

# Open Design of a Multi-Mission Medium-Altitude-Long-Endurance UAV Using COTS Components

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## Abstract

This paper presents a systematic preliminary design methodology for a multi-mission medium-altitude-long-endurance (MALE) unmanned aerial vehicle (UAV) capable of executing intelligence, surveillance, reconnaissance (ISR), search and rescue (SAR), and combat missions with minimal configuration changes. An open-design architecture utilizing commercial off-the-shelf (COTS) components enables rapid mission reconfiguration while maintaining design flexibility and cost-effectiveness. The initial sizing methodology employs constraint analysis and matching chart techniques to establish design parameters, resulting in a platform with maximum take-off mass (MTOM) of 1450 kg, wing area of 14 m<sup>2</sup>, and 112 kWatt power requirement. The selected configuration features a Rotax 916 engine with high-aspect-ratio tapered wing (AR = 18.21) using NLF-0215 and NACA 0009 airfoils, achieving 38-hour endurance, 1250 km range, and 7000 m service ceiling. Modular payload integration accommodates up to 400 kg of mission-specific equipment including electro-optical/infrared sensors, synthetic aperture radar, satellite communication systems, and warfare payloads. Stability analysis confirms adequate longitudinal and lateral-directional characteristics across operational mass range from 675 kg to 1816 kg, with the X-tail configuration providing satisfactory damping in short-period and Dutch roll modes. Performance calculations using Breguet equations demonstrate mission-specific capabilities: ISR baseline configuration achieves 5908 km optimum range and 30.37 hours endurance, while combat configuration maintains 2037 km range with full weapons payload. The methodology demonstrates that systematic application of classical aircraft design principles combined with COTS integration can accelerate preliminary design phases for multi-mission MALE platforms.

**Keywords:** MALE UAV, Multi-mission aircraft, COTS components, Preliminary design, Constraint analysis, Aircraft stability

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## 1 Introduction

The demand for multi-mission unmanned aircraft vehicle (UAV) rapidly increases in recent decade. A medium-altitude-long-endurance (MALE) UAV is one of best design low-speed aircraft candidates to accommodate many missions, such as intelligence, surveillance, reconnaissance (ISR), defence/combat, and search and rescue (SAR) mission (Haoqin et al., 2015). Several designs (Goraj, 2003; Austin, 2010) had been successful to carry out certain kind of mission, but only few of them are able to serve flexible mission with minor modification.

To achieve more robust design, in the aircraft design process, we must follow each of the design phases to ensure the new design meet its objectives (Gudmundsson, 2013). In designing MALE UAV that is able to perform many missions, configuring the payloads and determining the size

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of aircraft are two of practical approaches to begin (Verstraete, 2018). Since the number of payload system is small, the iteration process can be done less laboriously. By doing an open-design approach, a reliable MALE platform can be used as a starting point to accelerate the design configuration and move faster to the detail design phase. This sort of approach in designing fixed-wing UAV, particularly MALE, had not been demonstrated so far, although the knowledge in low subsonic aircraft was mature enough decades ago.

In this paper, a thorough analysis in preliminary design phase of MALE UAV is elaborated in detail. Starting with the initial sizing method and payload configuration, the final goal is to produce a initial MALE design which meet the requirement and stable in all longitudinal dan lateral-directional mode that is able to carry out various type of missions.

## 2 Initial Sizing Method

The initial step to determine the aircraft size is to construct a matching chart (Raymer, 2018; Sadraey, 2012) based on the design requirement (Gundlach, 2012) and objectives. This requirement is set according to the aircraft capability to carry out its mission. The details are specified as follows:

- Short take-off and landing distances  $\leq 650$  meter;
- The minimum rate of climb is 5 m/s;
- The cruise speed  $\leq 36$  m/s;
- The minimum range is 1250 km;
- The endurance is reached 38 hours;
- The maximum payload mass is 400 kg;
- The service ceiling is 7000 m.

