DEVELOPMENT APPROACH OF THE PW_103 - AN INCREASED RELIBILITY MALE UAV - UNDER THE CAPECON PROJECT WITHIN THE V FR OF EU

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Abstract

PW-103 aircraft of MALE class, designed at Warsaw University of Technology within the frame of CAPECON project sponsored by European Union under V Framework is presented. PW-103 version was preceded by former versions – PW-101 and PW-102 aircraft. The analysis of the PW-101 concept led to a list of main drawbacks which had to be corrected in order to improve the concept [3]. PW-101 had compact configuration, however efficiency not high enough (mainly due to low aspect ratio of main wing). Additionally, redundant power unit was required in emergency. The new PW-102 configuration had a sufficient efficiency and auxiliary power unit in emergency, however the fuselage should be redesigned to improve its aerodynamics and then to increase the propeller efficiency. The PW-103 configuration, with improved aerodynamics of fuselage and central part of wing satisfies the requirements of efficiency and performances.

1 Introduction

The reliability and sustainability of any UAV is very important because it is closely related to their affordability, mission availability and acceptance into civil airspace. Improved reliability offers savings by reducing maintenance and by decreasing the number of spares and attrition aircraft procured. Increased reliability improves the general safety level of the other national airspace users and people on the ground. Among the primary causes of UAV's mishap histories there are the power unit and flight control systems failures.

Within V Framework three projects related to UAVs are in progress: (1) **UAV-NET** is a thematic network to advance the development of UAVs for civilian purposes, co-ordinated by IAI - Israel; (2) **USICO** is a RTD programme to improve the safety of civil UAVs and enable their integration within civilian airspace, co-ordinated by Aerobotics - Germany; (3) **CAPECON** is a RTD programme to investigate new directions for future civil UAV development, applications, technologies and economic viability, co-ordinated by IAI - Israel. CAPECON project has the following objectives: identification and definition of potential civil UAV applications and; definition of configuration for those applications (3 HALE, 2 MALE, 2 Rotary) meeting safety criteria in ATC/ATM environment, while demonstrating economic effectivity compared to other airborne (manned), spaceborne (satellites) and ground based systems. The twin-boom, pushing main power unit, selected for MALE configuration, offers high mission flexibility (payload can be quickly and easy exchanged without extensive influence on stability and maneuvrability). Emergency power to increases the safety level (if in emergency because of the main engine failure, then the auxiliary power unit is activated and the aircraft is able to return home safely). It is an additional cheap, low weight of order 15 kg, multi-fuel engine, often used by flying targets as the main power unit (for example model AR 731 of 38 hp and 7800 rpm), preferably a rotary piston engine. Two-blade, feathered propeller in tractor configuration is placed at the nose of fuselage.

Wing loading was chosen in order to have a good endurance, rate of climb & short take-off and to be relatively insensitive to gust. Diesel engine and 5 blade propeller was selected because of very low SFC (8.8 l/h @ 0.4 PNOM & 18.5 l/h @ 0.6 PNOM). Airplane silhouette results from the placement of antennas, SAR, FLIR etc and their undisturbed fields of vision.

The light structure weight was obtained using honey-comb sandwich and graphite rowing. All on-board safety related systems are doubled or three-fold redundant.

2 Requirements

The main requirements for MALE-UAV are defined in Table 1

Table 1

Parameter	Requirement
Altitude	1-3 km
Flight Speed	40-60 m/s
Endurance	16-18 h
Take off & landing	Non dedicated flat fields shall be acceptable in several cases
Payload volume	- FLIR 0.2 m3 - SAR 0.4 m3 - SATCOM LOS
Payload Weight	150 kg
Payload Power	1 kW

The PW-103 MALE UAV was designed as 2-beam configuration. It is a cantilever mid-wing monoplane with an inverted V-tail. The 2-beam configuration was selected due to:

- makes it easier to locate payload close to the airplane CG,
- is not very sensitive to any changes in payload weight,
- decreases moments of inertia.

The wing loading was chosen in order:

- to have good endurance, rate of climb & short take-off,
- to be relatively insensitive to gust.

Diesel engine with 5 blade propeller, situated at the back of fuselage, was selected because of very low SFC (8.8 l/h @ 0.4 PNOM & 18.5 l/h @ 0.6 PNOM). Emergency power unit was added to increase the safety level (if in emergency because of the main engine failure, then the auxiliary power unit is activated and the aircraft is able to return the home base safe).

