Journal of Aeronautics & Aerospace Engineering
ISSN: 2168-9792
Yuvaraj and Veeranjaneyulu, J Aeronaut Aerospace Eng 2016, 5:4
DOI: 10.4172/2168-9792.1000175

Research Article
Open Access

Buoyancy Lift Augmentation

Yuvaraj G* and Veeranjaneyulu K

Department of Aeronautical Engineering, Marri Laxman Reddy Institute of Technology, Laxman Reddy Avenue, Dundigal 500043, Hyderabad

Abstract

This paper proposes an idea of lift augmentation for conventional subsonic aircraft at low along with mathematical analysis. This paper mainly addresses certain changes in power plant requirements and performance characteristics of aircraft after implementation of buoyancy lift augmentation technique. There are certain factors which must be considered for practical implementation of it towards an aircraft without degrading its primary performance and mission profile. Those considerations are discussed with respect to total weight or overall weight of the aircraft and vital changes required in design, manufacturing and operation are addressed. This document also formulates a brief overview on changes that would occur in flight aerodynamic characteristics after the supplementation as well as its impact on flight performance parameters.

Keywords: Augmentation; Flight; Aerodynamics

Nomenclature

γ: Gas constant of air

$\rho_{air:}$ Density of air

$\rho_{lift:}$ Density of lifting gas

A: Aspect ratio of wing

CD: Co-efficient of Drag

CL: Co-efficient of Lift

Cg: Center of gravity

D: Drag force

$D_{z:}$ Lift independent drag

$D_{i:}$ Lift dependent drag

E: Aerodynamic efficiency

E: Span wise wing loading

$F_{b:}$ Buoyancy Force

g: Gravitational acceleration

L: Lift Force

L: Distance between centre of gravity to the buoyancy force vector

M: Mach number of flight

p: Pressure

q: Dynamic pressure of air

S: Reference area of wing

T: Thrust force

Vol: Volume of lifting gas

V: Velocity of flight

$V_{md:}$ Minimum drag speed

$V_{mp:}$ Minimum power speed

Introduction

In this technique part of the aircraft weight is operated under heavier than air vehicle principles and other part by lighter than air vehicle principles. To incorporate these characteristics an aircraft can be supplemented by generating buoyancy force which will supplement lift force and reduces the effect of weight especially at zero lift conditions.

When any one of the aerodynamic forces is affected or subjected to considerable change then all other forces will tend to change correspondingly. Based on this phenomenon an aircraft's aerodynamic forces are changed considerably by varying any one of the aerodynamic forces i.e. lifts. Hence Lift is increased by generating a buoyancy force. Thus, effect of weight on an aircraft is reduced which will affect performance and power plant requirements of aircraft.

Lift Augmentation by Buoyancy Forces

Buoyancy lift augmentation is lift augmentation technique by means of increasing buoyancy force on an aircraft. Basically an aircraft immersed in air will have buoyancy force acting on just like any other body immersed in fluid but due to dynamic pressure buoyancy force is considered to be negligible when compared to resultant aerodynamic force. So, buoyancy lift augmentation is achieved by filling or storing lighter than air gas or fluid which is less dense than air in the aircraft. This gas Such that resultant of buoyancy force acts always in direction opposite to the weight of aircraft through the centre of gravity to avoid unnecessary moments.

Though aircraft is solid structure which moves in atmosphere it will have certain components which are hallow and are filled by air. To increase buoyancy force those regions are identified and filled with lighter than air gas. This can be done at preliminary design stage or even after completion of production. Once structure and weight of the vehicle is decided then region to fill the lifting gas are identified in the vehicle and filled with the gas such that control operations, stability and

***Corresponding author:** Yuvaraj G, Department of Aeronautical Engineering, Marri Laxman Reddy Institute of Technology, Laxman Reddy Avenue, Dundigal 500043, Hyderabad, Tel: 09652226061; E-mail: georgeyuvaraj2@gmail.com

Received July 27, 2016; **Accepted** October 26, 2016; **Published** October 31, 2016

Citation: Yuvaraj G, Veeranjaneyulu K (2016) Buoyancy Lift Augmentation. J Aeronaut Aerospace Eng 5: 175. doi: 10.4172/2168-9792.1000175

mission profile is undisturbed. The volume which contains lifting gas must be in leak proof container. Just like fuel tank (rubber tank with rectangular cross-section area) con-from of the lifting gas is coated with plastic or rubber to ensure gas is leak proof. Lift force will be produced by this lifting gas which must act in the opposite direction of the weight of aircraft [1]. The lifting gas should be selected with precise care out of all possible sources and should not tend to react with any parts of aircraft structure [2].

