Wing Support Structure LSU03 UAV Strengthen For Dynamic Load

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Abstract: LSU03 UAV was resulted by Aeronautics Technology Center, National Institute of Aeronautics and Space, LAPAN. This UAV has flight scenario like small UAV comprising taxi moves, take off, cruising, descending and landing. The operational of this craft was appeared stress structure specially wing support structure. The appearing of this stress was caused by the dynamic load or shock loads which the biggest at early landing and first touchdown in ground plane. With the dimensional data of wing support structure, analytical method, mission objective research and flight operational of LSU03 can be known that the structure can fulfill mission that is robust, light and strength. E-glass composite material was used as material of the wing support structure. This structure is strengthen receive dynamic load during flight time and landing.
Key Words: dynamic load, e-glass, LSU03 UAV, wing, landing

Nomenclature

v_r	: Rate of descent	ρ	: Air density
θ	: Angle of landing	σ_{max}	: Maximal stress
ω_n	: Natural frequency of system	V_o	: Local air velocity
E	: Elasticity modulus of system	V_{ud}	: Free air velocity
I	: Moment of Inertia	V	: Flight velocity
g	: Earth gravity	A_i	: Surface wing area
L_o	: Lift	σ_y	: Material yield stress
D_o	: Drag	F_t	: The load of take off
Y_i	: Wing span	SF	: Safety Factor

1. Introduction

LSU03 UAV is Unmanned Aerial Vehicle series from research program of National Institute Aeronautic and Space. This research programs are like i.e.: aerodynamic factor, aero structure, avionic, and propulsion technology. This UAV due to a flight vehicle which has not pilot in the body's and has mission as flight vehicle white GPS, camera or and others payload, but it's has autonomous control since flying vehicle or will be controlled by pilot in ground segment[1)]. This vehicle has primary structure component like nose, wing span, and twin boom, which make this UAV can fulfill mission come true. Beside this, the LSU03 UAV has power propulsion resource due to piston engine, and it's makes to rotates propeller for find thrust and flying. The operation of LSU03 UAV has high cycle frequency of takeoff and landing for maintenance and or refueling[2)]. Therefore this UAV must have a robust structure, primary support structure of wing span. Because, this structure can take dynamic load when comes to at first time in landing point. This dynamic load can be made this structure is failure before lifetime's. The failure structure by dynamic load can be prevented by used the robust structure of wing support structure. The structure like this can be made since design analysis and research activity about this. If the structure was given and excited, this wing support structure of LSU03 UAV necessary reanalysis about influence dynamic load for fulfill structure validation, before this vehicle will be flight test.

2. Research Method

Influence of dynamic load for wing support structure of the LSU 03 UAVs can be done by analytical method for dynamic load at first time in landing point with rate of descent in situ. Beside this, the analysis considerate about i.e.: Principle of dynamic load, and procedure analysis.

2.1. Dynamic Load of LSU03 UAV

Like which known that the dynamic load in wing structure will be accepted to wing support structure of the LSU 03 UAVs, and can be happened by shock load at first time in landing point with rate of descent in situ. As simplify to analysis structure, UAV can be assumed as a rigid body which fly in air[3]. The theatre of dynamic load when the UAV was landing can be shown in Fig. 2.1.1, white rate of descent v_o[3,4], or in Fig. 2.1.2.

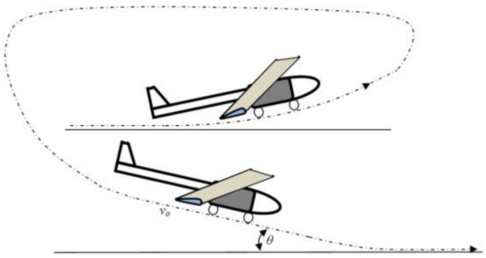

Fig. 2.1.1. The UAV will be landing

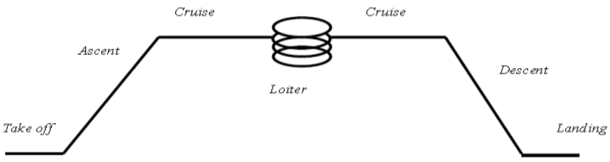

Fig. 2.1.2. Mission profile of a Small UAVs[5]