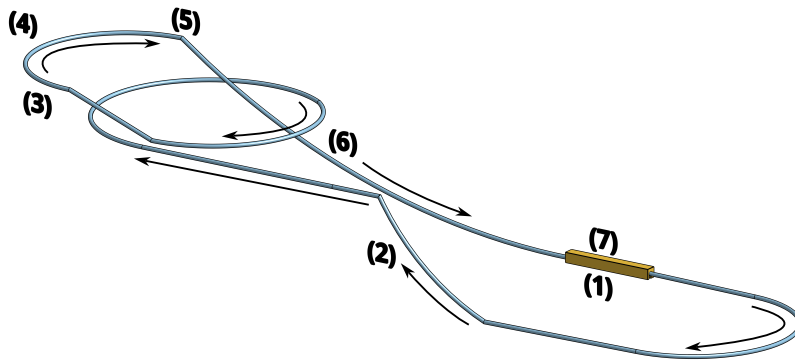


Figure 1: Basic mission Profile

Prior to estimating the gross maximum take-off mass (MTOM), the mission profile (Fredericks et al., 2013) is specified and divided into several segments as shown in Fig. 1 to estimate the fuel fractions required for the basic mission assumption. This assumption with additional maximum payload is selected because specific missions such as intelligence, surveillance, and reconnaissance (ISR), combat, and search and rescue (SAR) are less demanding in endurance and range. Table 2 provides the corresponding altitude information related to the specific mission segments that were define in the preliminary analysis.

Figure 2 represents the design space that meet the defined requirement set in this preliminary design. The grey area shows the region with better performance compared to that specified in the corresponding line plots. For a specific performance, the power-to-weight ratio ( $P/MTOM$ ) is calculated for various wing loading ( $W/S$ ). Detail of calculation can be found in Gudmundsson (2013) for single piston engine aircraft complied with CFR Part 23.

Figure 3 shows the contour of gross maximum take-off mass which was estimated for various  $P/MTOM$  and  $W/S$ . In this calculation, the fuel fraction  $m_{fuel}/MTOM$  is obtained from the

No	Mission Segment	Altitude (m)
1	Engine start, taxi, and take-off	0 to 15.24
2	Climb	25.24 to 4572
3	Cruise Climb Ingress	7620
4	Loiter	7620
5	Egress	7620 to 4572
6	Descent	4572 to 0
7	Landing, taxi, and shutdown	0

Table 1: The mission segment altitudes

specified mission segments in Table 2. The aerodynamics data, such as  $C_L$  and  $C_D$  required to carry out airborne mission segments were estimated using Prandtl Lifting Line Theory (Anderson, 2017) and empirical data for corresponding wing parameters like area  $S$ , taper ratio  $c_t/c_r$ , and aspect ratio  $AR$ . Here, the gross MTOM is defined as:

$$MTOM = m_{empty} + m_{payload} + m_{fuel} \quad (1)$$

The empty mass  $m_{empty}$  is approximated from statistical data of single-engine general aviation aircraft in Gudmundsson (2013) such that  $m_{empty}/MTOM = 0.8578 - 0.0333 \log MTOM$ . By providing the assumed MTOM, the iteration was run until the calculation is converged for estimated gross MTOM which is able to perform all the missions. The contour of MTOM is overlapped with the constraint plot to determine the initial point of our design. For this conceptual design, the  $P/MTOM = 0.077$  and  $W/S = 1000$  are selected with gross MTOM of 1450 kg, that is  $P \approx 112$  kWatt and  $S \approx 14 \text{ m}^2$ .

