Graduate Research in Engineering and Technology (GRET)

Volume 1
Issue 4 *Emerging Aerospace Technologies in Aerodynamics, Propulsion, and Materials.*

Article 13

January 2022

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K Ajay Kumar Goud
Institute Of Aeronautical Engineering, a6301864794@gmail.com

Y D Dwivedi
Institute Of Aeronautical Engineering, yddwivedi@gmail.com

Recommended Citation

Goud, K Ajay Kumar and Dwivedi, Y D (2022) "Effect of Twin Vertical Stabilizers on Lateral Directional Static Stability of an Aircraft – A Computational Study," *Graduate Research in Engineering and Technology (GRET)*: Vol. 1 : Iss. 4 , Article 13.
DOI: 10.47893/GRET.2022.1057
Available at: https://www.interscience.in/gret/vol1/iss4/13

Effect of Twin Vertical Stabilizers on Lateral Directional Static Stability of an Aircraft – A Computational Study

Y D DWIVEDI[a], K AJAY KUMAR GOUD[a*].

Department of Aeronautical Engineering, Institute of Aeronautical Engineering, Dundigal, Hyderabad, Telangana 500043, India.

Email: yddwivedi@gmail.com, a6301864794@gmail.com.

Abstract

The advantages of twin vertical Stabilizers over a single vertical Stabilizer of an aero plane are the rationale for this study. For conventional aero planes, the use of double vertical Stabilizers is being considered. The contribution to lateral stability has been examined for this application. XFLR5 software was used to conduct the overall analysis. The analysis was conducted for a single vertical Stabilizer as well as twin vertical Stabilizers, and the findings were compiled and correlated. It is critical to be able to fully explain and evaluate the stability and control parameters. It is crucial to understand the relationship between the aerodynamics of the airframe and its stability characteristics in order to increase flight endurance and deployment effectiveness. The stability analysis based on the dynamic model of the twin boom vertical Stabilizer is presented in this paper. The lateral-directional stability of an aero plane with a single vertical tail is determined to be 20% more efficient than that with twin boom vertical Stabilizers. The trim condition is moderately satisfied by an aircraft with twin vertical Stabilizers.

Key words: *Stability and control, Dynamic stability, Twin boom vertical stabilizers, Aerodynamic and stability characteristics*.

Introduction

This paper investigates the stability of airplanes with twin boom vertical fins. The stability of the vertical stabilizer was investigated with the XFLR5. It focuses primarily on lateral-directional stability and has been tested for various sideslip angles (β). Stability refers to the ability of an aircraft to correct for situations such as turbulence or flight control inputs. In another sense, stability refers to the ability of an aircraft to maintain its selected altitude. There are two types of general stability for an aircraft: static and dynamic. We only care about performance in civil aircrafts, not stability, but this does not negate the need of stability in civil aircrafts, particularly in extreme conditions such as weather and bird strikes. An aircraft is considered to have static stability if it has an "initial tendency" to return to equilibrium. Static equilibrium occurs whenever the aircraft is not accelerating. The aircraft design was built using NACA 2415 for the wing and NACA 0009 for the vertical and horizontal stabilizers. Key aerodynamic characteristics such as lift (L), drag (D), the moment (M) and their coefficients are found with different angles of attack (α) and different speeds. The (L / D) ratio, which is the most important aerodynamic characteristic for profile selection, was also found in this study (Dwivedi et.al 2017, Dwivedi and Bhargava, 2019). The static stability of all wings tested in the wind tunnel is calculated according to the following criteria (Dwivedi et.al, 2013). The experimental and CFD work was performed by Bhargava et.al 2017 on multi element analysis of the airfoil.

Static stability criteria:

An aircraft is considered to have static stability if it has an "initial tendency" to return to equilibrium. Static equilibrium always occurs in the absence of aircraft acceleration (linear or angular). For example, if you look at a rigid aircraft with fixed controls, the elevator is in a fixed position. Suppose the aircraft has been tested for free flight and its variations in XFLR5 software. The pitching moment with respect to the centre of gravity (Mcg) with the angle of attack was measured. Value of moment coefficient with respect to the centre of gravity (CM.cg). For zero lift ($\alpha0 = 0$), it is specified in CM.0. The value of $\alpha0$ when Mcg = 0 is represented by αe. This is balance or trim angle of attack. Even though the aircraft is in the trim position, the angle of attack changes when gusts cause disturbances. There may be chance to increase angle of attack or decrease in angle of attack. If the wing is tilted upwards, $\alpha a > \alpha e$, in this state the moment around cg is negative, Negative moments are counter clockwise, The profile tends to return to its original state because it tends to tilt the nose down. [ref YD DWIVEDI, M Satya Prasad, Sweta Dwivedi]. On the other hand, if the aerofoil is tilted downward due to a gust, $\alpha a < \alpha e$. The resulting moment around the centre of gravity is positive (clockwise) and tends to tilt the nose up. So, we have the situation again This tends to cause the wing profile to initially return to equilibrium (trim state) after disturbance. From this, we conclude that the wing with positive to negative fluctuations in CM.cg (airplane wing) is statically stable compared to αa. The criteria required for vertical balance and static stability are:

1. C_{M0} must be positive.
2. $C_{M\alpha}$ must be negative.

Methodology

Before designing an aircraft, make sure that loading aerofoils on the XFLR5 is a primitive task. Here, the NACA 2415 aerofoil was loaded by performing an X foil design, and NACA 0009 was selected from the NACA foil from the XFLR5 itself. The NACA 2415 aerofoil was constructed with a root chord length of 90 mm, a tip chord length of 55 mm and a span of 500 mm. Empennage system is being constructed by using NACA 0009 aerofoil. The aerodynamic characteristics of an aircraft were obtained by defining an analysis in XFLR5. The ring vortex method (VLM2) is used to define the analysis of aircraft. There are two methods for XFLR5, VLM1 and VLM2. VLM1 uses a horseshoe-shaped vortex on each panel, with two side-drag vortices extending infinitely downstream. VLM2 uses four side vortices on each panel, with only the rearmost panel vortices extending indefinitely. These are alternative methods that give similar results in most cases. I noticed that they diverge especially when a body is included in the scan. It is recommended to use VLM2.

Our model aircraft must be tuned to function, but also stable and controllable. Stability analysis is a feature of "empty-handed testing"

Flight control analysis measures an aircraft's responses to pilot instructions. To some extent, this can be solved by simulation. An option was added in XFLR5 v6 for this purpose.

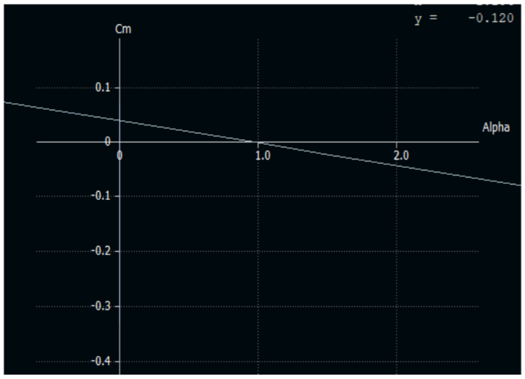

Fig 1. Coefficient of moment Vs Angle of attack

To perform analysis of dynamic stability it should be statically stable, this can be understood by observing C_m vs α graph (fig .1). The negative slope indicates that the aircraft tends to make its nose down. Since we were used NACA 2415 which cambered aerofoil to design wing generate lift even at zero angle of attack.

The condition for the aircraft to have static stability for certain trim conditions is that the Cl vs. Alpha plot has a positive gradient.

See fig .2.

Obviously, a very wide range of gradient values is possible, and the magnitude of the gradient determines the degree of stability of this aircraft. Changes in the degree of static longitudinal stability it is shown in Figure 2. This is the central tendency of gravity moving forward from the natural point of the aircraft is high.

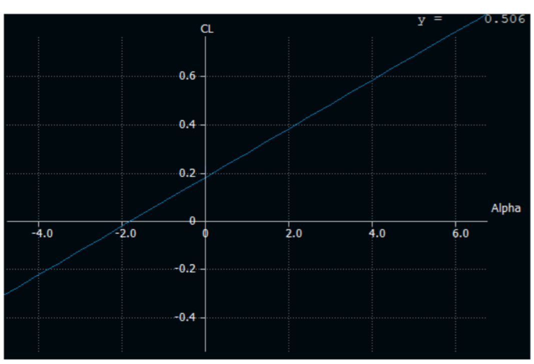

Fig 2. Coefficient of lift Vs Angle of attack

Directional Stability:

There is no contribution of the wing to the directional static stability if it does not have a sweep. For the contribution of the vertical stabilizer, 2 units were considered as 1 unit. For a single unit,

Slope of the coefficient of lift ($C_{L\alpha v}$) = 0.045 degree^{-1}.

$MAC = rc \times 2/3 \times ((1 + t + t^2) \div (1 + t))$

t = taper ratio, rc = root chord

mean aerodynamic chord = 0.050 m

area (S_v) = 6 m^2

Aerodynamic centre = 8.44% of the mean aerodynamic chord.

Distance from cg to the aerodynamic centre (L_{vt}) = 0.650 m.