Out of all available lifting gases inert gas especially be Helium would more suitable with a ρ_{he}=0.178 Kg/m^3 and being inert gas it tendency to react with aircraft structure is practically impossible. Even Hydrogen can be selected but care should be exercised when gas is filled near to engine as is highly reactive in nature. Even with the conform surface of the structure hydrogen can is high and other issues like heat impact of gas and low heating value. Since the density of the gas is very low it will provide required lifting force for which gas is needed be compressed to certain level and the density of compressed gas should also be less than the density of air that is ρ_{air}=1.292 Kg/m^3 [3].

As the altitude of the aircraft increases the density of air and gravitational acceleration decreases as it is function of altitude. However, for a simple subsonic speed the gravitational acceleration effect is assumed to be negligible and mathematical analysis is performed for aerodynamic Characteristics and power plant requirements assuming gas is filled enclosed in adiabatic boundary and the effect of aerodynamic negligible.

But the lifting force should act through Cg (centre of gravity). Such that lifting force generated by lifting gas should be Fb (Buoyancy Force) [2,4].

$$F_b=(\rho_{air}-\rho_{lift})Vol \cdot g \tag{1}$$

Lifting gas should be filled at certain areas of aircraft structure such that its sum of algebraic moments regarding centre of gravity should be zero. In other words, it should exactly act at Cg. Since, it is the direction of body force that is weight (W). With respect to centre of gravity the produced buoyancy force should not disturb the stability of aircraft i.e. the static margin of aircraft must not change. This phenomenon can be ensured by following equation 2 which states that the algebraic sum of moments generated by buoyancy forces and moment arm which may vary throughout flight trajectory must be zero.

$$\Sigma^{n}_{i=1} li \cdot F_{bi} = 0 \tag{2}$$

Here, li is distance from Cg to the corresponding buoyancy force and Fb is buoyancy force. Substituting equation (1) in equation (2) we get,

$$\Sigma^{n}_{i=1} l_i \,(\rho_{air} - \rho_{lift-i})Vol_i \cdot g = 0 \tag{3}$$

From the above equation wing, can be choosing to infuse lifting gas. Since wings are symmetrical regarding longitudinal axis and can be easily managed to attire condition stated in equation (3).

There is also a change centre of gravity as fuel is continuously consumed by power plant. After certain altitude gas, will not produce any lift but only contribute weight. This will help in stabilize centre of gravity this is demonstrated in Table 1 where density of atmosphere and density of lifting gas almost becomes equal and thus from equation 1 no lift is produced by this lifting gas but the weight of gas still do act on aircraft.

Buoyancy force generated always can't be greater than the weight of aircraft. Since performance of manoeuvres are greatly affected during climb, descent and high nose pitch up and pitch down even rolling. Therefore, this condition can be given mathematically by,

$$W>F_b \tag{4}$$

As the pressure of gas increases with decrease in volume that is revealed by increase in density of gas in this case. Proper composites must be used on corresponding areas of structure. Material used to supplement a hybrid aircraft should possess high tensile stress, high lower yield point and low density i.e., high strength to weight ratio materials such as plasticizers and carbon fibres [4]. These supplementing materials can be coated or layered on the interior surface of aircraft structure at corresponding area of which particularly lifting gas pressure is subjected. The elastic limit σ_{max} of composite should be sustainable to dynamic pressure-q, hydro static pressure of lifting gas and thermal impact along with mass of fuel and components if existing [4]. (Figures 1 and 2).