Airplane silhouette results from the placement of antennas, SAR, FLIR etc. and their undisturbed fields of vision. Structure is fully composite. Landing gear is conventional with arrester hook to make landing shorter.

MTOW of the configuration described is 930 kg. Wing loading resulting is 91 kg/m².

Fig. 1. PW-103 – overview

3 Development

Primary concept of UAV-MALE configuration (i.e. two beam configuration with pusher diesel engine and inverted V-tail) was the same during the development process. Also arrangement of equipment and payload has not been changed. Figures below present the first version PW-101.

Fig. 2. PW-101 – front view

Fig. 3 – PW-101 – back view

PW-101 had a compact configuration, however efficiency was not sufficient. Additionally the redundant power unit was required in emergency. The wing plan-form was changed in the second iteration, to improve performance parameters, especially the lift/drag ratio. The aspect ratio of the new wing was increased (from 9.4 to 14.7) but total wing area was the same. In this way the wing span was changed from 10m to 12.6m. The central part of the wing was not changed. Fig. 4 shows the main geometry improvement in the second iteration called PW-102.

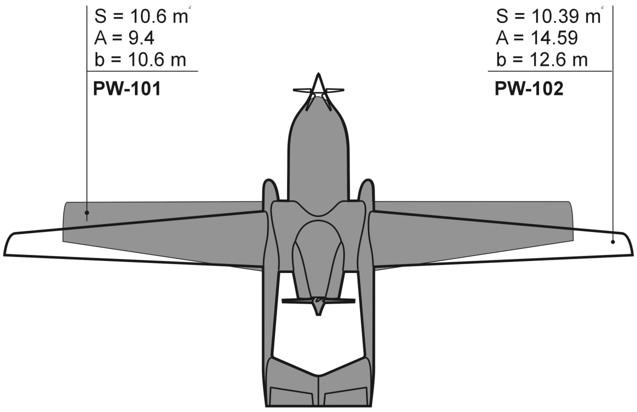

Fig. 4. PW-102 aircraft of increased aspect ratio

The aerodynamic efficiency of PW-102 was just sufficient, however the fuselage could be redesigned to improve its aerodynamics and then to increase the propeller efficiency. The fuselage shape was changed, Fig.5.

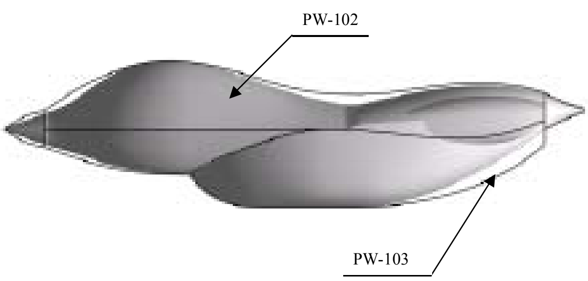

Fig. 5. Improvement of PW-103 MALE fuselage – side view

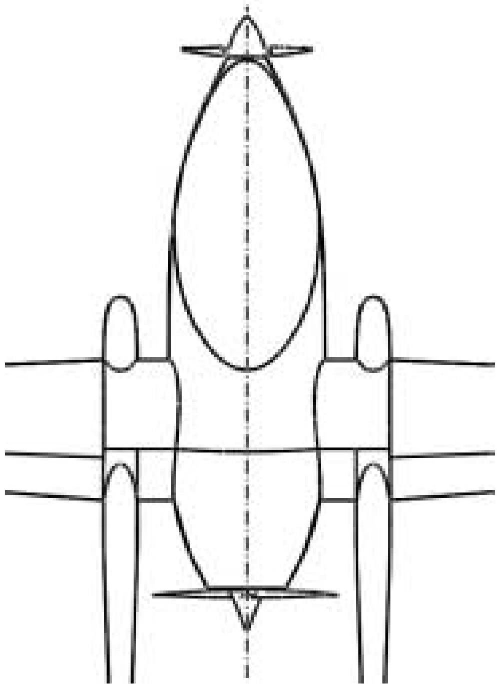

Fig. 6 - Improvement of PW-103 MALE fuselage and central part of the wing –top view

The shape of the tail beams, central part of the wing and sweep of the outer parts of wing were also changed. The reasons of these changes were not only due to aerodynamics. It was also due to mass breakdown analysis. The advantage of the wing shape improvements that main spar is perpendicular to symmetry axis. Next figures show the way of the body shape evaluation. The side view and top view of successive versions (form PW-101 to PW-103) are presented.