The LSU 03 UAVs can be noted has small category UAV. However it has mission profile as composed of 6 different steps like Fig. 2.1.2. After the take off, the aircraft climb to the target altitude (ascent); after reaching this altitude there is cruise segment necessary to reach the mission target, then a phase of loitering around the target, finally a cruise to come back to the launching site, a descent and a landing, with or without a parachute[5]. Mathematical models can be used to do structural analysis like Wing Structure Support System as caused dynamic load when it's a descent and a landing. The study of mathematical models which involve physical and geometric parameters such as mass density ρ, elastic modulus E, Poisson's ratio v, lengths, and cross-section shape characteristics. In many practical engineering applications, these parameters frequently do not have well defined values due to non-homogeneity of the mass distribution geometric properties or physical errors, as well as variation arising from the assembly and manufacturing processes, structural loading and environmental conditions [6,7].

The wing support structure like Fig. 2.1.1 can be modeled as simple support system structure in Fig. 2.1.3 and 2.1.4 below.

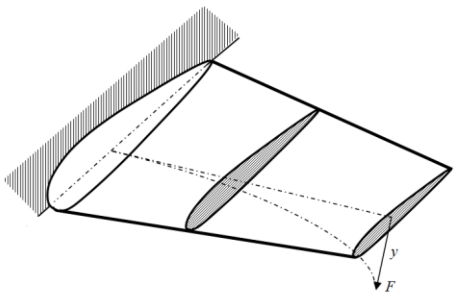

Fig. 2.1.3. Wing Structure Support System

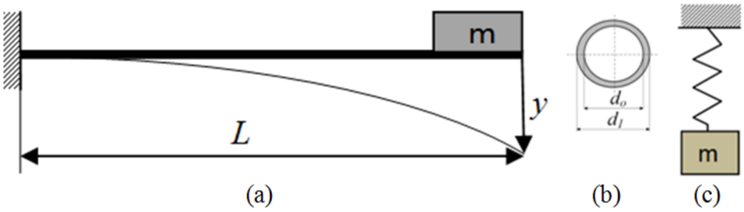

Fig. 2.1.4. Simple support system
(a). Simple beam, (b). Cross section of beam, (c). Element vibration model

The dynamic load that is shock load like Fig. 2.1.3 and 2.1.4 will make amplitude *A* in wing support structure, which can be written on the mathematical model like below[4,8].

$$A = \sqrt{x(o)^2 + \left(\frac{v_r}{\omega_n}\right)^2} \qquad (1.)$$

Where:

$v_r = v_o \sin\theta$

v_r = rate of descent
θ = angle of landing
ω_n = natural frequency of system

$$\omega_n = \sqrt{\frac{k_{eq}}{m}} \qquad (2.)$$

$$k_{eq} = \frac{3EI}{L^3} \qquad (3.)$$

E = Elasticity modulus of material
I = Moment of Inertia

When the UAV was landing at *t=0*, and the system in the static equilibrium, it's has static deflection like equation below 9).

$$x(o) = -\frac{g}{\omega_n^{\ 2}} \qquad (4.)$$

g = earth gravity

When the UAV was flying, it's has aerodynamic force as drag and lift. The drag is parallel to the direction of air flow freely, while the lifting forces perpendicular 10), likes Fig. 2.1.5.