Aerodynamic Forces

Steady flight

When aerodynamic forces and behaviour of flight in steady level state are considered its mathematical analysis as follows. In a steady flight, the algebraic sum of all forces should be zero. Therefore, L+W=0, T+D=0 [2].

$$L=W \tag{5}$$

$$T=D \tag{6}$$

For an aircraft supplemented with lift augmentation equation (4) can be written as,

$$L=W-F_b \tag{7}$$

Here W is total aircraft weight including weight contributed by lifting gas. Since lift produced by the lifting gas is considerably opposite in direction of weight, buoyancy force acts in the direction opposite

Altitude (km)	Temperature	Density (kg/m^3)	-	-
0	288.16	1.225	-	-
1	281.66	1.11164	-	-
2	275.16	1.00649	-	-
3	268.66	0.90912	-	-
4	262.16	0.81912	-	-
5	255.66	0.73611	-	-
6	249.16	0.65969	-	-
7	242.66	0.58949	-	-
8	236.16	0.52516	-	-
9	229.66	0.46634	-	-
10	223.16	0.4127	-	-
11	216.66	0.36391	-	-
12	216.66	0.31083	-	-
13	216.66	0.26548	-	-
14	216.66	0.22675	-	-
15	216.66	0.19367	He gas density 0.164 @300 k	
16	216.66	0.16542		
17	216.66	0.14129	-	-
18	216.66	0.12068	-	-
19	216.66	0.10307	-	-
20	216.66	0.08803	H_2 Gas density 0.082@ 300 k	
21	217.66	0.07487	-	-

Table 1: Change in density of atmosphere as a function of altitude.

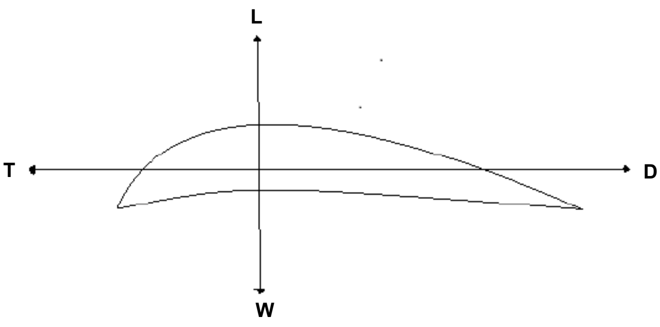

Figure 1: Representation of forces acting on aerofoil of an aircraft.

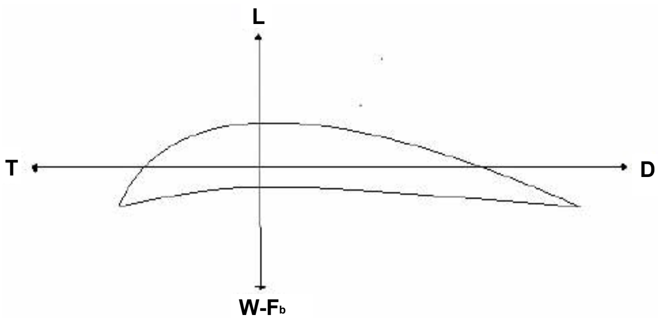

Figure 2: Representation of forces acting on aerofoil with buoyancy force.

to the weight. Thus while resolving components Fb is considered negative [3].

$$L=W-\left(\Sigma^{n}_{i=1}\left(\rho_{air}-\rho_{lift\text{-}i}\right)Vol_i \cdot g\right)$$

Generally, lift for a heavier than aerial vehicle is given by equation (8) [2].

$$L=(1/2)\rho V^2 SC_L=(1/2)\gamma pM^2 SC_L \qquad (8)$$

Equating equation (7) and equation (8) [1], it can be concluded that lift required to generate for a steady `1g' flight is lesser after buoyancy lift augmentation when compared to a heavier than aerial vehicle of same payload, structure and power plant systems.