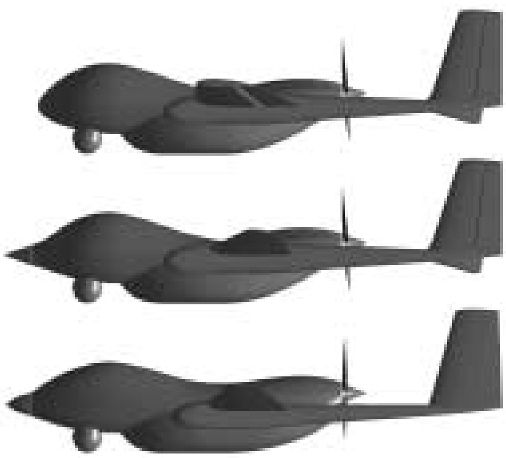

Fig. 7. From PW-101 to PW-103 – body shape evaluation (side view)

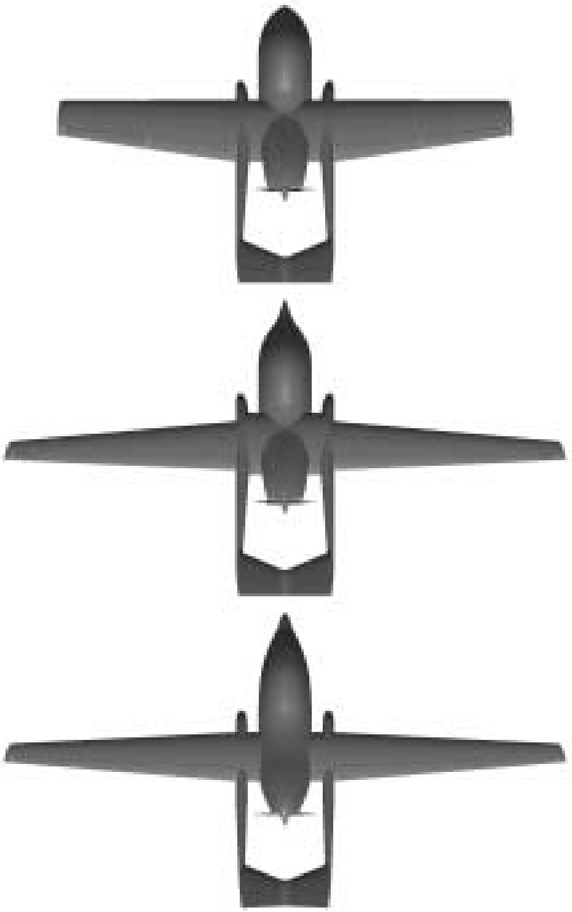

Fig. 8 – From PW-101 to PW-103 – body shape evaluation (top view)

Table 2

Geometric and mass data:	
Wing area	10.22 m^2
Wing span	12.6 m
Aspect ratio	15.5
Main aerodynamic chord	0.874 m
Taper ratio	0.36
Wing airfoil thickness	15 %
C.G position	24÷25 % MAC
Wetted area:	
Wing	17.79 m^2
Fuselage	12.48 m^2
Beams	6.71 m^2
Tail	5.16 m^2
Total	42.14 m^2
Wing airfoil	NACA 2415
Tail airfoil	NACA 0012
Total mass	930 kg

Empty airframe	488 kg
Fuel mass	225 kg
Payload mass	217 kg
Wing loading	91 kg/m^2
Power loading	6.9 kg/KM

4. Main components

4.1 Fuselage

The body of fuselage could be divided into two main sections. Central section has visible division into upper and lower part. Both parts pass smoothly into the main propulsion unit cowling. Front fuselage section contains emergency propulsion unit with foldable propeller and SATCOM antenna. FLIR head is located below. Lower part of central section begins behind the FLIR head. It contains front leg of the landing gear and SAR antenna. Main engine with pushing propeller are located in the rear fuselage section.

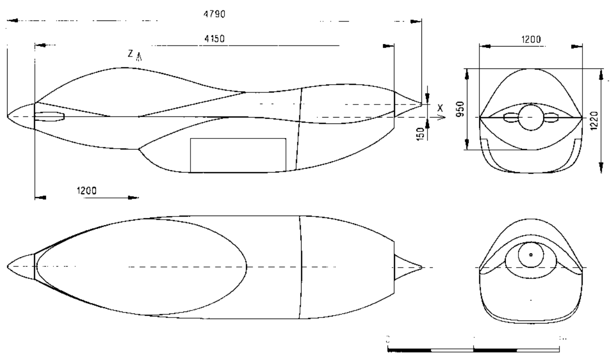

Fig. 9. Fuselage

4.2 Wing

The wing consists of centre-wing and demountable outer wings. NACA2415 airfoil is applied along the whole wing span. Centre-wing is rectangular. It is not twisted. Outer wings hale trapezoid contour with rounded tips. They have –2° of geometric twist measured in reference to 35% of the local chord points. Outer wing dihedral is equal to 3° in reference to the centre-wing. Line of 35% of chords is orthogonal to aircraft plane of symmetry. Incidence angle is equal to 4° in reference to the fuselage axis.