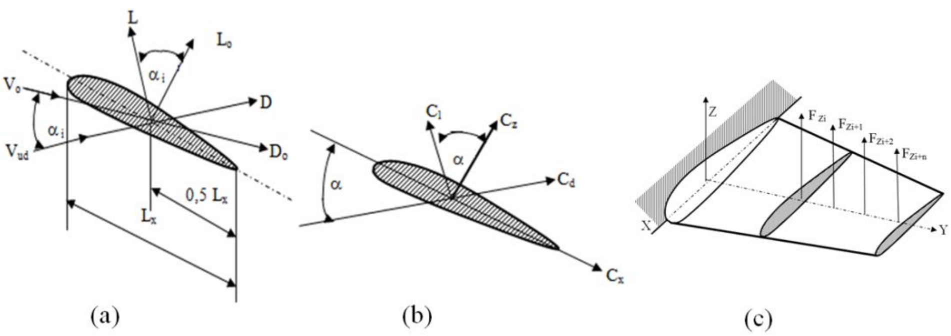

Fig. 2.1.5. Aerodynamic Load10)

(a) = Position and direction of Wing Aerodynamics load
(b) = Aerodynamic load coefficient was described to the direction axis X, Y and Z
(c) = The aerodynamic load distribution on the UAV wing structure

From Fig. 2.1.5. was found [9] :

$$L = L_o Cos\alpha_i - D_o Sin\alpha_i \tag{5.}$$
$$D = L_o Sin\alpha_i + D_o Cos\alpha_i \tag{6.}$$
$$C_x = C_l Sin\alpha - C_d Cos\alpha \tag{7.}$$
$$C_z = C_l Cos\alpha + C_d Sin\alpha \tag{8.}$$
(9.)
$$M_{zi} = \sum F_{zl} Y_i \tag{10.}$$

Where:

$$F_{zi} = 0{,}5 C_z \rho V^2 A_i \tag{11.}$$

L_o = Lift, V_o = Local air velocity
D_o = Drag, V_{ud}= Free air velocity
Y_i = Wing span, V = Flight velocity
ρ = Air density, A_i = Surface wing area

From amplitude A and natural frequency ω_n can be found maximal acceleration of vibration system a_{max}, maximal moment M_{max} for maximal stress structure σ_{max}, and Safety factor of structure SF. It's can be wrote like equation below [3,8,9].

$$a_{\max} = \omega_n^2 .A \tag{12.}$$
$$-M_{\max} + mg\frac{l}{2} = -m\ddot{x}\frac{l}{2} \tag{13.}$$
$$M_{\max} = m\left(g + \ddot{x}\right)\frac{l}{2} \tag{14.}$$

For simple beam like Fig. 2.1.5 in static equilibrium can be found a moment maximal as:

$$M_{\max} = -F_1 L_1 - F_2 L_2 - F_n L_n \tag{15.}$$

The stress maximal as[4,10]:

$$\sigma_{\max} = \frac{M_{\max} c}{I} \tag{16.}$$

Even though the thrust of UAV take off with flight velocity C_o in the t second time, and mass of UAV is m, It's be found load of UAV take off like equation below [11, 12].

$$F_t = m\frac{dC_o}{dt} \tag{17.}$$

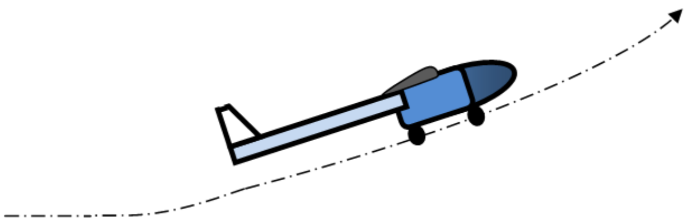

Fig. 2.1.6. UAV was take off

If The load of take off as F_t are bigger rather than total weight of UAV, its means that the UAV can take off and fly.
Safety factor *SF* of Support structure of wing span can be found by computation of equation below.

