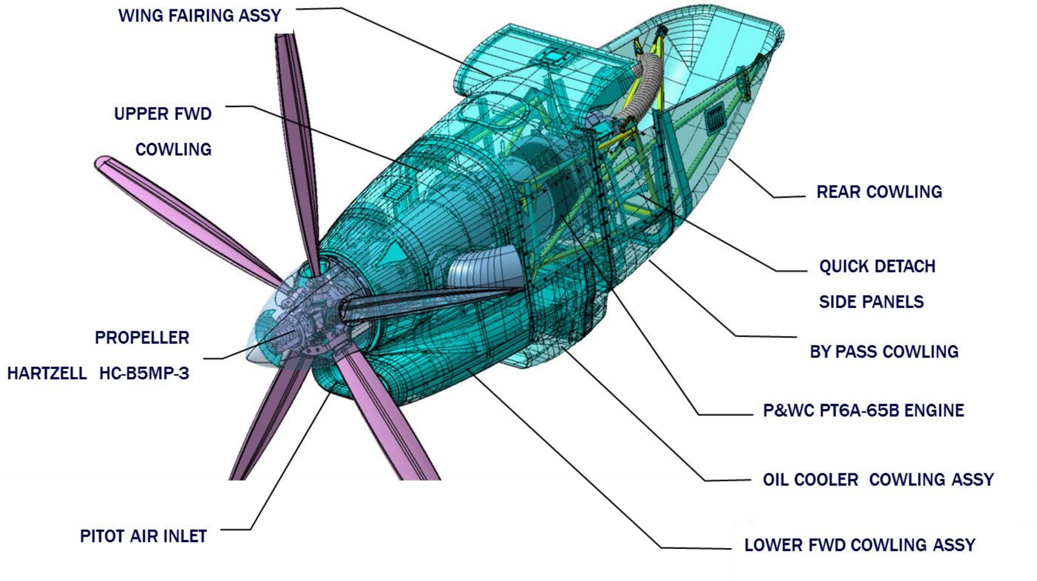

Fig. 7 – Nacelle mains assemblies

Nacelle mains assys are as follows (Fig. 7):

- The Upper Forward Cowling Assy is positioned between propeller spinner and front frame of the nacelle supporting structure and split at the bottom with a horizontal plane passing through engine axis to accommodate engine exhaust stubs. Its typical structure has a skin with riveted stiffeners and doublets on edges. Installation on Lower Forward Cowling is assured by six centering pins welded on brackets and four Hartwell Latches – male side. Design requirements assure necessary gap to propeller spinner, propeller governor and engine exhaust stubs. Cooling ventilation is assured by two NACA submerged air intakes.
- The Lower Forward Cowling Assy is positioned between propeller spinner and front frame of nacelle supporting structure and split at the upper side with a horizontal plane passing through engine CL, to accommodate engine stubs. At the bottom it accommodates Pitot air intake duct comprising air inlet lip and diffuser. The Lower Forward Cowling is centered and bolted to the front frame of nacelle supporting structure. Installation of Upper Forward Cowling is assured by six centering holes on welded brackets and four Hartwell Latches – female side. (see Fig. 11). Design requirements assure necessary gap to propeller spinner, and engine exhaust stubs. Air inlet geometry requirements are fully detailed in [5].
- The Oil Cooler Cowling Assy allows the Oil Cooler installation and removal for maintenance. This assy comprises Front Oil Cooler Cowling Assy and Rear Oil Cooler Cowling Assy, welded constructions, bolted to each other, to oil cooler flanges and to Nacelle supporting structure. The Front Oil Cooler Cowling Assy comprises a front cowling with an inlet lip similar to Pitot air inlet, and an inlet air

duct assuring necessary air flow to enter the cooler. This welded assy is reinforced with riveted intercostals. The Rear Oil Cooler Cowling Assy comprises a rear cowling, an exit air duct, welded construction and a riveted doubled-connector.