### 3 Results and Discussions

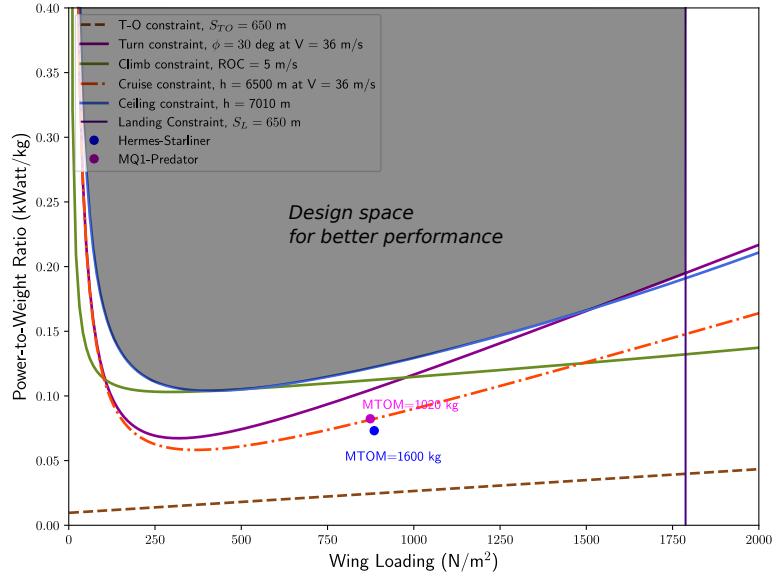


Figure 2: Constraint Plot

#### 3.1 Engine and Wing Selection

Based on the design point chosen in Fig. 3, the Rotax 916 series was selected with 2-blade propeller. This engine is able to generate 117 kWatt power at 5800 rpm. Accordingly, the taper wing with high aspect ratio was configured to get a close performance with those specified in the design objective. The detail of wing parameter in Table 3.1. The airfoil used for the wing is the

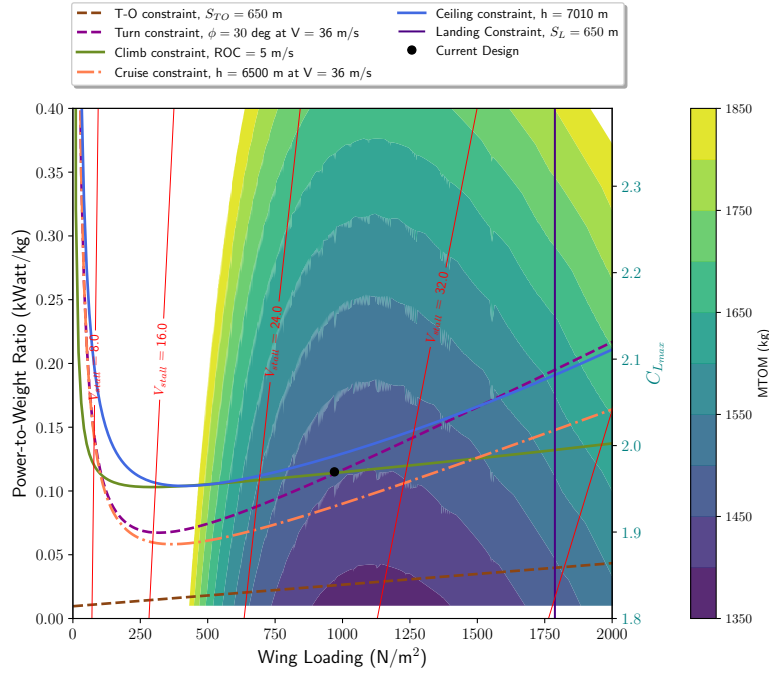


Figure 3: Matching Chart

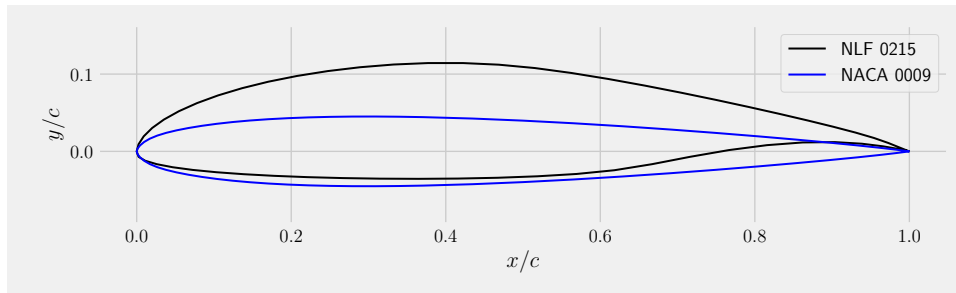


Figure 4: Wing Airfoil

laminar airfoil NLF-0215 which suitable for low speed aircraft. This selection is based on the design matrix that was generated to evaluate several airfoil candidates (see Table 2). Additionally, it is also reported that the aerodynamics characteristics of this airfoil does not varied significantly for Reynolds number  $Re = (3 - 9) \times 10^6$  and Mach number  $M \leq 0.3$  Somers (1981).