It is assumed that the vertical stabilizer subjected to the same dynamic pressure. Then the slope of the coefficient of yawing moment as a function of the side slip angle due to the vertical stabilizer is

($C_{n\beta}$) = 0.003125 degree^{-1}.

The entire slope of the yawing moment coefficient with sideslip angle ($C_{n\beta}$) was found to be 0.003100 degree^{-1}.

Lateral Static Stability:

The overall slope of the coefficient of rolling moment due to vertical stabilizer ($C_{l\beta v}$) was found to be - 0.03125 degree^{-1}. I decided to keep the dihedral angle of 5 degrees to improve lateral stability. Rolling coefficient slope moment due to the wing ($C_{l\beta w}$) was found to be -0.1 rad^{-1} or – 0.00176 rad^{-1}.ref (Kamal Darlami[1], Aditya Amatya[2], Bikash Kunwar[2], Sanjeeb Poudel[2]*, Ujwal Dhakal[2] [1]Assistance Professor, [2]Graduated students).

The analysis was performed at a fixed free flow rate (15 m / s). In addition, there are other alternative modes for performing analysis

- Fixed angle of attack (aoa).
- Fixed lift
- Beta range.

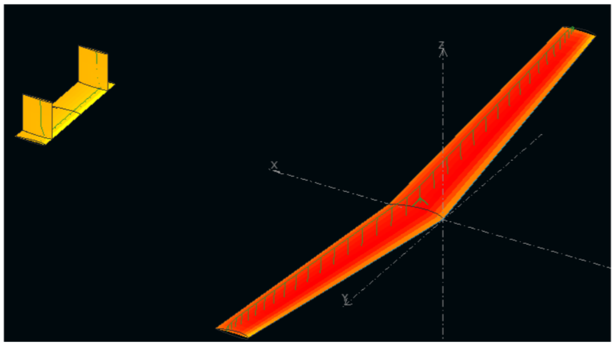

Fig 3. Simulated model in XFLR5.

Measurements of pressure distribution across the chords of an aircraft wing in flight are often performed during flight tests and flight research programs for new aircraft designs. The importance of the measurement lies in the ability to numerically predict the pressure distribution and / or check all wind tunnel tests performed on the scale. By measuring the air pressure distribution, it is possible to calculate the flight load, and the aircraft can the structure works within the design load conditions.

V	=	15.00 m/s
Alpha	=	0.000°
Beta	=	0.000°
CL	=	0.178
CD	=	0.001
Efficiency	=	0.908
CL/CD	=	221.479
Cm	=	0.037
Cl	=	0.000
Cn	=	0.000
X_CP	=	38.168 mm
X_CG	=	53.506 mm

Fig 4. Aerodynamic Characteristics.

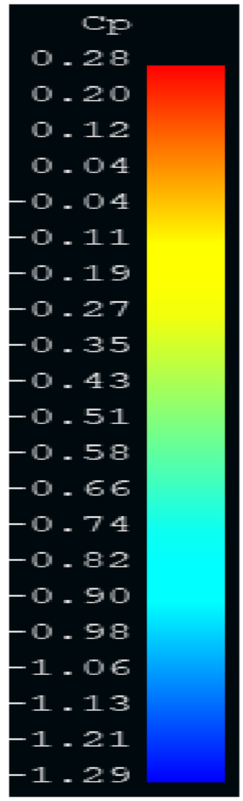

Fig .3. Pressure distribution.

If the analysis is defined using the beta region type, the sequence toolbar requests the beta region from start to finish. The wing planform was used as the reference dimension for xflr5. The shape of the wing when viewed from directly above is very important in dealing with three-dimensional airflow and understanding the performance and flight characteristics of aircraft wings. In the simplest sense, it is a reduction in chord or wing thickness from the root of the wing to the tip of the wing.

Plane Name		
Wing Span	=	1000.000 mm
xyProj. Span	=	996.195 mm
Wing Area	=	72500.000 mm²
xyProj. Area	=	72224.116 mm²
Plane Mass	=	1330.000 g
Wing Load	=	0.018 g/mm²
Tail Volume	=	1.105
Root Chord	=	90.000 mm
MAC	=	73.908 mm
TipTwist	=	0.000°
Aspect Ratio	=	13.793
Taper Ratio	=	1.636
Root-Tip Sweep	=	3.005°
XNP = d(XCp.Cl)/dCl	=	84.673 mm
Mesh elements	=	690