$$SF = \frac{\sigma_y}{\sigma_{\max}} > 1 \qquad (18.)$$

Where: σ_y = Material yield stress

2.2. Procedure Analysis

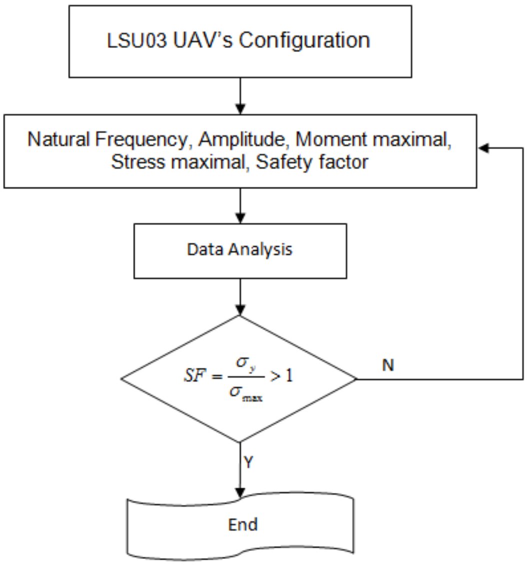

Fig. 2.2.1. Procedure Analysis

3. Result and Discussion

3.1. Result

Data analysis of this research can be found by consideration to configuration support structure of wing span include dimension data, rate descent, and material of this structure, mission statement, and analytical method for dynamic load strengthen of the LSU03 UAV wing support structure. Therefore from this research can be known relationship of each parameter, likes stress of this structure in flight operational the LSU03 UAV.

3.1.1. Configuration Wing support structure

Dimension of Wing structure LSU-03 UAV was sawn as Fig. 3.1.1.1, the wing support structure of LSU03 UAV was pipe profile with thickness and inner radius like Fig. 3.1.1.1 and 3.1.1.2, whereas the vehicle's in Fig.3.1.1.3.

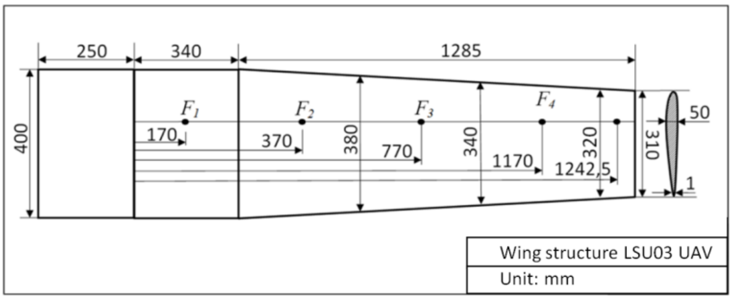

Fig.3.1.1.1 Dimension of Wing structure[12)]

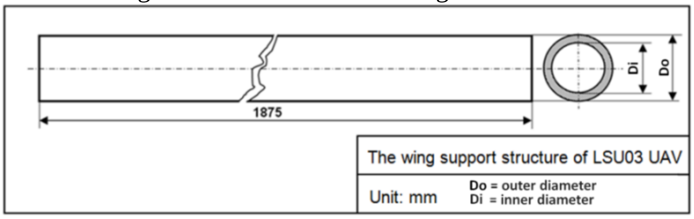

Fig. 3.1.1.2. The wing support structure of LSU03 UAV

Fig. 3.1.1.3. LSU03 UAV's Configuration[12,13)]

3.1.2. Mission Statement

Dimension of LSU03 UAV's is shown in Table 3.1.2.1, below.

Table 3.1.2.1. Specifications of LSU03 UAV [13)]

No.	Spesification	Unit
1	Wing span	3500 mm
2	Vehicle length	2000 mm
3	Weight without payload	24 kg
4	MTOW	30 kg
5	Velocity flight	100 km/hr
6	Engine type	Piston engine

From Table 3.1.2.1 can be made mission statement of wing structure design characteristic of LSU03 UAV, likes Table 3.1.2.2

Table 3.1.2.2. Mission Statement of Wing structure LSU03UAV

No.	Spesifikation	Unit
1	Wing span	3500 mm
2	Landing g-shock	2 g
3	Wing material	composite
4	Angle of descent	2^o
5	Rate of descent	7.5 km/hr
7	Material wing support structure	e-glass composite Modulus elasticity = 30 G Pa, Yield strength = 650 M Pa , Density = 1700 kg/m^3
8	Structure type	Robust, Useable, Light and Strength, Shock load resistant, strong, easy to use