No	Airfoil Characteristics	NACA 23015	NACA 64215	NLF 0415	NLF 0215	Evaluation Scores‡			
1	$c_{l_{max}}/c_{d_{min}}$	216.662	227.2452	199.4933	253.5098	2.4	2.5	2.2	3
2	Thickness ratio	0.15	0.15	0.15	0.15	1	1	1	1
3	$\alpha_{c_{l_0}}$	-1.25 deg	-3 deg	-4.25 deg	-5.5 deg				
4	$c_{l_{max}}$	1.5578	1.4271	1.3386	1.6757	2.5	2.3	2	3
5	$\alpha_{c_{l_{max}}}$	16.5 deg	17.5 deg	15 deg	17 deg	2.8	3	2.6	2.9
6	Stall characteristics†	C	B	C	A	1	2	1	3
7	$c_{d_{min}}$	0.0072	0.0063	0.0067	0.0066	2.6	3	2.8	2.9
8	Sensitivity to surface quality	No	Yes	Yes	Yes	1	0	0	0
9	$(c_l/c_d)_{max}$	90.95	120.62	118.36	139.71	2	2.6	2.5	3
10	$c_l$ at $(c_l/c_d)_{max}$	1.2224	0.718	0.7942	1.2965	2	3	2.6	1
11	$c_l$ range at drag bucket	0.2 - 0.75	0.125 - 0.96	0.1 - 0.8	0.38 - 1.38				
Total score						17.3	19.4	16.7	19.8

† For this characteristics, the A represents the best performance

‡ The score ranges from 0-3 where the highest score gives the best performance

Table 2: Airfoil Matrix.

The wing is designed with various airfoils (Austin, 2010) where NFL-0215 and NACA 0009 are

No	Wing Parameters	Values
1	Airfoil at the root	NLF-0215
2	Airfoil at the tip	NACA-0009
3	Wing area	14.05 m
4	Aspect Ratio	18.21
5	Chord length at the root	1.257 m
6	Mean Aerodynamics Chord (MAC)	0.933 m
7	Taper ratio	0.4
8	Wing span	16 m
9	Dihedral angle	4 deg
10	Root-to-tip sweep angle	1.0 deg
11	Washout angle at the root	5 deg
12	Washout angle at the tip	-5 deg

Table 3: Wing geometric parameters

located at the root and the tip, respectively (see Fig. 4). Half of the span, the NLF-0215 was used to maximize the additional fuel tank at the wing. Then, for another half span, a gradual change in airfoil shape and size was implemented. Regarding this, we need to emphasize the decision was made to maintain the dynamic response of aircraft to pursue more flexible missions with wide range of payload.

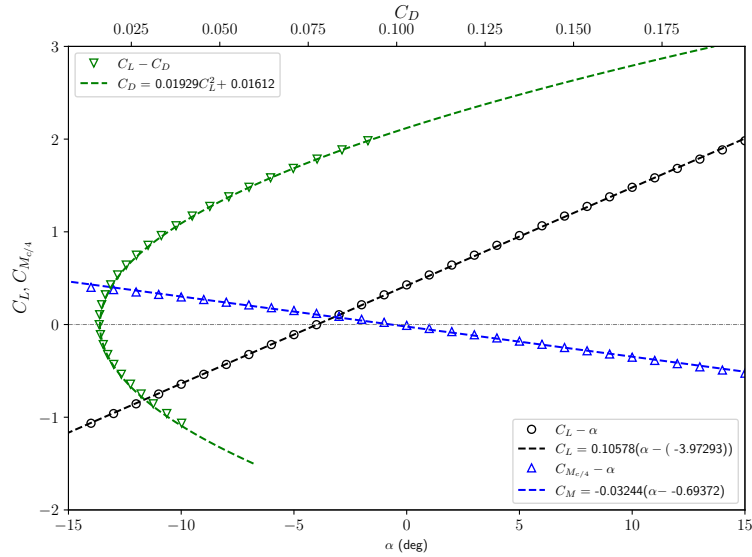


Figure 5: Aircraft aerodynamics profile during cruise (operating mass = 925.7 kg for basic mission).

