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Research Article

Exergy Mapping of a UAV Through a Reconnaissance Flight Envelope

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Abstract

In this study, exergy mapping of an unmanned aerial vehicle (UAV) is investigated during its reconnaissance flight. A turboprop UAV is selected for the application of the exergy of lift method covering a full flight envelope (from takeoff to landing) for the first time in the literature. The results from the lift exergy method show that this method is an advantageous instrument to analyze the destruction of exergy in a UAV and its components. The exergy destruction level is presented by comparing the results at different flight points, and it is seen that it is at a maximum at the beginning of the climb and a minimum during the loiter. Similarly, exergy destruction in UAV subsystems is calculated comparatively and it is shown that the engine subsystem is the highest. In addition, the lift exergy consumption is presented for all UAV subsystems and it is calculated that fuel and fuselage subsystems consume the highest lift exergy. The method of exergy of lift can be used for assessment of different air vehicles, such as passenger aircraft, military aircraft, and others. for future studies in light of this study.

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Bir Keşif Uçuş Zarfı Boyunca Bir İHA'nın Ekserji Haritalaması

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Öz

Bu çalışmada, bir insansız hava aracının (İHA) keşif uçuşu sırasında ekserji haritalaması incelenmiştir. Literatürde ilk kez tam uçuş zarfını (kalkıştan inişe kadar) kapsayan taşıma ekserjisi yönteminin uygulanması için bir turboprop İHA seçilmiştir. Taşıma ekserjisi yönteminden elde edilen sonuçlar, bu yöntemin bir İHA ve bileşenlerinde ekserji yıkımını analiz etmek için faydalı bir araç olduğunu göstermiştir. Ekserji yıkım seviyesi farklı uçuş noktalarındaki sonuçlar karşılaştırılarak sunulmuş, tırmanışın başlangıcında maksimum ve keşif sırasında minimum olduğu görülmüştür. Benzer şekilde, İHA alt sistemlerindeki ekserji yıkımı karşılaştırmalı olarak hesaplanmış ve motor alt sisteminin en yüksek olduğu gösterilmiştir. Ayrıca, tüm İHA alt sistemleri için taşıma ekserjisi tüketimi sunulmuş ve yakıt ve gövde alt sistemlerinin en yüksek taşıma enerjisini tükettiği hesaplanmıştır. Taşıma ekserjisi yöntemi, bu çalışma ışığında gelecekte yapılacak çalışmalar için yolcu uçakları, askeri uçaklar vb. farklı hava araçlarının değerlendirilmesinde kullanılabilir.

NOMENCLATURE

$\dot{Ex}_D$	:	Exergy destruction rate
$\dot{Ex}^{LI}$	:	Exergy rate of lift
$\dot{Ex}^{TH}$	:	Exergy rate of thrust
C_L	:	Coefficient of lift
F_{drag}	:	Drag force
F_{lift}	:	Lift force
M_a	:	Weight of aircraft
M_i	:	Weight of ith subsystem
V_∞	:	Free stream velocity
V_y	:	Velocity in the vertical direction
V_{y0}	:	Dead state velocity in the vertical direction
S	:	The surface area of the wing
a	:	Aspect ratio
g	:	Gravitational acceleration
ρ	:	Density of air

1. INTRODUCTION

The unmanned aerial vehicle (UAV) term appeared in the last quarter of the 1900s for the first time and was named a robotic aircraft. It was then named a remotely piloted vehicle until a definition of a UAV was included in the Department of Defense Dictionary [1]. Since

2010, UAV technology has made significant technical progress.

The development and design of an efficient and high-performance UAV gains importance about the numerous manufactures with a wide range of military and civil application fields, including agriculture, civil engineering, photography, logistics and transportation, remote sensing and detection, surveillance, and shadowing enemy vessels, reconnaissance, target designation, and so on [2-6].