- Wing fairing assy connects front nacelle and wing box assuring easy access to engine oil deep stick through a visiting lid. The skin fairing is reinforced with riveted stiffeners. The assy is bolted to nacelle supporting structure and wing box. The lid assy uses Camloc quickly detachment fasteners.
- The Rear Cowling assy encloses rear part of nacelle. It is bolted to nacelle supporting structure and to the rear brackets of engine frame, presses against wing underneath, assuring an aerodynamic profile of nacelle section. Its structure comprises a skin reinforced with stiffener and a flange on upper contour. A sealing gasket fixed on this flange seals rear cowling and wing underneath.
- Side panels are bolted to nacelle supporting structure with Camloc fasteners to allow quick detachment and easy access to engine accessories. Rear left panel assy is a riveted structure comprising a skin panel reinforced with riveted stiffeners and quick detaches Camloc fasteners on contour which allow its mounting on nacelle supporting structure. Right Forward panel assyis a riveted structure comprising a skin panel reinforced with riveted stiffeners and quick detach Camloc fasteners on contour which allow its mounting on nacelle supporting structure and a vent door for engine blow-off valve air discharge.

3. NACELLE SYSTEMS

The air inlet system (Fig. 8) is designed to provide the maximum possible total pressure at the engine intake screen, over a wide range of flight conditions. Maximum ram pressure recovery is required to obtain efficient power levels and minimum specific fuel consumption.

The design of air inlet system has to assure that high velocity free stream air (Mach no. 0.4÷0.6) is reduced to the engine radial intake screen at Mach no. 0.05÷0.07, and at the same time, minimize the loss of available ram pressure.

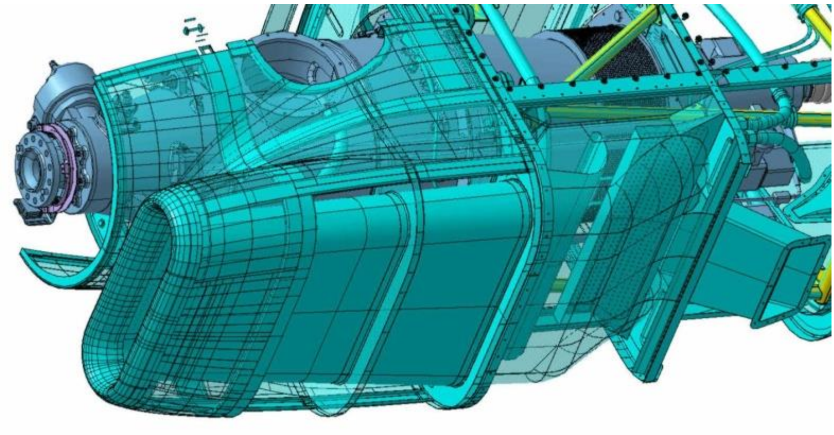

Fig. 8 – The air inlet system

The air inlet system consists of four sections: the inlet, the diffuser, the inertial separator and the plenum chamber.

The design of the inlet system is made according to Installation Handbook procedure and consists in diffusing with a 2:1 ratio upstream of the inlet and then diffuses internally at a rate equivalent to an eight degree cone angle. This means that the diffuser exit plane area to inlet plane area ratio of at least two.

The principal requirements of the plenum area is to assure nominal engine envelope 22.5 in diameter and a minimum 3.5 in clearance between intake screen and plenum is assured.

The inertial separator is a key assy in nacelle certification assuring high life for engine and a safe deicing too. Inertial separation is achieved by turning the air flow from diffuser exit to the engine inlet screen. The main features of the separator are as follows:

- Welded bottom assy (with rounded bottom) comprising inlet duct, hump and side walls
- Fixed vane assuring 107.7 mm high throat, shedder assy comprising ant icing screen (Hooper), vertical back wall, by pass duct assy

The Hooper has a wire mesh surface (or perforated surface) and provides a cavity into which ice can accumulate without causing deterioration of the separator system. It should be capable to withstand aerodynamic loads up to 2 psig. The hump on the lower separator wall serves to control the flow distribution in the separator and provides a means to optimize the separation / loss characteristics of the system. The bypass duct provides a means for the separated particles to be expelled outside. It is designed to minimize impingement in critical areas, and to control the bypass flow at the minimum value. Inertial separator supports, at the bottom, engine oil cooler.