The fuselage shape was selected based on the shape that generate the minimum drag coefficient in which befitted with all the payload. A drag correction was defined in the XFLR analysis for a fuselage with  $C_d \approx 0.3$ . The X-tail configuration was selected to ensure the aircraft stability in longitudinal and lateral-directional mode. The NACA 0012 airfoil was used for the empennage.

### 3.2 Avionics and Payload

Table 4 shows the list of avionics and payloads needed for various missions. The intelligence, surveillance, and reconnaissance (ISR) mission is set as the baseline configuration where the payload is considered as a “minimum required” payload. For the other type of missions, such as combat and SAR, additional payloads are needed. In the case of combat and defence, it can carry 2 warfare systems mounted at the wing and 1 electronic jammer at the fuselage belly. Therefore,

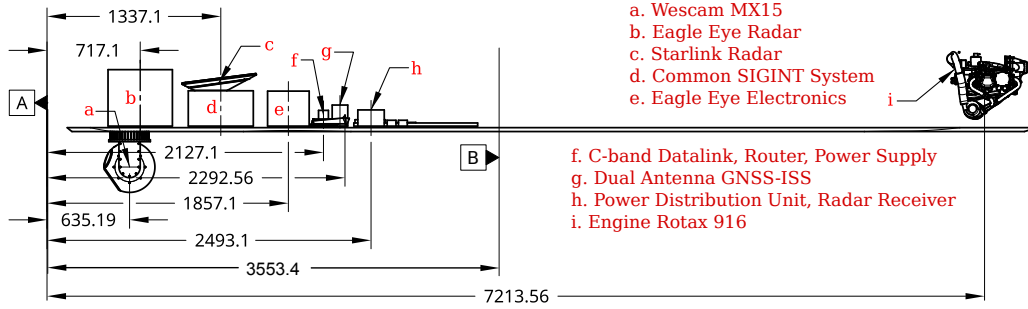


Figure 6: Avionics and payloads arrangement. The **A** and **B** are the position of nose-tip and leading edge of the wing root, respectively.

Mission Type	Avionics and Payload Components	Name of COTS	Mass (kg)
Baseline:	Automatic landing-takeoff system	Okis(Airborne Segment)	2.5
- Monitoring	KA-band satellite comm sensor	MPT 46WGX(antenna)	14.25
- Surveillance		MPT 46WGX(KPSU)	5
- Intelligence	C-band datalink	C-band Datalink	0.87
- Reconnaissance	Autopilot (FCC)	Vector 600	0.18
	Mission control Computer (MCC)	Vector MCC	0.16
	Baykar IMU	Bas 201	0.26
	Gnss-ins (imu+gps)	CGI-610 Dual-Antenna GNSS-INS	1.15
	AIS (Automatic Identification System)	The RadarPlus6 SA161-MH Receiver	0.57
	Power Amplifier	TA1216	0.65
	Air Data Recorder	XLDR	2.27
	SAR and ISAR	Eagle Eye (Electronic)	62
		Eagle Eye (Radar)	
	EO/IR/MTI	Wescam MX-15	45.5
	Wide Area Motion Imagery	Redkite Block II Pod	17
	Satcom (dish)	Starlink (Flat) High Performance	5.9
	Satcom (power supply)	Starlink Power Supply	1.5
	Satcom (Router)	Starlink Router	1
	Power Distribution System	900W PDU	1.35
	Lithium battery	ABLi-25	4.3
Combat	Baykar Bomb Rack Unit		1
	SIGINT (Signal Intelligence System)	Common SIGINT System 1500	38.56
	Warfare systems	Anti Submarine Warfare Systems Pod	340
	Electronic Jammer	Sledgehammer Pod	272.2
SAR	Life Raft	R0101A102	16.33

Table 4: Mass Budget of Avionics and Payload

the combat mission is considered as the heaviest mission of this MALE.