The design of a UAV is usually comprised of structural, aerodynamics, flight dynamics, propulsion system, autopilot, ground station, and launch system design routines. According to another approach, the component-based design of a UAV is also possible, such as wing, tail, fuselage, propulsion system, landing gear, autopilot, ground station, and launch system design procedures. Ordinarily, any UAV design and development follow conceptual and preliminary design, detail design and improvement, manufacturing, and testing steps. A manufactured UAV also completes its life cycle through usage, phase-out, and disposal steps. To design a UAV, a requirement for a specific application should be first defined. Then a conceptual design is conducted to underlie the preliminary design. After examination of the preliminary design outcomes, a detailed design step is initiated or a preliminary design is optimized. At the end of the detail design step, the UAV is manufactured to be tested. After test procedures, the UAV is put on the market for the end-user [3].

In the accessible literature, it is possible to find numerous papers on design and/or optimization of various UAV types. In Ref. [7] aerodynamic performance assessment and stability analysis of a light UAV for a reconnaissance mission is presented. In this context, aerodynamic performance and efficiency of both airfoil and wing are examined with the aid of computational fluid dynamics. At the end of the study, aerodynamic improvement is asserted considering the computational optimization results. In another paper [8] the conceptual design of a blended wing body medium-altitude long-endurance UAV is discussed. Pre-sizing and simulation tools are jointly employed. Therefore, an aerodynamic performance prediction of the blended wing body medium-altitude long-endurance UAV is introduced, and it is compared with a conventional type of UAV in terms of performance indicators to outline the pros and cons of the blended wing body. The design and performance evaluation of a fixed-wing vertical take-off and landing UAV is presented to the literature in Ref. [9].

The paper reveals the aerodynamic design steps and sizing of the wing and control surfaces, while power demand, energy consumption, and endurance for each flight phase are calculated. Aerodynamic design optimization of an Aegis UAV is discussed by Azabi et al [10]. The purposed method is suggested for employment in the conceptual and preliminary design steps of any UAV. At the end of the optimization, optimal wing profiles are determined for different flight speeds, whereas objective functions for the optimization are identified. In Ref. [11] optimization of a UAV conceptual design based on drag and lift coefficients is outlined. Regarding the optimization results, modifications of landing gear and wing tips are evaluated to improve the aerodynamic efficiency of the UAV. In addition to other aerodynamic performance-based design and optimization studies [12-16], many papers focusing on fuel consumption and emissions-based aerodynamic optimization of UAVs are also available in the literature [17, 18].

The significance of thermodynamics in aerial vehicle and subsystem design is reported in many previous texts [19-24] as well as flight dynamics and aerodynamics. The second law analysis of thermodynamics, namely exergy analysis, is beneficial in understanding the limitations of the evaluated system. In other words, exergy analysis enables us to comprehend the maximum available useful output of any system and its irreversibility within the system. The exergy of a system is zero while the system is in complete equilibrium with the ambient temperature in terms of physical and chemical conditions. Therefore, it is obvious that deviation of the system from the environment yields an increase in the exergy of the system. From this point of view, a definition of the environment or reference conditions plays a key role in exergy analyses [25-29].

The second law analysis of propulsion systems, in particular, has been discussed by many researchers [30-40]. However, motion and effecting forces on an aerial vehicle can be evaluated with the aid of exergy. Paulus, Jr. and Gaggioli [41] associate the forces affecting an aircraft with the exergy. Researchers define exergy of lift whereas an exergy flow diagram of an aircraft and its components is described. In another study, Berg et al. [24] identify the exergy mapping methodology of an aerial vehicle. The approach asserted in Ref. [41] is also preferred to calculate the exergy of lift for a hypothetical aircraft powered by five different engines at the climb and cruise flight phases in Ref. [42].

In the current paper, exergy mapping of a UAV during a typical reconnaissance flight as per the scenario is studied for the first time. Within this scope, the UAV modelled and sized in a previous study of Dinc [18] is now evaluated in terms of exergy. Unlike in previous studies, not only cruise and climb phases, but also each flight phase is considered in the assessment of the UAV.