Outer wing has three movable surfaces: flap, flaperon and aileron. They have span of 1660 mm and chord percentage of 34.5% each. Rotation axis of each control surface is located in 70% of the current chord. Maximum deflections are the following:

-aileron:	30° up
	20° down
-flaperon:	15° up
	45° down
-flap:	5° up
	45° down

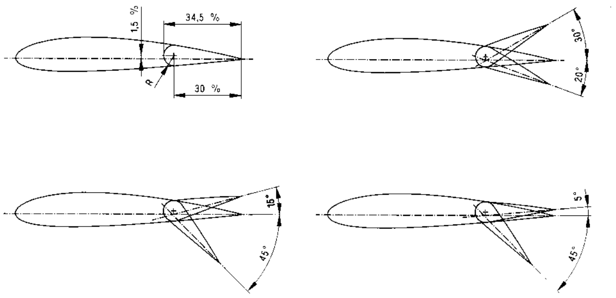

Fig. 10 – Wing section with ailerons, flaperons and flaps

4.3 Landing gear

Three-cycle landing gear with front wheel is retractable forward in flight. Main legs are retractable into tail beams. Front leg is retractable into the fuselage.

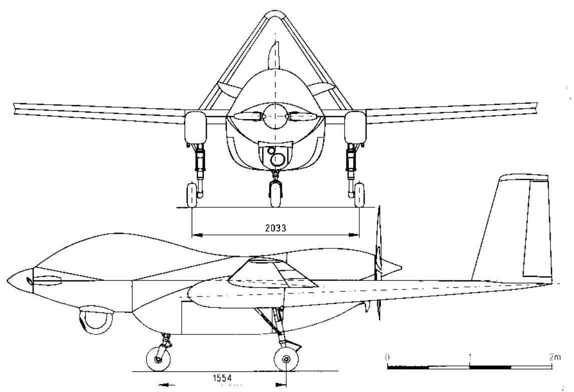

Fig. 11. Wheel base and wheel track

5. Wing section selection

A number of wing sections as candidates for MALE UAV has been studied and some aerodynamic characteristics have been compared. As a result the traditional wing section NACA 2415 was adopted for the main wing, and NACA 0012 was adopted for the tail plane. Among these profiles under consideration there were:

- ILL415 – a wing section developed in the Institute of Aviation (Warsaw) for general aviation aircraft, having the pitching moment smaller than GAW_1 (no more than 0.07 of absolute value) and at least the same maximum lift coefficient;
- ILL517 – a wing section also developed in the Institute of Aviation (Warsaw), having the pitching moment even less than 0.07 (namely 0.03) and at least the same maximum lift coefficient. The efficiency C_L/C_D should be no less than 80 in the range of $0.4<C_L<0.7$;
- ILL515 – a wing section also developed in the Institute of Aviation (Warsaw), having the same mean line as ILL517 and linearly rescaled (from 17% to 15 %) with respect to ILL517. Most of aerodynamic characteristics have remained the same and relative thickness was reduced on 2 %;
- DoA5 - a wing section developed by Dornier;
- NACA 2415.