Figure 6 illustrates the internal arrangement of the avionics and payload. The layout was designed to accommodate better static and dynamic stability characteristics which large part of the components are placed at the fore region of the wing. In addition to that, small additional payload mass up to 8 kg can be placed at the rear region of fuselage without significantly change the dynamics of aircraft.

### 3.3 Aircraft Performance

The optimum range and endurance of this aircraft for various missions estimated from the classic Breguet formula [Ruijgrok \(2009\)](#) as shown in Table 3.3. Here, the propeller efficiency and specific fuel consumption (SFC) of piston engine are assumed constant, regardless of speed and altitude. For the engine installed on this UAV, SFC is 315 g/(kW·h). The lift-to-drag ratio ( $C_L/C_D$ ) for this calculation is set at  $(C_L/C_D)_{max}$  for each configuration. The calculation of maximum endurance used the parameter  $\sqrt{(C_L^3/C_D^2)_{max}}$  at the cruising attitude

No	Mission Types	MTOM (kg)	Optimum range (km)	Max Endurance (hr)
1	Monitoring, surveillance, intelligence, reconnaissance	925	5908	30.37
2	Search and rescue	966	5761	29.12
3	Defence and combat	1427	2037	7.07

Table 5: The mission segment altitudes

### 3.4 Static and Dynamic Stability

#### 3.4.1 Longitudinal Mode

The time-invariant state space equation (Nelson, 1998) for longitudinal mode can be written as  $\dot{\mathbf{x}}(t) = \mathbf{A}\mathbf{x}(t) + \mathbf{B}\mathbf{u}(t)$ . For baseline configuration, the aerodynamics stability derivatives estimated from the XFLR5 model can be found as follow: For maximum zero fuel of ISR mission, the oscillation in phugoid mode is amplified. To damp the oscillation, a 4 deg angle of elevator on upper-half of X-tail is required to stabilize the aircraft. (Ciliberti et al., 2017)

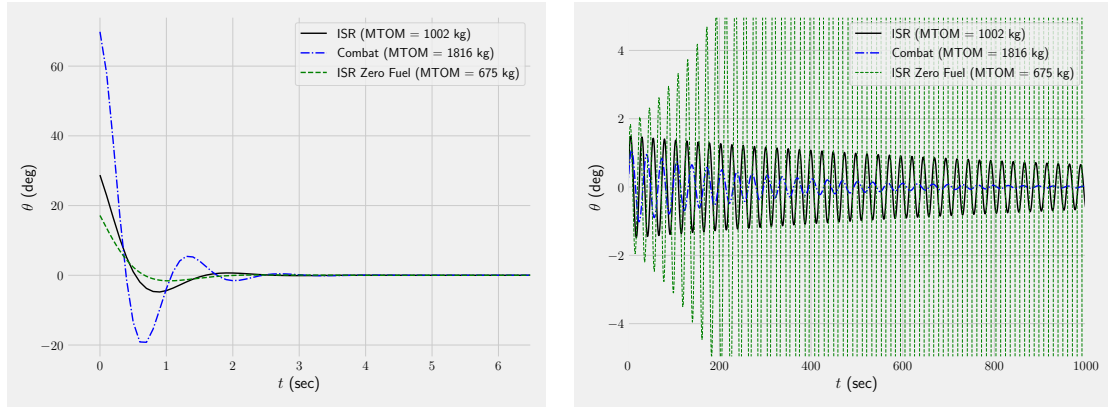
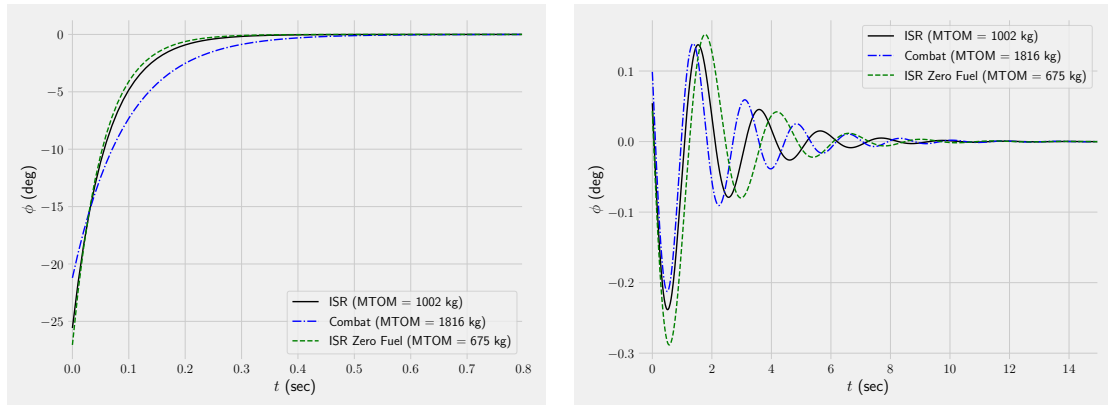