2. MODELLING THE UAV AND ITS FLIGHT ENVELOPE

As mentioned previously, a requirement for a specific mission flight profile should be defined to design a UAV. The mission flight profile is an essential scenario as a principal design input or requirement which includes airspeed, flight altitude, duration of operation, payload to be carried, and so on. The profile of the reconnaissance mission flight envelope assumed for the UAV is illustrated in Fig. 1, based on outputs of the genuine computer code. The investigated UAV is powered by a turboprop engine and is remotely piloted. According to the records of the manufacturer, the first flight of the UAV dates back to 2001. It is a highly modular UAV capable of carrying various payloads, such as electro-optical/infrared multi-mode radar, multi-mode maritime surveillance radar, electronic support measures, laser designators, and various weapons. The examined UAV is currently in service of many governmental institutions, including the U.S. Air Force, the U.S. Department of Homeland Security, NASA, the Royal Air Force, the Italian Air Force, the French Air Force, and the Spanish Air Force, for different missions [43].

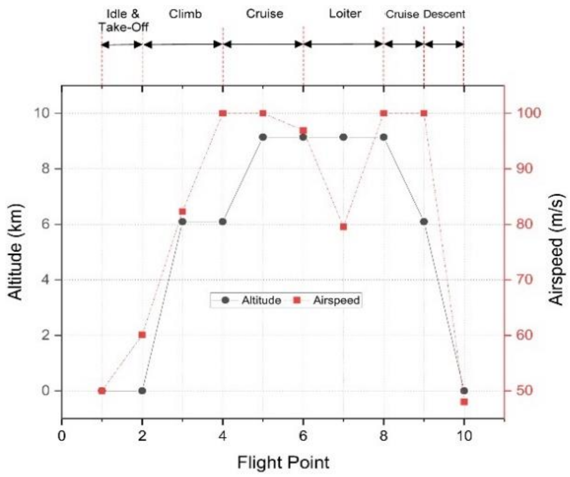

Figure 1. Profile of the assumed reconnaissance mission flight envelope.

Sizing and modelling of the UAV and its flight envelope are performed using the specifications of the UAV obtained from the manufacturer's data and the literature. The main specifications of the UAV are listed in Table 1. Based on the specifications, a genuine computer code comprised of UAV sizing and performance equations is employed. More detailed information about both the code and the modelling study can be found in Ref. [18].

Table 1. The main specifications of the UAV [43].

Specification	Value
Wingspan	20 m
Length	11 m
Maximum take-off weight	4763 kg
Fuel capacity	1769 kg
Internal payload capacity	386 kg
External payload capacity	1361 kg
Ceiling altitude	15240 m
Maximum endurance	27 hours
Maximum airspeed	240 KTAS

3. EXERGY MAPPING OF THE UAV

In the current paper the 'exergy of lift method', formerly presented by Paulus and Gaggioli [41] is employed for the exergy mapping of the evaluated UAV. According to this approach, the exergy rate associated to lift is expressed as follows [41]:

$$\dot{Ex}^{LI} = F_{lift}(V_y - V_{y0}) \quad (1)$$

In Eq.1, F_{lift} represents lift force while V_y and V_{y0} denote the velocity and dead state velocity of the component y. This statement is beneficial in assessing the entire aircraft in terms of the exergy, while the lift force is the vertical component of the total lift force developing over the wing. In addition, any subsystem of the UAV can also be evaluated with the aid of Eq. 1. In this case, lift force in the expression corresponds to the vertical component of the force delivered to the subsystem from the wing.