3.1.3. Dynamic Load for Wing Support Structure of LUS03 UAV

From Table 3.1.2.2 can be known that the LSU03- UAV will flight in maximal velocity about 100 km/hr, and descent on 7.5 km/hr. This velocity can be caused acceleration, and produced dynamic load when the UAV was landing[3,8,9]. Therefore the wing structure must fulfill requirements and failure criteria[14,15]. LSU03 UAV's of LAPAN will be operated with flight scenario likes Fig. 3.1.3.1 as small UAV flight scenario[5]. Operational of this scenario has result performance of Wing Support Structure LSU03 UAV for dynamic load was which strengthen to stress structure of this wing support structure at Lift and Velocity like Fig. 3.1.3.2. The stress structure as caused this operation can be shown in Fig. 3.1.3.3, with Safety factor in Fig. 3.1.3.4

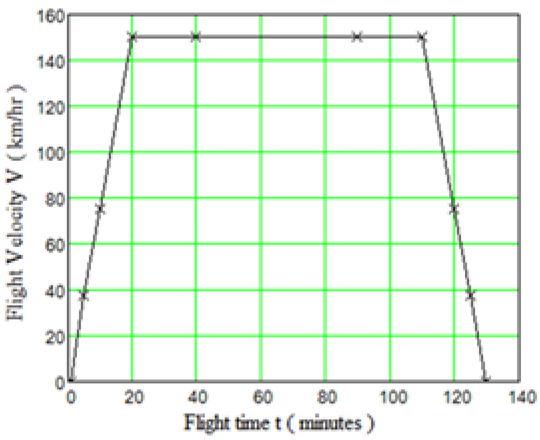

Fig. 3.1.3.1 Flight Scenario of LSU05

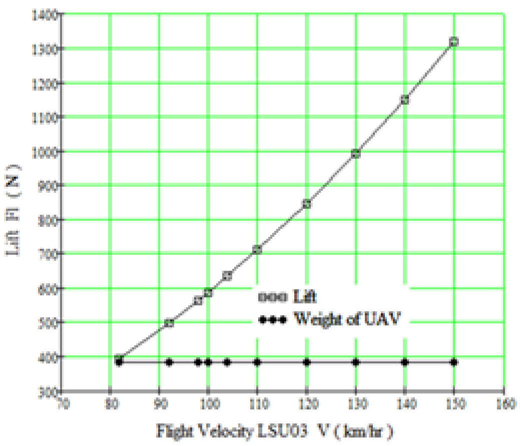

Fig. 3.1.3.2. Lift of LSU03 on Flight Velocity[12)]

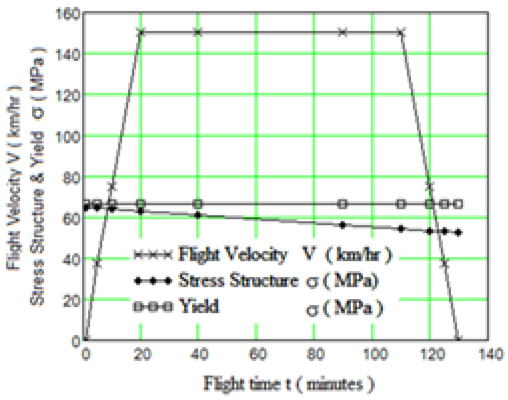

Fig. 3.1.3.3. Stress of Wing Support Structure

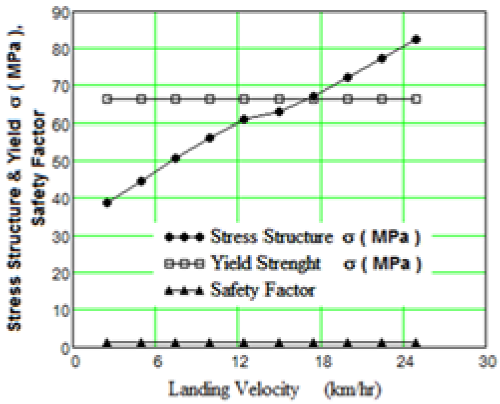

Fig. 3.1.3.4 Stress Structure and Safety factor when the LSU03 UAV was landing

As for landing during the ongoing operational flight velocity, the stress structure that occurs in the wing support structure, listed in Fig. 3.1.3.5.