Figure 7: Pitch angle,  $\theta$ , for longitudinal mode for various MTOM. Short oscillation mode (left figure) and phugoid mode (right figure).



#### 3.4.2 Lateral-Directional Mode

## 4 Conclusion

This paper presented a comprehensive preliminary design methodology for a multi-mission MALE UAV capable of performing intelligence, surveillance, reconnaissance (ISR), search and rescue (SAR), and combat missions with minimal configuration changes. The design approach employed systematic constraint analysis and matching chart methodology to establish the initial sizing parameters, resulting in a platform with MTOM of 1450 kg, wing area of 14 m<sup>2</sup>, and power requirement of 112 kWatt.

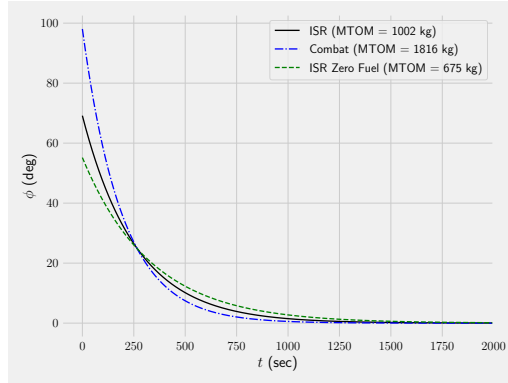


Figure 8: Bank angle,  $\phi$ , for lateral-directional mode for various MTOM. Roll mode (top left figure), dutch roll mode (top right figure), and spiral mode (bottom figure).

The selected Rotax 916 engine paired with a high-aspect-ratio tapered wing ( $AR = 18.21$ ) using NLF-0215 and NACA 0009 airfoils provides the necessary performance characteristics to meet all design requirements, including 38-hour endurance, 1250 km range, and 7000 m service ceiling. The open-design architecture demonstrates flexibility across mission types, with the ISR baseline configuration achieving 5908 km optimum range and 30.37 hours maximum endurance, while maintaining payload capacity up to 400 kg for more demanding combat missions.

Stability analysis confirmed that the X-tail configuration provides adequate longitudinal and lateral-directional stability across the full range of operational mass from 675 kg (ISR zero fuel) to 1816 kg (combat MTOM). The short-period and Dutch roll modes exhibit appropriate damping characteristics, though the phugoid mode at maximum zero fuel condition requires 4 $\times$  elevator deflection for stabilization. The modular avionics and payload arrangement, featuring COTS components including Wescam MX-15, Eagle Eye radar systems, and Starlink communication, enables rapid mission reconfiguration while maintaining favorable center of gravity characteristics.

The methodology presented demonstrates that leveraging mature low-subsonic aircraft design principles with systematic constraint analysis and COTS integration can accelerate the preliminary design phase for multi-mission MALE platforms. Future work should focus on detailed structural analysis, comprehensive flight envelope characterization, and experimental validation of the aerodynamic model predictions (Dalamagkidis et al., 2008).