In Eq.1, it is essential to determine the dead state velocity. For this purpose, a minimum drag condition is assumed to be the ideal case. Minimum drag is stated as follows [41]:

$$F_{drag,min} = \frac{\rho\, S\, V_\infty^2\, C_L^2}{2\, \pi\, a} \quad (2)$$

If the minimum input exergy rate of the wing is given in the following statement as horizontal, the dead state velocity is considered to be zero [41]:

$$\dot{Ex}^{TH}_{min} = \frac{\rho\, S\, V_\infty^3\, C_L^2}{2\, \pi\, a} \quad (3)$$

If the general exergy balance is reminded the exergy balance on the wing is written as [41]:

$$\frac{dEx}{dt} = \dot{Ex}^{TH} - \dot{Ex}^{LI} - \dot{Ex}_D = 0 \quad (4)$$

$$\dot{Ex}^{TH} - \dot{Ex}^{LI} = 0 \quad (5)$$

If the statements are derived the dead state velocity can be calculated by [41]:

$$V_{y0} = \frac{\rho\, S\, V_\infty^3\, C_L^2}{2\, \pi\, a\, M_a g} \quad (6)$$

If the following expressions are reminded [41]:

$$F_{lift}^2 = (0.5\, \rho\, S\, V_\infty^2\, C_L)^2 \quad (7)$$

$$F_{lift} = W_a = M_a g \quad (8)$$

Then the dead state velocity is re-written as follows [41]:

$$V_{y0} = -\frac{2\, M_a\, g}{\pi\, a\, \rho\, S\, V_\infty} \quad (9)$$

Reconsideration of Eqs. 1 and 9 yields the exergy rate of lift expression for the *ith* subsystem as follows [41]:

$$\dot{Ex}_i^{LI} = M_i g \left(V_y + \frac{2\, M_{UAV}\, g}{\pi\, a\, \rho\, S\, V_\infty}\right) \quad (10)$$

In Eq. 10, M_{UAV} and M_i are the mass of the UAV and its i^{th} subsystem. The mass of each subsystem at flight points that are obtained by the genuine computer code is also given in Table 2.

Table 2. Mass of the UAV subsystems in units of kg.

Subsystem (*i*)	Flight Point								
	1	2	3	4	5	6	7	8	9
Fuel	1761.8	1742.6	1696.8	1696.8	1617.2	1617.2	111.6	111.6	36.2
Engine	168.239	168.239	168.239	168.239	168.239	168.239	168.239	168.239	168.239
Propeller	69.420	69.420	69.420	69.420	69.420	69.420	69.420	69.420	69.420
Wing	610.171	610.171	610.171	610.171	610.171	610.171	610.171	610.171	610.171
Fuselage	1335.82	1335.82	1335.82	1335.82	1335.82	1335.82	1335.82	1335.82	1335.82
Payload	816.697	816.697	816.697	816.697	816.697	816.697	816.697	816.697	816.697

Including the wing loading and dynamic pressure of the free stream in Eq. 10 leads to [41]:

$$\dot{Ex}_i^{LI} = M_i g \left(V_y + \frac{V_\infty\,(M/S)}{\pi\, a\, q_\infty}\right) \quad (11)$$

Herein dynamic pressure of the free stream is 2211.705 kg.m^{-1}.s^{-2}, 3264.031 kg.m^{-1}.s^{-2}, 2291.913 kg.m^{-1}.s^{-2}, 2153.005 kg.m^{-1}.s^{-2}, 1450.830 kg.m^{-1}.s^{-2}, 2291.913 kg.m^{-1}.s^{-2}, and 3264.031 kg.m^{-1}.s^{-2} for flight points 3, 4, 5, 6, 7, 8, and 9, respectively.

For exergy mapping it is essential to draft the exergy flow diagram through the UAV. In Fig. 2 the exergy flow diagram of the evaluated UAV is illustrated.

