

# ANALYSIS OF THE MASS AND AERODINAMICAL CHANGES DUE TO IMPLEMENTATION OF AN EXTERNAL RESCUE SYSTEM ON A MEDIUM RANGE UAV

BRANISLAVA OSTIĆ

Military Technical Institute, Belgrade, [brankaostic@yahoo.com](mailto:brankaostic@yahoo.com)

MIODRAG MILENKOVIĆ-BABIĆ

Military Technical Institute, Belgrade, [miodragmbm@yahoo.co.uk](mailto:miodragmbm@yahoo.co.uk)

VANJA STEFANOVIĆ-GOBELJIĆ

Military Technical Institute, Belgrade, [vti@vti.vs.rs](mailto:vti@vti.vs.rs)

BRANISLAV OSTOJIĆ

Military Technical Institute, Belgrade, [vti@vti.vs.rs](mailto:vti@vti.vs.rs)

**Abstract:** Upgrading process of any aircraft or UAV system leads to a new design verification in almost every aeronautical field and at the end to an accepted compromise between all design points with the aim of reaching a light, reliable, durable and economical aircraft. A change in the center of aircraft mass position is in a direct correlation with aircraft performance and stability. Any additional change on the existing aircraft or UAV (implementation of a new system or a component) requests analysis of the aircraft mass, position of the center of mass and aircraft performances. This paper presents an analysis of the change in the center of mass position of the medium range UAV due to the integration of the aircraft rescue system at the wing hardpoint, and comparison of the aircraft performances before and after that integration.

**Keywords:** mass, center of mass position, aircraft performances, UAV, external aircraft rescue system

## 1. INTRODUCTION

The implementation of external rescue systems, such as parachutes, aims to enhance the UAV's survivability, reduce the possibility of damage other's property and protect valuable payloads. However, these systems introduce additional weight, potentially compromising flight efficiency and operational capabilities. Upgrading process of any aircraft or UAV system leads to a new design verification in almost every aeronautical field and at the end leads to an accepted compromise between all design points with the aim of reaching a light, reliable, durable and economical aircraft. In the presented paper the medium-range UAV shown in Figure 1 has been analyzed with the UAV characteristics given in Table 1.



Figure 1. Medium-range UAV

Table 1. Medium range UAV characteristics

Wing span (with winglet)	7.025 m
Wing aspect ratio	9.08
Length	5.556 m
Mean aerodynamic chord	0,736 m
Wing area	4.33 m <sup>2</sup>
Engine power	38.8 KW
Propeller diameter	0.86 m
Maximal mass of UAV	265 kg
Center of mass	2080 ±50 mm

## 2. THE MASS AND CENTER OF MASS POSITION CHANGE

To assess the impact of an external rescue system on UAV mass and center of mass position, a comprehensive analysis was conducted using a medium-range UAV model.

Several different possibilities of installing a rescue system were analyzed.

It was not possible to install it in the rear part of the fuselage due to the significant change in the center of gravity position. That would cause the center of the mass to move too far back. In this case, the rescue system

would also be at a relatively small distance from the engine and propeller.

Space was the main limitation for installing the system in front part of the fuselage.

The third analyzed possibility, the centroplane part of the wing, was acceptable in terms of centering but it required major changes to the UAV, which would lead to high costs and repeated or additional testing.

For the above reasons, the adequate position of the center of gravity will be provided with an underwing installation of a rescue system.

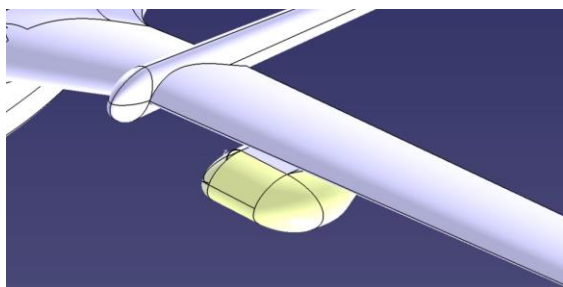
Two different types of a rescue system were identified as a possible solution, Soft pack system (Figure 2a) and OUT unit (Figure 2b). Soft pack system requires the construction of an integral container, mounting rocket on it and covering them with an aerodynamically shaped cover (Figure 2c). OUT unit only requires the creation of an adapter for installation on the existing support. Since the masses and positions of both systems are almost the same, due to the better availability of the Soft pack system, this is the system that will be presented in this paper.