Therefore, variable parameters such as velocity V and wing are S can be reduced as per changed force. Since wing area S is fixed value in many cases varying V is a suitably significant method.

$$(1/2)\rho V^2 SC_L=W-\left(\Sigma^{n}_{i=1}\left(\rho_{air}-\rho_{lift\text{-}i}\right)Vol_i\, g\right) \qquad (9)$$

Similar to lift and weight, thrust should be equal to drag. Thrust required for an aircraft should be equal to overall drag.

$$D=qS(C_D+KC_L^{\,2}) \qquad (10)$$

qSC_D is lift independent drag and almost constant. It is dented by D_Z. So, it can't be affected with any change in weight of the aircraft. Lift independent drag that is sum of induced drag and parasite drag.

Whereas lift dependent drag $qSKCL^2$ can be affected by weight. Moreover, K will be $1/\pi Ae$ for an in compressible flow.

$$D=(1/2)\rho V^2 S(C_D+KC_L^{\,2})=(1/2)\gamma pM^2 S(C_D+KC_L^{\,2}) \qquad (11)$$

Lift dependent drag is function of weight, Mach number and dynamic pressure which can be related as

$$D_i=K(W-F_b/S)^2/(1/2)\gamma pM^2 \qquad (12)$$

Flow over conventional sub-sonic aircraft is in-compressible and $K=1/\pi Ae$ when wing loading is elliptical across its span [1]. Thus equation (12) will be,

$$D_i=(1/\pi Ae(W-F_b/S)^2)/(1/2)\gamma pM_2 \qquad (13)$$

Lift independent drag Dz almost remains constant and total drag for subsonic aircraft will sum of lift dependent drag and lift independent drag [2].

$$D=D_z+D_i \qquad (14)$$

$$D=(1/2)\rho V^2 SC_{Dz}+(1/\pi Ae(W-F_b/S)^2)/(1/2)\gamma pM^2 \qquad (15)$$

Here equation (15) can be written in terms of $Y=1/2\rho C_{Dz}S$, $Z=(K)/(1/2\rho S)$, W is weight and V is velocity.

$$D=YV^2+Z(W-Fb)^2/V^2 \qquad (16)$$

Based on equation (16) minimum drag speed will be given differentiating it with equivalent air speed [1].

$$Vmd=(Z(W-Fb)2/Y)1/4 \qquad (17)$$

As lift independent drag and velocity are reduced total drag is reduced and dynamic pressure are decreased. Consequently, thrust required to produce by engine mill also be reduced. These will be illustrated on equation (18) which is an elaboration of equation (17) [1].

$$V_{md}=[2(W-F_b)/\rho S]^{0.5}[K/C_{Dz}]^{0.25} \qquad (18)$$

Since minimum drag speed is correspondent to thrust producing engine minimum power speed has to be calculated for power producing engine which is relatively proportional to minimum drag speed and can be given by equation (19) and equation (20) [1].

$$V_{mp}=V_{md}/3^{0.25} \qquad (19)$$

$$V_{mp}=[2(W-F_b)/\rho S]0.5[K/C_{Dz}]^{0.25}/3^{0.25} \qquad (20)$$

However the thrust required for level flight is product of drag and true air speed,

$$T=(D_Z+D_i)V \qquad (21)$$

As thrust required to be produced by power plant system is reduced and this indicates fuel efficiency. To reduce required thrust value there should be a decrement in velocity which can be accomplished by buoyancy lift augmentation. This indicates low mass flow rate and less fuel consumption. Therefore, fuel efficiency can have achieved without losing any considerable flight's aerodynamic characteristics.

Even though there are significant changes in aerodynamic forces and body forces the aerodynamic efficiency of hybrid aerial vehicles is same as aircraft of selected structure.

$$L/D_{min}=E_{max}=1/2[KC_{DZ}]^{1/2} \qquad (22)$$

Parameters K and C_{DZ} are independent of weight. So, varying weight may not influence aerodynamic efficiency.