## 5 Acknowledgements

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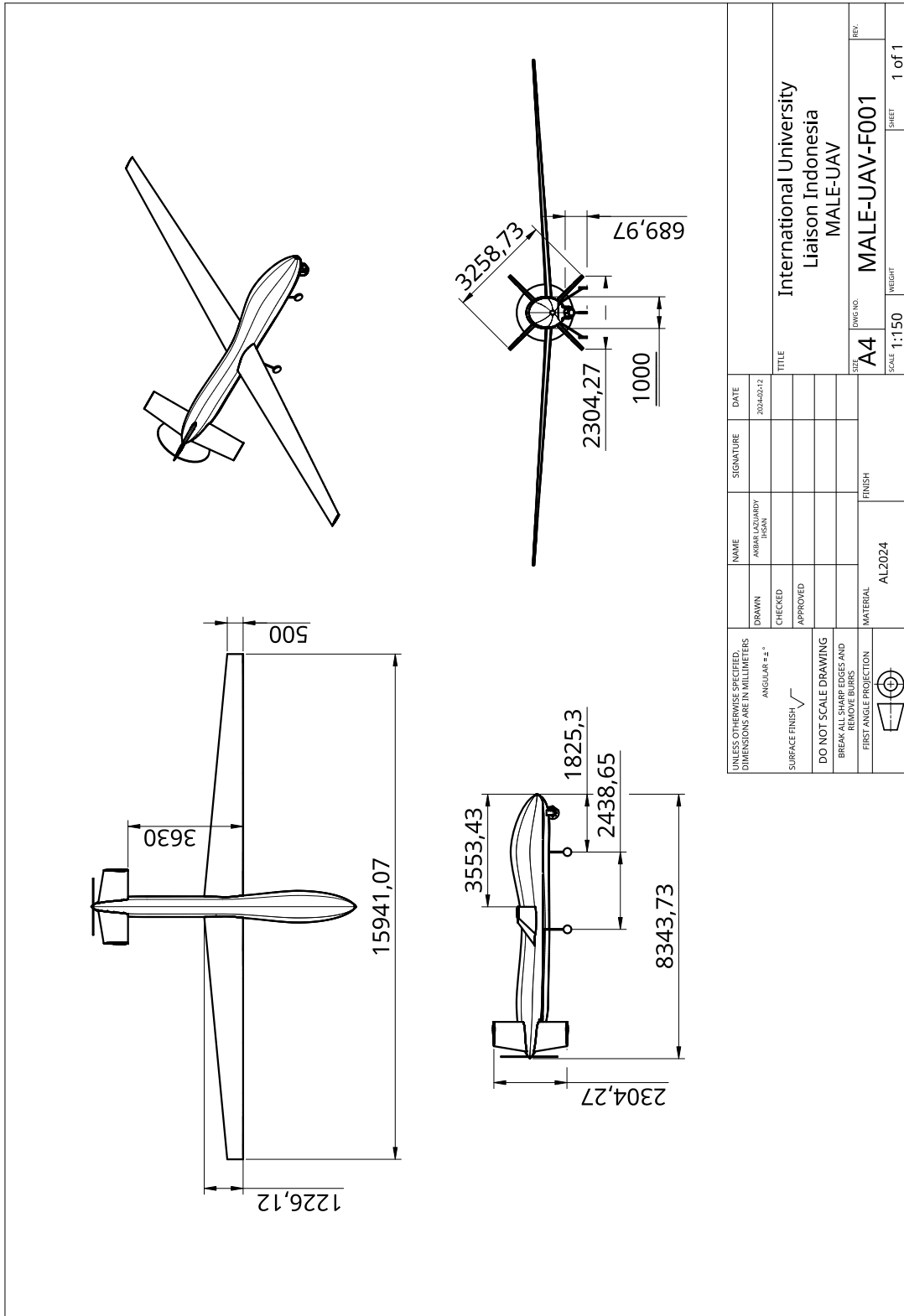


Figure 9: Three-View Drawing

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