**Figure 2a.** Medium-range UAV with external rescue system – Soft pack with container and rocket



**Figure 2b.** Medium-range UAV with external rescue system – OUT unit



**Figure 2c.** Soft pack system with an aerodynamically shaped cover

External rescue system – Soft pack system with an aerodynamically shaped cover at the left wing hardpoint is selected for analysis and given on Figures 2a and 2c. The system is mounted on the existing weapons carrier and together weights 6.5% to the UAV's total weight. So, as it was in the case of armed UAV, the UAV equipped with rescue system also needs reduction of the available amount of fuel, which will ensure that the maximum permissible UAV's mass of 265 kg as shown in Table 1., is not exceeded.

The implementation of external rescue system on this UAV reduces usable fuel from 70 to 59 kg.

Table 2. shows the UAV's mass and center of the mass position before and after the system integration on the UAV with reduced amount of fuel. Total take-off mass fulfills the condition from the Table 1. regarding maximum UAV mass.

Change in the center of mass position from 2.069 to 2.067 m is insignificant and does not compromise the given range in Table 1.

Table 2. also shows the change in the relative position of the center of mass in relation to the length of the mean aerodynamic cord from 34.4 to 34.15% of MAC which is also negligible.

**Table 2.** The mass and center of mass position change

Configuration	m	X <sub>c.m.</sub>	X <sub>c.m.</sub>
	(kg)	(m)	(%MAC)
1 UAV with 59 kg of fuel and without weapon carriers	244.6	2.069	34.40
2 Weapon carriers	6.7	2.214	
3 Parachute	11.0	2.088	
4 Total take-off mass	262.3	2.067	34.15

### 3. ESTIMATION OF PERFORMANCE

The integration of the aircraft rescue system has multiple effects on UAV endurance as the most important flight characteristic and the most important effects are:

- Reduction of the maximum fuel weight as the UAV's maximum mass could not be exceeded.
- Additional drag due to the integration of the rescue system.
- Influence on stability and control and trim drag.

The integrated rescue system will have the same effect as weapons carriage. The additional parasitic drag can be estimated by the components build-up method that is summarized in Raymer's book [1] or by using software like OpenVSP [2]. The OpenVSP is conceptual design software developed by NASA. This tool enables detailed and precise parasitic drag calculations by leveraging the existing model components and a variety of atmospheric, skin friction, and form factor equations.

As mentioned in [1], the most important factor affecting

skin friction drag is the extent to which the aircraft has laminar flow over its surfaces. The skin-friction drag can be doubled if the flow is turbulent rather than laminar. In many real aeronautical cases, the boundary layer transitions from laminar to turbulent flow will happen at the front of the body and this will increase drag force.

Any flight can be divided into several segments, each clearly distinguished by its nature. In this paper, the evaluation of the medium-range UAV endurance will be analyzed. The endurance is one of the most important UAV characteristics. Starting from the well-known equation explained in [3]:

$$dt = \frac{-1}{c_t T} dW, \quad (1)$$

the endurance equation can be solved through numerical integration. The limits are the final and initial weight during the analyzed segment. In the well-known "Breguet" endurance equation  $t$  represents time,  $c_t$  represents thrust-specific fuel consumption [1/sec],  $T$  represents thrust [N], and  $W$  represents the UAV's weight [N]. To solve the endurance equation it is necessary to find the specific fuel consumption, that is given in [4]. Finally, some assumptions must be made and in the presented paper the constant airspeed/constant attitude cruise has been assumed with the equations:

$$R_{cScA} = \frac{V}{c_t} \frac{C_L}{C_D} \ln \left( \frac{W_{initial}}{W_{final}} \right). \quad (2)$$

In the equation 2 the  $C_L$  is UAVs lift force coefficient,  $C_D$  is the UAVs drag force coefficient and  $W_{initial}$  and  $W_{final}$  represents initial and final UAVs weight. By implementation of the Component build-up method, the additional drag of the integrated rescue system can be estimated by the data given in Table 12.6 from [1]. The assumption that an integrated rescue system has a similar drag force coefficient as the Bullet shape (blunt back) has been made. The parasite drag force coefficient of the integrated rescue system has been estimated to have a value of  $C_D=0.3$  based on the reference frontal area. The additional fuel weight reduction has been estimated at 11 kg. This value is equivalent to the parachute rescue system weight. The results of the just mentioned analysis are given in Table 3. as a function of UAV airspeed.