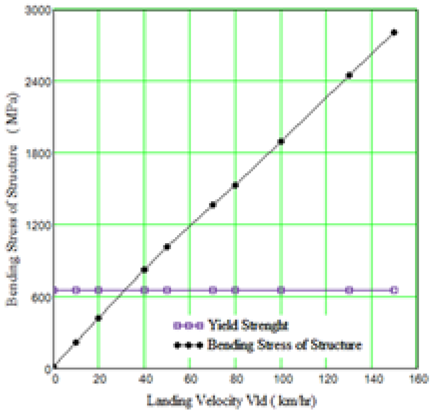

Fig. 3.1.3.5. Stress Structure when the LSU03 UAV was landing in flight velocity

3.2. Discussion

3.2.1. Dynamic load caused stress for the Wing support structure LSU03 UAV

The LSU03 UAV was resulted by Aeronautics Technology Center, Indonesian National Institute of Aeronautics and Space, LAPAN. This UAV will be operated as small UAV's scenario[5)] like Fig. 2.1.1 comprising take off, cruising and landing. The flight scenario of LSU03 own was listed in Fig. 3.1.3.1, this is not too different from the Fig. 2.1.1. Implementation of this scenario, one of which can cause the structure interference in terms of stress, as influence of the LSU03 mass, acceleration and aerodynamic load like result study in references number 2,8 and 9. The flight scenario operational of the LSU03 UAV like Fig. 3.1.3.1 has been done at maximal velocity 150 km/hr and can do operational on 130 minutes flight time from take off until landing can result the stress on wing support structure as caused by dynamic load, and it could cause failure. From table 3.1.1 and 3.1.2 can be known too, that LSU03 will do take off at 100 km/hr and landing at 7.5 km/hr. In this velocity the UAV's wing has lift as 586,881 N, bigger than its weight as 390 N, meanning that the UAV can flight. Really that LSU03 UAV's can take off from 82 km/hr with lift as 394,619 N, until 150 km/hr[12)] like Fig. 3.1.3.3. By entering the dimensional data LSU03 Wings in Fig. 3.1.3.1 and 3.1.3.2, as well as data Tables 3.1.1 and 3.1.2 to Eq. (1) – (18) with research methods in Fig. 2.1.1 above, is obtained the stress value as caused by dynamic load of LSU03 wing support structure during flight time for takeoff, cruising, and landing. The magnitude of each stress was listed on the graph Fig. 3.1.3.3, and the stress of wing support structure that occurs when the LSU03 landed at landing operations velocity of 03 LSU listed in Fig. 3.1.3.4.

As noted in Fig. 3.1.3.5, LSU03 moves horizontally on the ground plane, then an early flight at 82 km/h as a minimum speed to takeoff, forwarded fly cruising, and landing[12).]. Since that the interference structure is taking place, including stress of the wing support structure. The wing support structure will be made from pipe profile of e-glass composite with 3.0 mm as outer diameter, and 2.0 mm as inner diameter, and the other dimension like Fig. 3.1.3.1 and 3.1.3.2. Material composite like e-glass or fiber carbon are similar in many ways. They appeared to be the most weight efficient. However, the manufacturing cost of the carbon fiber spar is expected to be higher than that of an aluminum spar[16], same like e-glass composite. From Fig. 3.1.3.3 was known that the LSU03 was flying, it takes aerodynamic load and acceleration moves with the weight of LSU was 394,619 N[12)]. The aerodynamic loading under the cruise conditions is based on the performance parameters considered for the aircraft, and the wing is known as lifting component in the aircraft structure. Majority of the lift load will be acting on the wing, beside this the total lift load on the aircraft structure is normally distributed as 80% of the total load on the wings and remaining 20% of the total load on the fuselage[17).] The aerodynamic load would be calculated by the aerodynamic load calculation like Eq. (6) – (11) and followed until Eq. (16) has result a graph of stress of wing support structure like Fig. 3.1.3.4 up to 3.1.3.5. Fig. 3.1.3.3 gave information that since LSU03 will be operated, the wing support structure will receive dynamic load which caused structure stress until along flight time, but this stress can not cause failure for this structure. Value of this stress was just smaller rather than capability of e-glass material yield strength, it means that the structure was stronger rather than operational stress structure. The stress was concern decrease starting from taxi move, take off, cruising until descending. This was caused decreasing fuel weight combusted during the flight, so the dynamic load decrease too, and influence decreasing stress structure. From this research shows that using e-glass composite materials can make this structure such as strength and light was achieved. It was seen that use of composites alone in design, without employing metals, can make the structure significantly strong[18),] and the application of the advanced composites plays an important role in improving the aero craft structure performances [19)], and the LSU03 UAV is also aero craft category. So the wing support structure could meet mission objective of structure as robust, light and strength. Be known that the mission objective is derived from the stakeholder expectation and which initiates the system engineering process and is put at the forefront of every stage of the effort[20).]