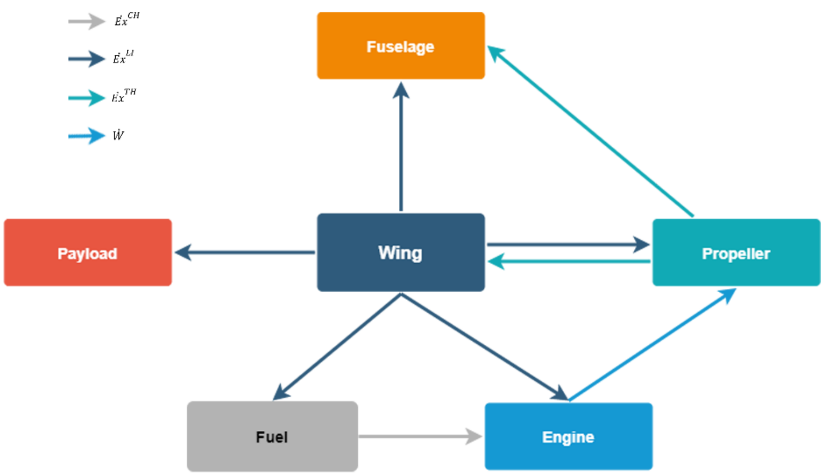

Figure 2. Exergy flow diagram through the UAV (Derived from Ref. [41]).

Regarding the exergy flows through the aircraft, the exergy balance and related formulas for each subsystem of the UAV are listed in Table 3. In the current study, exergy assessment of the UAV subsystems according to the exergy of lift method is deployed by the exergy balance statements in Table 3.

Table 3. Exergy balance of the UAV subsystems [41].

Subsystem	Exergy Balance
Fuel	$\frac{dEx_{fuel}}{dt} = \dot{Ex}_{fuel}^{LI} - \dot{Ex}_{fuel}^{CH} - \dot{Ex}_{D,fuel}$
Engine	$\frac{dEx_{engine}}{dt} = \dot{Ex}_{engine}^{LI} + \dot{Ex}_{fuel}^{CH} - \dot{W}_{prop} - \dot{Ex}_{D,engine}$
Propeller	$\frac{dEx_{prop}}{dt} = \dot{Ex}_{prop}^{LI} + \dot{W}_{prop} - \dot{Ex}_{prop}^{TH} - \dot{Ex}_{D,prop}$ $\dot{Ex}_{prop}^{TH} = \eta_{prop}\, \dot{W}_{prop}$
Wing	$\frac{dEx_{wing}}{dt} = \dot{Ex}_{wing}^{TH} - \dot{Ex}_{wing}^{LI} - \dot{Ex}_{D,wing}$ $\dot{Ex}_{wing}^{LI} = \dot{Ex}_{net}^{LI}$
Fuselage	$\frac{dEx_{fuse}}{dt} = \dot{Ex}_{fuse}^{TH} + \dot{Ex}_{fuse}^{LI} - \dot{Ex}_{D,wing}$ $\dot{Ex}_{fuse}^{TH} = 0.5\, \rho\, A_{fuse}\, V_{\infty}^{2}$
Payload	$\frac{dEx_{payload}}{dt} = \dot{Ex}_{payload}^{LI} - \dot{Ex}_{D,wing}$

4. RESULTS AND DISCUSSION

In the current paper, exergy mapping of a UAV is presented using the exergy of lift method. For this purpose, the modelling and flight performance parameters of the UAV are developed. Then the exergy of lift approach is employed to assess developed flight performance parameters.

For flight points 1 and 2, the exergy rates are found to be zero for each UAV subsystem, where the UAV is still touching the ground, and not flying. During an exergy analysis, it is important to determine the reference environment. In the current study, the reference environment and altitude are assumed to be the environment and altitude of the runway. As a known fact, exergy is evaluated dependent on the reference environment. Therefore, in the current paper, the equality of reference environment and flight points of 1 and 2 yields exergy rates at flight points of 1 and 2 as zero. Tables 4-10 summarize the results obtained from the exergy mapping of the UAV at the flight points. (-) values of the exergy rates indicate the direction of the exergy flow from subsystem to the environment or another subsystem. In other words, the (-) value means exergy outflow.

In Table 4, the exergy mapping results of the UAV at the end of take-off, where the climb begins, are given. It can be seen from the table that the highest exergy destruction is found to be 1679.714 kW within the engine. On the other hand, the lowest exergy destruction occurs in the payload. Additionally, the exergy rate of the lift produced by the wing is delivered to the fuel with the highest percentage. Most of the exergy rate of thrust produced by the propeller is also delivered to the fuselage.