**Table 3.** Estimated endurance results

$V$ [km/h]	$t_{cScA}$ [h]	$t_{cScA}$ [h]
135	12.92	9.89
150	12.03	9.14

## 4. RESULTS AND DISCUSSION

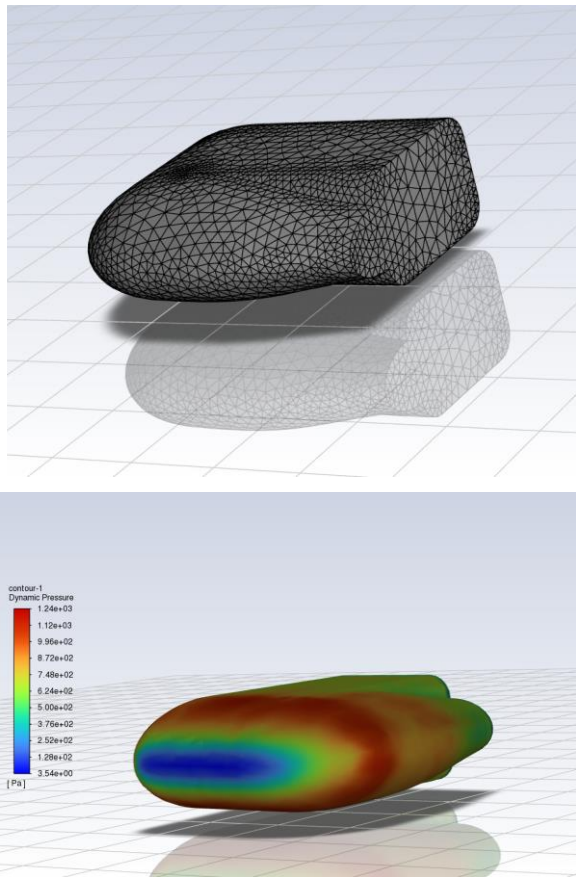
In order to find the adequate position for integration of the rescue system the different possibilities have been analyzed. The rear and front position was inadequate due to the unacceptable position of UAVs center of gravity and restricted space for integration of the rescue system. The central part of the wing section possesses an adequate volume for the integration of the rescue system. The main drawback is the fact that it is divided in the left- and right-wing section and request two small independent parachutes and additional wing modification. This modification and implementation would require significant work to be done. It would require the change in the UAVs geometry and tooling for UAVs production. It is the main reason why this option has not been deeply analysed in this paper.

On the other hand, the wing attaching point has been the other possible solution. This position would not affect the change of the center of gravity position significantly. The attaching points on the wing are near the center of gravity of the UAV. As a consequence of all mentioned the attaching point under left-wing has been chosen as the optimal solution that was deeply analyzed in the presented paper.

The results indicate a noticeable decrease in usable fuel mass due to integration of external rescue systems. A parachute-based rescue system adds 4.2% to the UAV's total weight. So, integration of the rescue system requires a reduction in the available amount of fuel.

In order to verify the estimated results for the rescue system drag force coefficient, the computational fluid dynamics (CFD) was performed in the commercial ANSYS Fluent software by the finite volume methods. The K-omega-SST turbulence model has been used. The working fluid was defined as ideal gas-air. Computations have been done until the convergence criteria have been achieved. The computational surface mesh and dynamic pressure distribution on the design rescue system has been given on Figure 3.

Computational fluid dynamics estimated the drag force on value 13.994 N. The reference surface area was defined as 4.24 m<sup>2</sup> and it was assumed that UAV is flying on altitude of 3000 m with the airspeed of 42 m/s. The estimated drag force coefficient based on the reference rescue system frontal area is  $C_D=0.29091$ . The excellent agreement with the results from reference [1] has been achieved ( $C_D=0.3$ ). The error is up to 3%. This small error will not affect the performance estimated results.



**Figure 3.** The resolution of a surface mesh on rescue system and dynamic pressure distribution

The effect of the reduction of usable fuel from 70 kg to 59 kg will produce an endurance reduction of 17.8%. The additional endurance reduction of 5.6-6.2% has been a consequence of the additional drag of the integrated parachute rescue system. If the UAV could have the same amount of fuel and the integrated rescue system attached under the left-wing pylon the flight endurance would be just 6% reduced.

The presented approach for estimating UAVs flight performance has been successfully implemented during medium range UAV flight performance estimation and verification that is given in the reports [5, 6].

## 5. CONCLUSION

Integrating an external rescue system on a medium-range UAV has been given in the presented paper. The possibility to integrate rescue system on existing UAV required comprehensive UAV mass and weight analysis.

In the presented paper a parachute-based rescue system adds 4.2% to the UAV's total weight and requires reduction in the amount of usable fuel.

In the presented paper effect of an integrated parachute rescue system on UAV endurance has been presented. The integrated rescue system will have a similar effect as the integration of one additional air-to-ground missile. It has been shown that the biggest effect would be the consequence of fuel weight reduction. Additional endurance reduction of 5-6% will be the price for additional drag of the integrated system as one payload under the wing.

The method provided fast and precise results of flight endurance characteristics that can be easily estimated in the preliminary design phase. The obtained data are in good agreement with the flight test data. The presented method will be used in future aircraft and UAV projects in VTI.

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