The most common planform for low-speed aircraft is the straight wing and its variations. In contrast, for high-speed (transonic or supersonic) aircraft, the usual planform is a swept wing and, more rarely, a delta wing. After determining the stability analysis, we are given four modes in which we can animate different rolls to clearly understand the damping of an aircraft until it stable. The same analysis of lateral-directional stability is being defined for an aircraft with single vertical tail. The results obtained in xflr5 were compiled and correlated. The analysis of the spring lateral stability is carried out for this aircraft (twin boom vertical fins) on XFLR5 simulation environment. Then flying in equilibrium at 8000 ft, head angle decreased by 2° due to unforeseen circumstances, unexpected perturbation and stability of the lateral spiral mode are described as follows. When the aircraft is in steady state, the roll rate and yaw rate are zero. But, for sudden head angle deviations, they oscillate and gradually return to zero in a very short time. The results are shown in the figure below.

A well-designed aircraft should be tested for an odd number of 20 various modes for stability. Among those 20 and 4 natural longitudinal modes and 4 natural lateral modes the most important thing.

Aircraft with twin boom vertical fins response for lateral-directional stability modes:

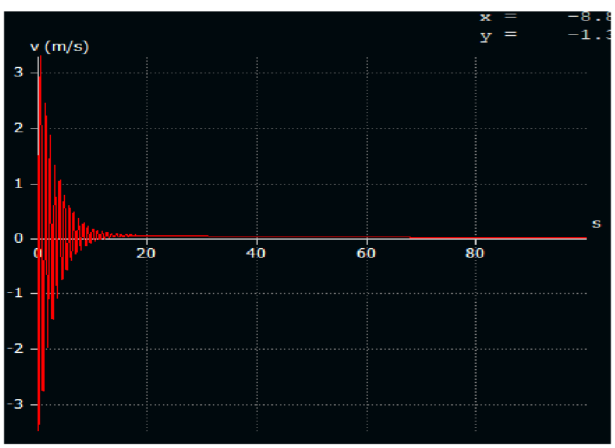

Fig 4 . Response to disturbance (v(m/s) Vs T(sec)), Lateral speed variation v= dy/dt about the steady state value V = (U_0,0,0)

Some decay is seen before the aircraft stabilizes. The number of attenuations per second, called frequency.

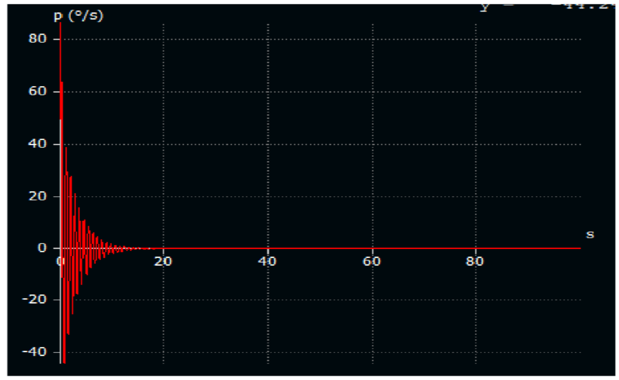

Fig 5. Roll rate deviation P = dθ/dt, r

response to disturbance (P(°/s) vs T(sec)).

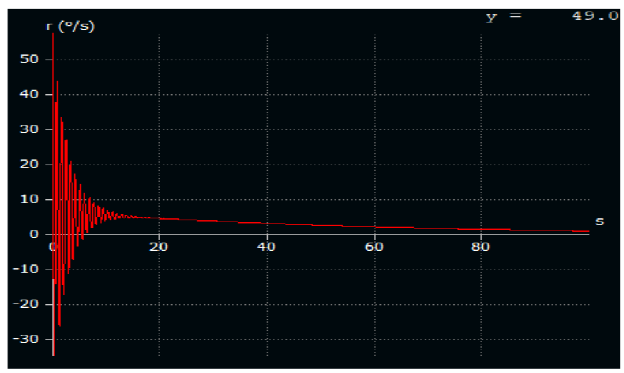

Fig 6 . Yaw rate variation r = dψ/dt, Response to disturbance (r(°/s) vs T(sec)).

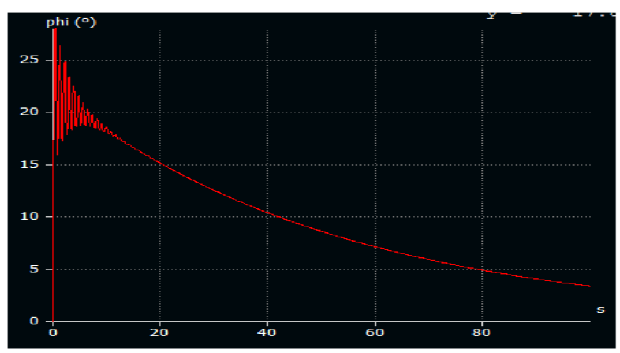

Fig 7. Heading angle variation φ, Response to disturbance (phi(°) vs T(sec)).