Table 4. Exergy mapping results for flight point 3.

UAV Subsystem	$\dot{Ex}^{LI}$ (kW)	$\dot{Ex}^{CH}$ (kW)	$\dot{Ex}^{TH}$ (kW)	$\dot{W}$ (kW)	$\dot{Ex}_D$ (kW)	dEx/dt (kW)
Fuel	2.321	-2141.811			2.321	-2141.811
Engine	0.230	2141.811		-462.327	1679.714	0.000
Propeller	0.095		-369.862	462.327	92.560	0.000
Wing	-5.591		55.394		49.804	0.000
Fuselage	1.827		314.468		316.295	0.000
Payload	1.117				1.117	0.000

Table 5 shows the decomposition of exergy flow among the UAV subsystems at the end of the climb. The highest share of exergy destruction is found to occur within the engine. The exergy of thrust provided by the propeller is delivered to the fuselage and wing, with the fuselage having the greatest share. In addition, the exergy of lift is mostly delivered to the fuel.

Table 5. Exergy mapping results for flight point 4.

UAV Subsystem	$\dot{Ex}^{LI}$ (kW)	$\dot{Ex}^{CH}$ (kW)	$\dot{Ex}^{TH}$ (kW)	$\dot{W}$ (kW)	$\dot{Ex}_D$ (kW)	dEx/dt (kW)
Fuel	1.986	-1341.959			1.986	-1341.959
Engine	0.197	1341.959		-476.367	865.790	0.000
Propeller	0.081		-381.093	476.367	95.355	0.000
Wing	-4.783		45.582		40.799	0.000
Fuselage	1.564		335.511		337.075	0.000
Payload	0.956				0.956	0.000

As can be seen in Table 6, at flight point 5 the exergy destruction rate of the engine is 810.75 kW while the fuselage is the runner with a value of 224.44 kW. Different from flight points 3 and 4, the exergy of lift consumption of the fuel and fuselage is extremely close at flight point 5. The fuselage also consumes most of the exergy of thrust produced by the propeller.

Table 6. Exergy mapping results for flight point 5.

UAV Subsystem	$\dot{Ex}^{LI}$ (kW)	$\dot{Ex}^{CH}$ (kW)	$\dot{Ex}^{TH}$ (kW)	$\dot{W}$ (kW)	$\dot{Ex}_D$ (kW)	dEx/dt (kW)
Fuel	2.632	-1166.724			2.632	-1166.724
Engine	0.274	1166.724		-356.247	810.750	0.000
Propeller	0.113		-284.998	356.247	71.362	0.000
Wing	-6.524		62.733		56.209	0.000
Fuselage	2.174		222.265		224.440	0.000
Payload	1.329				1.329	0.000

In Table 7, the results of the analysis for flight point 6 are summarized. According to the table, the highest exergy destruction is found to be 776.531 kW within the engine, while the lowest exergy destruction occurs in the payload. Moreover, the exergy rate of the lift produced by the wing is delivered to the fuel with the highest percentage. Additionally, most of the exergy rate of thrust produced by the propeller is delivered to the fuselage with a value of 218.598 kW.

Table 7. Exergy mapping results for flight point 6.

UAV Subsystem	$\dot{Ex}^{LI}$ (kW)	$\dot{Ex}^{CH}$ (kW)	$\dot{Ex}^{TH}$ (kW)	$\dot{W}$ (kW)	$\dot{Ex}_D$ (kW)	dEx/dt (kW)
Fuel	2.717	-1130.376			2.717	-1130.376
Engine	0.283	1130.376		-354.128	776.531	0.000
Propeller	0.117		-283.302	354.128	70.942	0.000
Wing	-6.733		64.704		57.971	0.000
Fuselage	2.244		218.598		220.842	0.000
Payload	1.372				1.372	0.000

At flight point 7, where the speed of the UAV reaches the lowest value during the loiter phase, the exergy of lift is mostly delivered to the fuselage among all of the subsystems. According to Table 8, the highest exergy destruction occurs within the engine, while the fuselage is the highest subsystem after the engine in terms of exergy destruction.