The exhaust system (Fig. 9) consists of two stacks mounted on the L&R side of engine exhaust flanges, discharging the exhaust gases into the atmosphere. The PT6A65-B engine is fitted with a twin port exhaust case with flanges to which the exhaust stubs are bolted. The location, orientation, flange dimension and maximum load caring capacity of these exhaust ports are shown in appropriate Installation Drawing. Actual Engine standard nozzles should be redesigned to assure minimum aerodynamic drag (oval shape outside nacelle) and minimum internal exit losses (by utilizing guide vanes in nozzle bend) for engine consumption reduction.

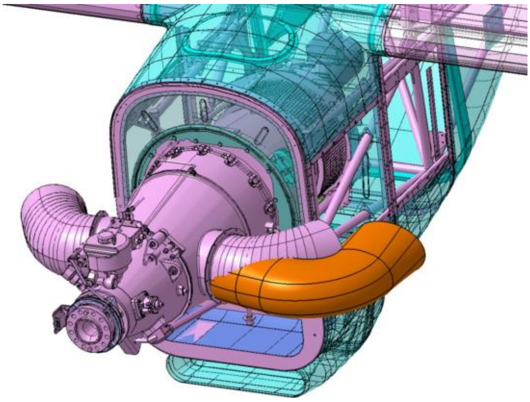

Fig. 9 – The exhaust system

Also improving nacelle cooling may be obtained utilizing a small composite bulkhead around nozzle at nacelle opening. Utilizing CFD software and tests on scaled mock-up are very useful for final design solution.

CS 23 regulation provides necessary requirements for designing a safe, efficient and reliable fire protection system for engine nacelle. Fire protection consists of prevention, containment, detection and extinguishment. According to CS 23.1181 designated fire zones and engine mounted fire seals on compressor case and gas generator case it was proposed nacelle fire classification and configuration as follows:

- The compartment before engine FWD firewall assy is fire zone due to exhaust stubs with a high temperature and oil and fuel ducts mounted on the engine (Fig. 10).

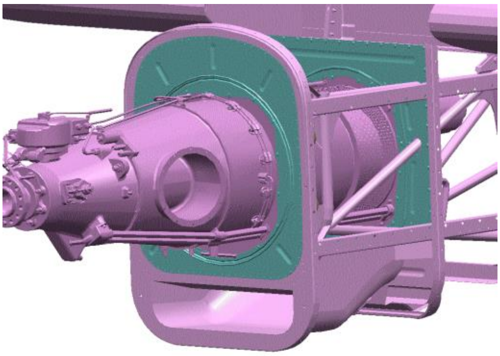

Fig. 10 – Engine firewalls

- The compartment after engine rear firewall assy is a fire zone due to overheated equipment (like starter-generator) and oil and fuel ducts in this area.

FWD firewall assy seal presses against Upper and Lower FWD Cowlings fire seals creating a ventilation stop, liquid tight.

Rear firewall assy seal presses against Rear baffle creating a ventilation stop too.

The Oil Cooler Cowlings Assy allows the Oil Cooler installation and removal for maintenance.

This assy comprises Oil Cooler LORI L8538233, Front Oil Cooler Cowling Assy, Rear Oil Cooler Cowling Assy, Oil Cooler Pipes Assy, Oil Breather Pipes Assy (Fig. 11).