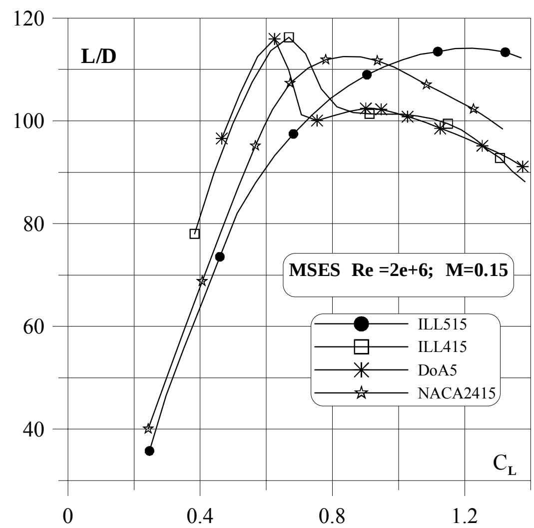

Fig. 12. Comparison of the airfoil efficiency in the full range of lifting force

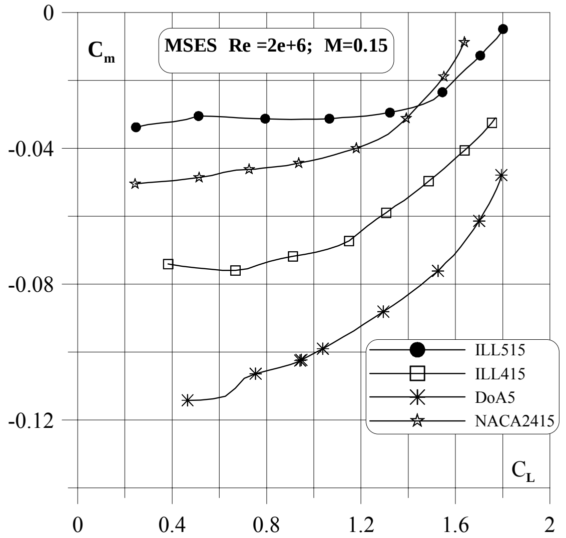

Fig. 13 – Comparison of pitching moment in the full range of lifting force

Airfoil NACA 2415 was selected basing on the efficiency comparison, Fig.12, pitching moment comparison, Fig.13 and an additional requirement to avoid the laminar flow, being difficult to fulfil because of insects.

6. Performance parameters

Performances with main engine (W=930 kg)

Stall speed 107 km/h (at see level)
Max. speed 325 km/h (h=4000 m)
Vc – cruise velocity in indicated airspeed
130 km/h (EAS for longest endurance)
152 km/h (EAS for longest range)
Max Vc 280 km/h
Rate of climb (SLS) 7 m/s
Max Ceiling altitude 9,00 km

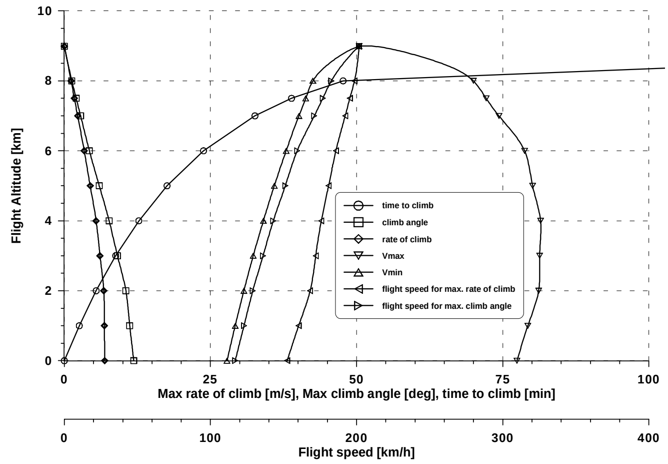

Fig. 14 - Flight envelope (at the take-off weight)

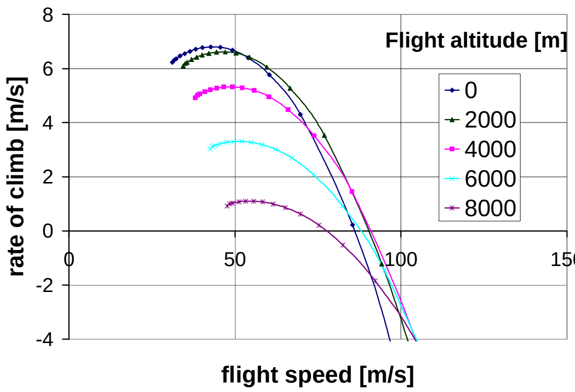

Fig. 15 – Rate of climb versus flight speed and altitude

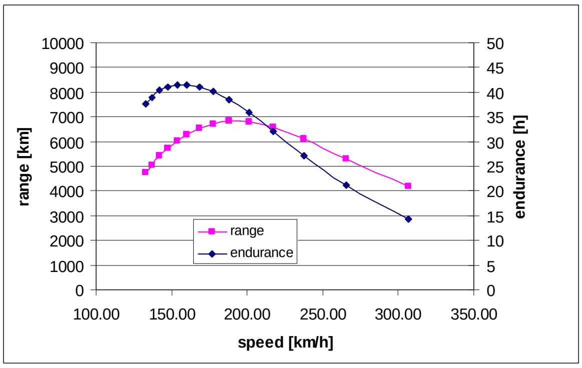

Fig. 16. Endurance and range versus flight speed (H=4000m)