Table 8. Exergy mapping results for flight point 7.

UAV Subsystem	$\dot{Ex}^{LI}$ (kW)	$\dot{Ex}^{CH}$ (kW)	$\dot{Ex}^{TH}$ (kW)	$\dot{W}$ (kW)	$\dot{Ex}_D$ (kW)	dEx/dt (kW)
Fuel	0.230	-630.793			0.230	-630.793
Engine	0.347	630.793		-343.489	287.651	0.000
Propeller	0.143		-274.791	343.489	68.841	0.000
Wing	-5.156		35.792		30.637	0.000
Fuselage	2.753		238.999		241.752	0.000
Payload	1.683				1.683	0.000

According to Table 9, the exergy of lift is mostly delivered to the fuselage with approximately half the percentage among all of the subsystems. The highest exergy destruction occurs within the engine with a value of 512.187 kW. The exergy destruction rate of the fuselage is approximately half the percentage of the engine subsystem with a value of 258.696 kW. In addition, the lowest exergy destruction is observed in the fuel with a value of 0.183 kW compared to all of the subsystems.

Table 9. Exergy mapping results for flight point 8.

UAV Subsystem	$\dot{Ex}^{LI}$ (kW)	$\dot{Ex}^{CH}$ (kW)	$\dot{Ex}^{TH}$ (kW)	$\dot{W}$ (kW)	$\dot{Ex}_D$ (kW)	dEx/dt (kW)
Fuel	0.183	-868.158			0.183	-868.158
Engine	0.276	868.158		-356.247	512.187	0.000
Propeller	0.114		-284.998	356.247	71.363	0.000
Wing	-4.105		28.493		24.389	0.000
Fuselage	2.192		256.504		258.696	0.000
Payload	1.340				1.340	0.000

At flight point 9, corresponding to the descent phase, the exergy of lift is mostly delivered to the fuselage among all of the subsystems. According to Table 10, the highest exergy destruction occurs within the engine. In addition, the lowest exergy destruction is found to be 0.043 kW in the fuel compared to all of the subsystems.

Table 10. Exergy mapping results for flight point 9.

UAV Subsystem	$\dot{Ex}^{LI}$ (kW)	$\dot{Ex}^{CH}$ (kW)	$\dot{Ex}^{TH}$ (kW)	$\dot{W}$ (kW)	$\dot{Ex}_D$ (kW)	dEx/dt (kW)
Fuel	0.043	-1099.399			0.043	-1099.399
Engine	0.199	1099.399		-476.367	623.231	0.000
Propeller	0.082		-381.093	476.367	95.355	0.000
Wing	-2.865		19.050		16.185	0.000
Fuselage	1.577		362.044		363.621	0.000
Payload	0.964				0.964	0.000

The exergy destruction rates of the subsystems at each flight point are plotted in Fig. 3. As shown in the graph, the maximum exergy destruction rate is calculated to be 1.679 MW for the engine at flight point 3 where the climb begins. On the other hand, the minimum exergy destruction is found to be 0.042 kW for the fuel at flight point 9. As can be deduced from Fig. 3, the highest exergy destruction occurs within the engine among all of the other subsystems for each flight point.