Aircraft with single vertical tail response for lateral-directional stability modes:

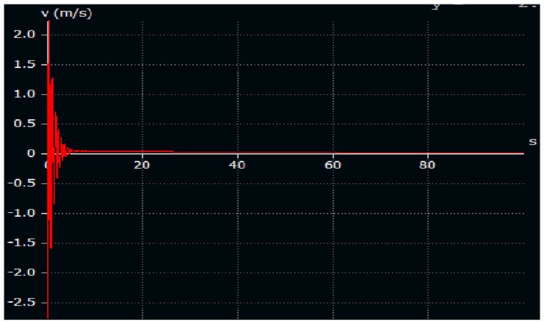

Fig 8. Response to disturbance (v(m/s) Vs T(sec)). =, Lateral speed variation v= dy/dt about the steady state value V = (U_0,0,0)

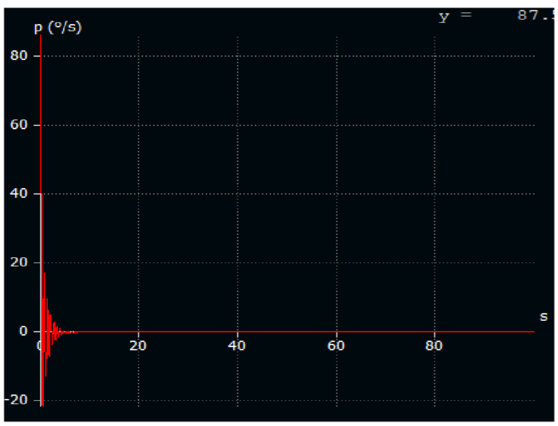

Fig 9. Roll rate deviation P = dθ/dt, Response to disturbance (P(°/s) vs T(sec)).

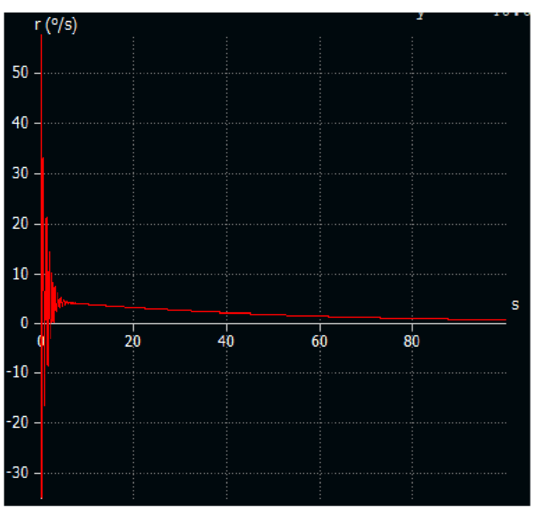

Fig 10. Yaw rate variation r = dψ/dt, Response to disturbance (r(°/s) vs T(sec)).

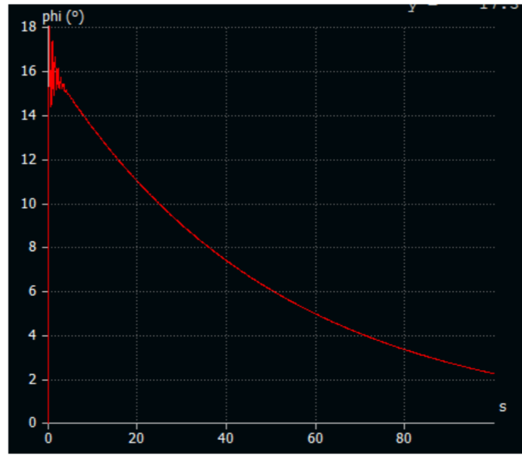

Fig 11. Heading angle variation φ, Response to disturbance (phi(°) vs T(sec)).

Conclusion

Based on this stability analysis of an airplane with a double-boom vertical stabilizer, it has been shown that the lateral stability of an airplane with a double-boom vertical stabilizer is less effective than that of an airplane with a single fin. Aircraft with twin vertical fins were exposed to more vibration to maintain stability than aircraft with single vertical fins.

It did not meet the adjusted requirements for basic stability and control characteristics. The main problem was the centre of pressure, and the centre of gravity was mistaken for a natural point. Therefore, a temporary slight imbalance in climbing may not be stable. Obviously, the gradient from 5^0 to $5^0$was zero, which was positive at 7^0. Therefore, it is unstable when climbing.

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