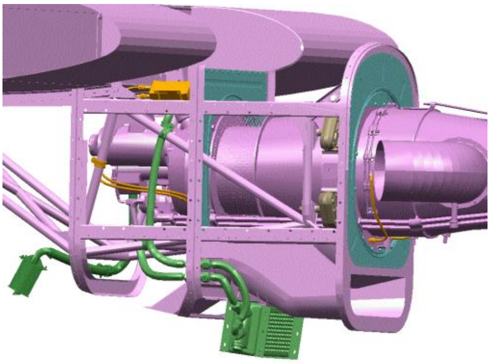

Fig. 11 – Oil system

The Front Oil Cooler Cowling Assy comprises a front cowling with an inlet lip similar to Pitot air inlet, and an air duct assuring necessary air flow to enter the cooler. This welded assy is reinforced with riveted intercostals. The Rear Oil Cooler Cowling Assy comprises a rear cowling, an exit air duct, welded construction and a riveted doubled-connector.

The Engine Control System is a simple manual-mechanical one, using 3 levers and push-pull flexible cables to:

- regulate the power setting of the engines (see Fig. 12, power control cable)
- regulate the setting of the speed control spring, Beta valve and feathering dump valve of the propeller governor (see Fig. 13)

- regulate the position of the fuel control lever on the fuel control unit (FCU)
- stop the flow of fuel to the engine during normal and emergency procedures.

Specification for quadrant levers and power plant control cables procurement (power control, propeller speed control and condition control) will include: type and requirements for equipment & cables (loads, bend radius, usable stroke, etc.), connecting elements spec. like: clevis, rod end bearings, swivel angle, telescopic angles, bulkhead swivel assys, connectors, etc.

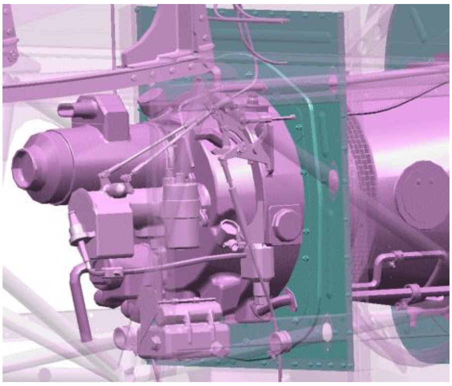

Fig. 12 – Power control

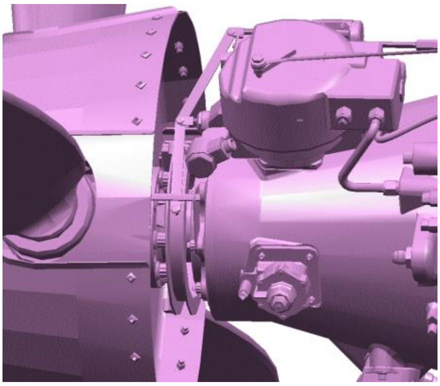

Fig. 13 – Propeller control

4. NACELLE EXPERIMENTAL MODELS

Fig. 14 present this model which comprise mainly air intake assy, engine simulation assy, welded inertial separator assy with its by-pass, flow measurement assy.

This model is designated to be tested in wind tunnel in order to estimate its total air flow, total pressure drop and by-pass ratio. Air from flow measurement assy is extracted with a blower which simulates the engine. The model is instrumented [3], [4] with total pressure rakes in four sections namely:

- air intake throat
- by-pass mid section
- engine screen
- flow measurement exit section

After testing will be applied modification to reach imposed parameters and new tests will be done until necessary.

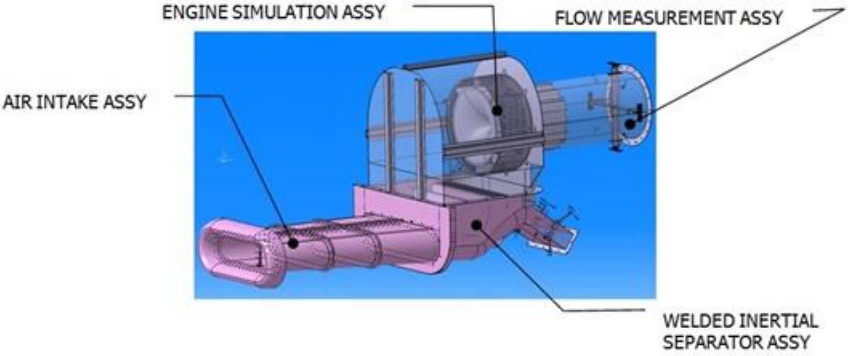

Fig. 14 – Air system model

Fig. 15 present this model which comprise mainly propeller spinner model, nacelle model, wing model, nozzle model, oil cooler model, starter-generator air inlet model; all these models are instrumented with total pressure rakes and static pressure tapings.