Unsteady flight/accelerated flight

In an unsteady flight, such as ascent or while performing maneuvers space required to perform maneuvering is function of weight. Thus, for this case area required for performing maneuvers can written as,

$$Area_{req}=f(W-F_b) \qquad (23)$$

However, moments generated on each plane or axis may demand much higher force to set system into static and dynamic stability. Fb

Citation: Yuvaraj G, Veeranjaneyulu K (2016) Buoyancy Lift Augmentation. J Aeronaut Aerospace Eng 5: 175. doi: 10.4172/2168-9792.1000175

when observed flight and relative area in Newtonian frame of reference yields above conclusion regarding Eulerian frame of reference. Thus, symmetric system of forces are desired in distribution of buoyancy force is desired. So, area of loading for lighter than air gas must be opted carefully while filling gas such that it obeys equation 2 and equation 3 in axis or plane individually.

Effect of Altitude

As the altitude of aircraft increases the density of air decreases from sea level. If the density of lifting gas is equal to the density of air at certain height, then lift generated by buoyancy force can be concluded to be negligible. As the altitude increases there will decrease in weight due to increase in geocentric height which affects gravitational acceleration. These factors are analysed by a reference of ISA (International Standard Atmosphere) and a graph is plotted for buoyancy for as a function of altitude. This graph gives the maximum altitude till which buoyancy lift augmentation technique is liable to effective performance. This graph and table below shows that maximum altitude till which buoyancy lifts augmentation is effective. The following graph and table are applicable for the flight corridor of subsonic commercial aircraft. Subsonic commercial aircraft has maximum ceiling height of 35 Km as per civil aviation authority regulation (may slightly vary from 32-35 Km for each country based on climatic and geographical phenomena). Up to this altitude of 20 Km of altitude buoyancy lift augmentation is effective and lift force can generate by this type of lift augmentation. Table 1 shows that at 16 Km and 20 Km altitude buoyancy force generated by helium and hydrogen will become zero as the density of air and lifting gases is almost equal (Figure 3).

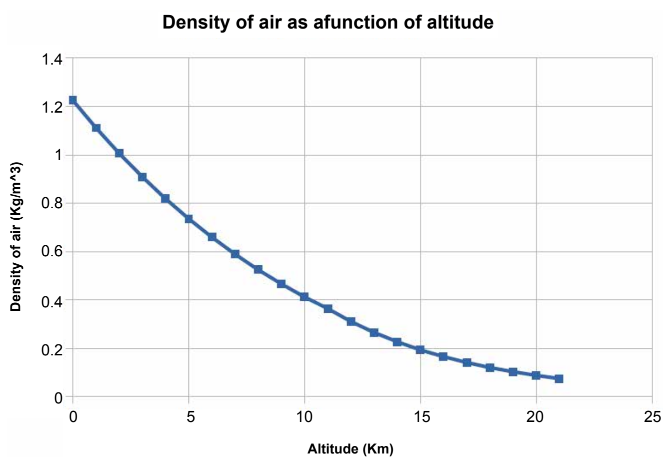

Figure 3: Change in density as a function of altitude.

Conclusion

Above results show that there won't be any buoyancy force as the density of air and lifting gas are nearly equal the difference between these will zero which can be observed from equation 1 and the decrease in gravitational acceleration will also contribute for this phenomenon. But the mathematical calculations show that within the altitude of 20 km from sea level it is effective. It will also help for heavy aircraft to ascent and take-off by affecting required thrust which will contribute for high specific thrust and low specific fuel consumption.

As aircraft weight and orientation is continuously changing it expected that the fluid particles inside the container tend to change in terms of path function and point function i.e. velocity, total pressure, temperature entropy and enthalpy. Their affect is assumed to be negligible here. But that case must be studied and analysed precisely for better understanding of this technique. Further emphasis must be done on thermodynamics of the fluid providing lift i.e., lifting gas and its relative parametric analysis with respect to flight dynamics long with effect of fluid on structural stability.

References

1. Li QM (2001) Strain energy density failure criterion. Int J of Solids and Structures 38: 6997-7013.
2. Eshelby ME (2000) Aircraft performance theory and practice. Butterworth Heinemann.
3. Anderson JD (2000) Introduction to flight. Tata Mcgraw-Hill Education Pvt. Print ISBN-10: 0073380245
4. Aeronautics (1924) Helium vs. Hydrogen. TIME.