Performances with auxiliary engine (W=750 kg)

Stall speed 107 km/h (at see level)
Max. speed 145 km/h (at see level)
Vc – cruise velocity in indicated airspeed

109 km/h (EAS for longest endurance)
138 km/h (EAS for longest range)

Rate of climb (SLS)	0.25 m/s
Max Ceiling altitude	1000 m
Max endurance	11.56 h
Max range	1400 km

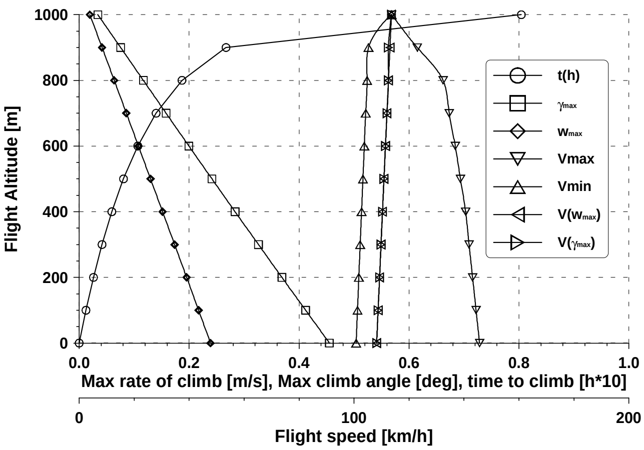

Fig. 17. Flight envelope with auxiliary engine (W=750 kg)

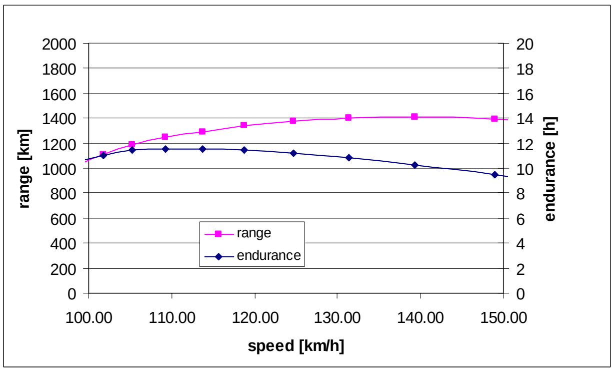

Fig.18. Endurance and range versus flight speed (at sea level)

7. UAV design description

The aircraft consists of several easily demountable sections. The size of each section was chosen so that they can be accommodated in the standard container. Landing gear design allows for easy sections' assembly including outer wings, tail beams and front fuselage section. Demountable front fuselage section allows to exchange the payload easily through exchange of the whole section.

7.1 Propulsion system

PW-103 UAV is equipped with two propulsion units. Main propulsion unit is arranged in pusher configuration. It is installed in the rear fuselage section, between tail beams. Emergency propulsion unit will be used in the case of main propulsion unit malfunction. It is installed in front fuselage section. Emergency propulsion unit has small power rating, large enough only for flight with shallow descent.

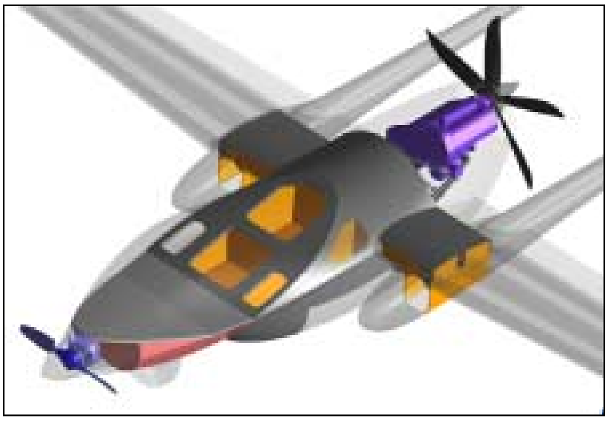

Fig. 19 - PW-103 propulsion system

Main propulsion unit consists of THIELERT TAE 125 engine and MÜHLBAUER MT-12 propeller. TAE 125 is a four-cylinder diesel turbo-charged engine with maximum power rating of 135 bhp. It is equipped with digital control FADEC (Full Authority Digital Engine Control).