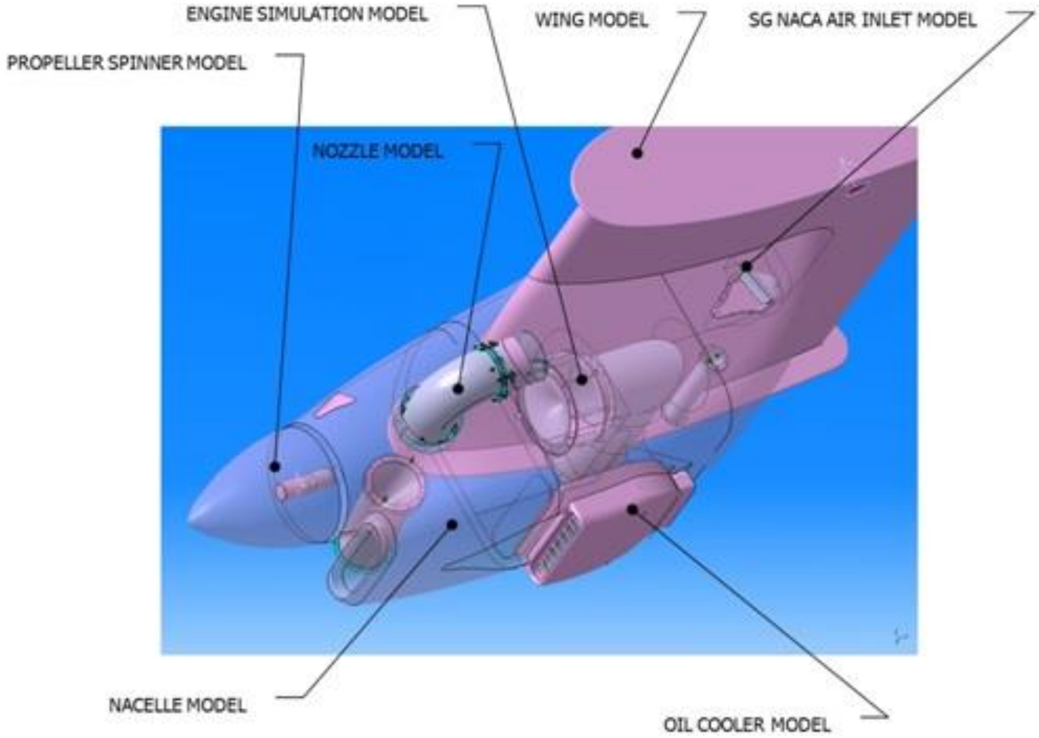

Fig. 15 – Nacelle experimental model

This model is designated to be tested in wind tunnel in order to estimate its performances and characteristics as follows:

- nacelle aerodynamic behavior, lift and drag characteristics [7]
- pressures distribution on nacelle for optimum position of auxiliary air intakes
- exhaust nozzle jet direction estimation and correction as required
- air flow rate of oil cooler and starter generator estimation.

5. CONCLUSIONS

Nacelle arrangement was proposed according to general requirements of engine manufacturer, specific standards and regulation experience gained in the field. Nacelle optimization for new types of airplanes or for those existing at the moment is more efficient utilizing experimental models for vital systems like air inlet/ exhaust system, engine frame, oil system etc. Composite materials used for nacelle fairings reduce noise and weight. Engine frame optimization assures vibration / noise smaller limits.

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