3.2.2. The Stress Toughness as Strengthen of LSU03 Wing support Structure

Followed descending, LSU03 UAV does to landing. Early landing which touch to ground plane, this craft will receive shock load as dynamic load to structure component and caused structure stress specially wing support structure. Fig. 3.1.3.4. gave information about these. Flight velocity for landed which not caused failure, can be done at 7.5 km/hr and maximal 15 km/hr, and recommended at 2.5 km/hr with Safety Factor 1.2. This Safety Factor can be became reference that the structure is safety, because the support structure will take strengthen that was skin layer composite and the others wing structure component. But if it's was landed faster rather than 15 km/hr can cause structure failure, the operational stress was above capabilities of e-glass material yield strength. Especially if it was landed at cruising velocity like Fig.3.1.3.2, or it fall when flights can be ensured that the wing support structure is damage. This phenomenon was listed in Fig. 3.1.3.5, where the operational stress above e-glass material of wing support structure yield strength, especially when early landing at the flight velocity above 30 km/hr. This velocity will cause acceleration of vibration increase and result the big banding moment, and increasing dynamic load, finally can appear that the bigger stress of wing support structure rather than capability yield strength of e-glass material, and the wing support structure which was made from this material was failure and collapse. This material has Modulus elasticity = 30 G Pa, Yield strength = 650 M Pa, Density = 1700 kg/m^3 as shown the Mission Statement of Wing structure LSU03 UAV in Table 3.1.2.2, while the operational stress in flight velocity above 30 km/hr was higher rather than yield strength of e-glass material. From this phenomenon was known that the acceleration of vibration has influence to generate stress structure[2,8)], including wing support structure of LSU03 UAV.

Therefore which was previous analysis of stress structure in the wing support structure of LSU03 UAV was known that the value of stress caused dynamic load during flight time for takeoff, cruising, and landing was just smaller rather than capability of e-glass material yield strength, if the aircraft just landing in maximal velocity is 2.5 km/hr. It means that the structure was stronger rather than operational stress structure, and it means that the structure has higher stress toughness as strengthen of LSU03 UAV wing support structure for dynamic load rather than operational stress which was caused dynamic load, and LSU03 UAV always be landing in maximal velocity 2.5 km/hr too. So this velocity is recommended as landing velocity for find higher the stress toughness rather than stress caused dynamic load. In fact the stress toughness of structure has properties are similar to fracture toughness. The fracture toughness decreased with increasing load, and the analysis about this is extremely important for many design application[21)]. So the stress toughness analysis must be done in doing research about structure, especially Wing support structure LSU03 UAV for find determination about strengthen of structure.

4. Conclusion

The wing support structure of wing span LSU03 UAV which be made from pipe profile of e-glass composite without metal material, has strengthen to receive dynamic load when comes landing at first time in ground plane. The robust, light and strength of structure can be fulfilled as like objective mission of this research structure. But the dynamic load can be made this structure is failure if the UAV craft was landed above velocity 15 km/hr. The descending or landing velocity in the ground plane as recommended at 2.5 km/hr with assume that the structure will take strengthen that is skin layer composite and the others wing structure component.

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