Fig. 20. THIELERT TAE 125 engine

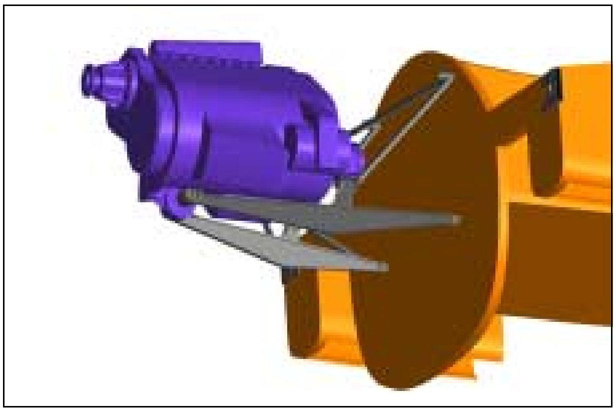

Fig. 21. THIELERT TAE 125 engine installed in PW-103

Engine drives the five-bladed, controllable-pitch, pushing propeller MÜHLBAUER MT-12. Engine is mounted in four points to the rear frame of the central fuselage section.

Emergency propulsion unit consists of the Wankel AAI AHF-12 engine and two-bladed foldable propeller. Engine has cubic capacity of 196.6 cm^3 and delivers the power of 22 bhp (16.4kW) when rotating with 7000 rpm. Propeller is folded and concealed in the fuselage niches when main propulsion unit operates. In the case of emergency niches' covers are jettisoned and propeller is opened. Emergency propulsion system has total mass of ca. 15 kg.

The same fuel is used for both engines. Common, integral fuel tank is located in the central fuselage section. It has the volume of 350 l.

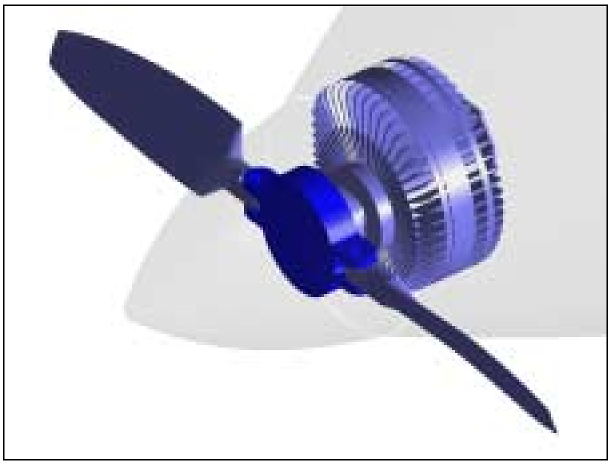

Fig. 22 Emergency propulsion system

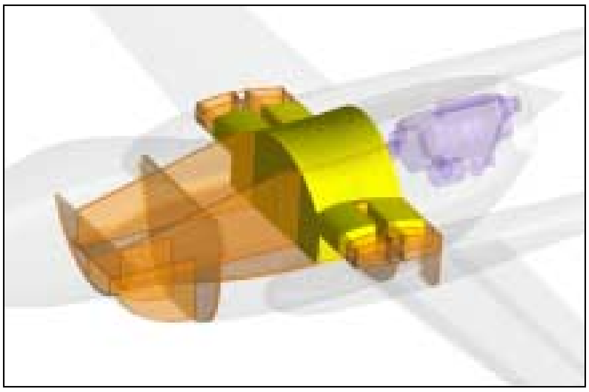

Fig. 23 Fuel tank

7.2 PW-103 payload

FLIR head and SAR radar are main components of the payload. FLIR head is located below the front fuselage section. SAR radar rotating antenna is located below the central fuselage section. In both cases location was selected so that constraints of the sensors' fields of observation due to the UAV structure are minimized.

Parabolic SATCOM antenna is used for communication with satellite system and ground station. It is installed over front fuselage section for appropriate satellite visibility.

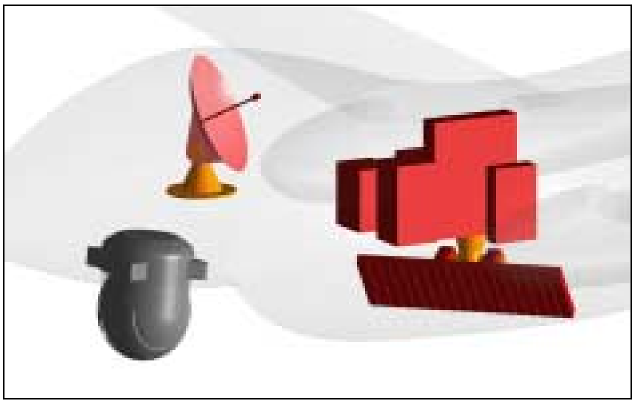

Fig. 24 - FLIR head, SAR and SATCOM antennas arrangement in the UAV3 General Style Preferences

7.3 Structure description

PW-103 UAV has mixed type of structure, made of metallic and composite materials. Carbon-epoxy composite is the most frequently used.