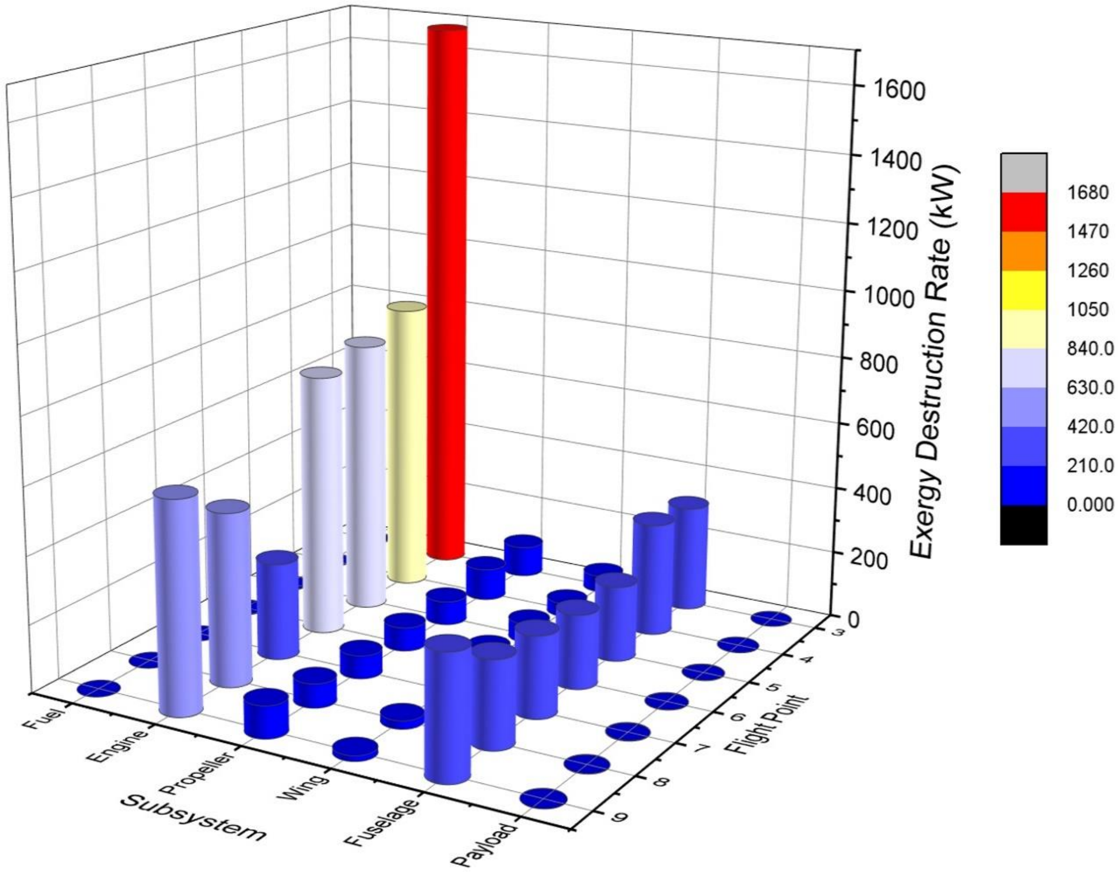

Figure 3. Exergy destruction rate of subsystems at flight points.

5. CONCLUSION

In the current paper, the exergy mapping of a UAV during a reconnaissance flight is presented. An existing, but little-known method, namely exergy of lift, is preferred to evaluate the UAV. At the end of the study, the following inferences may be addressed:

- The exergy of lift methodology is a beneficial tool to understand exergy destruction in a UAV and its subsystems.
- A comparison of flight points indicates that the highest exergy destruction occurs at the beginning of the climb.
- A comparison of flight points indicates that the lowest exergy destruction occurs at the loiter.
- A comparison of the subsystems indicates that the highest exergy destruction occurs in the engine subsystem of the UAV.
- A comparison of the subsystems indicates that the lowest exergy destruction occurs in the fuel.
- A comparison of the flight points indicates that the highest exergy destruction occurs at flight point 3.
- A comparison of the flight points indicates that the lowest exergy destruction occurs at flight point 7.
- The engine and fuselage subsystems consume more exergy of lift than any other subsystem of the UAV.

The authors consider employing the exergy of lift approach for assessment of different air vehicles, such as passenger aircraft, military aircraft, and so on. The methodology is also beneficial to those interested in aerospace, mechanical, and system engineering disciplines for air vehicle design, and performance examination to the best of the authors' knowledge.

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