The structure can be divided into the following components: central section containing main installation nodes, front fuselage section, tail beams with stabilizers and outer wings.

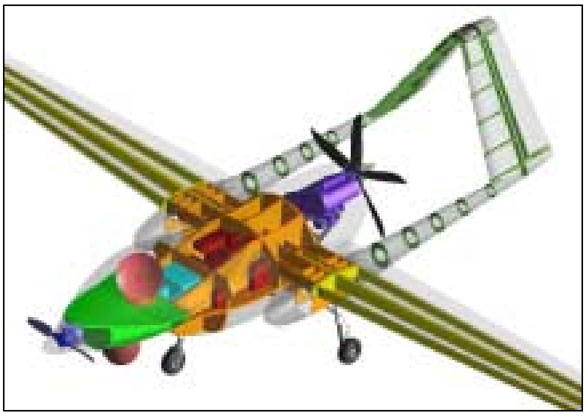

Fig. 25. PW-103 structure

The central section consists of central fuselage section, center-wing section and front tail beams' sections. It is made of metallic and composite components. Skins made of carbon-epoxy composite are riveted to the fuselage frames. Main frames are milled out of aluminium alloy. There is an integral fuel tank between main frames. UAV avionics compartment is located in the front. Front wheel well with leg brackets is located below the avionics compartment. Rotating SAR antenna is installed to the reinforced floor. Engine mount brackets are attached to the rear frame. Landing gear main legs are accommodated in the front part of the tail beams. Epoxy composite is used to make fairings of the landing gear, the antenna and the engine.

Brackets for front fuselage section installation are mounted to the front frame. Outer wings and tail beams are installed to the brackets in the main frames of the center-wing section.

7.3 Control system

Control system consists of the flight control computer and actuators. The system is able to control the aircraft both in case of standard and emergency flight conditions. Control surfaces are doubled to enable control In the case of emergency. Each control surface is driven by two actuators. Engine control is also doubled.

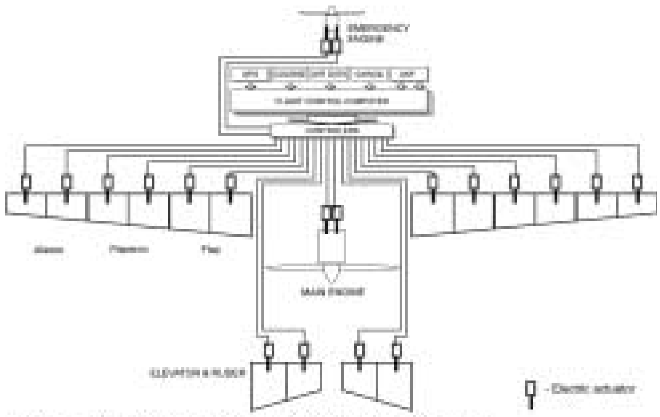

Fig. 26. Control system

Flight control computer analyses flight parameters measured by certain sensors and commands received from the ground station and calculates inputs for each actuator.

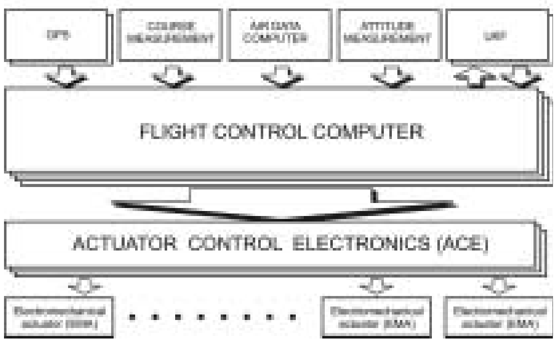

Fig. 27. Control system diagram

8. Conclusion

Technology available to-day allows to design an unmanned aerial vehicle fulfilling requirements for long endurance missions and being able to carry-on the sophisticated sensors, like FLIR, SAR etc. Redundant systems including power unit, flight control system, communications etc can deliver higher reliability and reduce risk in flight. Cost of such an aircraft is still high, mainly due to sensors on-board. Paper presents elements of a complete preliminary project of PW-103, developed under CAPECON umbrella within V FR of European Union.

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