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Research Article

# Analysis of Commercial Aircrafts Based on Maneuverability Condition

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***Abstract***— Performance estimation of an aircraft is required to make sure of the ability of the aircraft to perform conventional and mission specific maneuvers. An aircraft's maneuverability is defined by its capability to alter attitude and speed along its three axes: longitudinal, lateral, and vertical. To acquire the performance of the aircraft for the establishing the operational envelope, initial operation certification and gradual expansion of the flight envelope, an aircraft system is studied directly by conducting some experiments with it or by using its mathematical model. Nowadays, mathematical modelling is more preferred over real flight testing as rehearsal of several situations cannot be practiced in real life. Further, drastically reduced training costs and increased efficiency of the required results. The conceptual model of the specific static maneuvers of the aircrafts can be converted to computer model via programming in a flight simulator such as Matlab, which then simulates the reality. The maneuvering capabilities of an aircraft are decided according to the mission to be performed. Therefore, the commercial passenger aircrafts are more stable and less maneuverable compared to the commercial transport and the military aircrafts, designed so keeping in mind the passenger safety and security as the foremost aim. Hence, it becomes very important to estimate the responses of a commercial aircraft for the maneuvers it performs under its operational flight envelope. Such estimation firstly requires a study of these maneuvers. Secondly, converting them into a matrix model and then simulating them in the Matrix Laboratory to obtain the required results for further analysis to arrive at conclusions. The conclusions required from the flight simulator are the coefficient of lift, drag; load factor, velocity and time estimation for a particular maneuver that an aircraft is capable to perform.

***Keywords***— Maneuverability, Longitudnal, Lateral, Load factor, Operational envelope

## 1. Introduction

From the very beginning of the era of the Wright brothers who were responsible for first heavier than air flight. In less than a hundred years, airplanes have become crucial for national defense and commercial transportation. The Wright brothers' success was due to historical flight data, wind tunnel experiments, and flight tests from their contemporaries. They realized, through studying others' work and conducting their own experiments, that the main challenge for earlier generations in achieving powered flight was the insufficient control over the aircraft. Although the gliders designed earlier were inherently stable but they lacked maneuverability. Contrary, to which Wrights successful airplane was unstable and but quite maneuverable [1]. Therefore, they focussed much on improving the control capabilities of their gliders. Hence, powerful controls were essential for the pilot to maintain equilibrium and prevent accidents, which usually took place with many glider enthusiasts before the Orville and Wilbur Wright (1). An aircraft's maneuverability is defined by its capability to alter its attitude and velocity around its three axes: longitudinal, lateral, and vertical. This involves the skilled maneuvers or procedures a pilot uses to attain a desired position or move towards a predetermined goal (2). For an airplane to successfully complete its mission [2], it must meet two conditions: it must be capable of achieving equilibrium flight, and it must be able to maneuver across a wide range of flight velocities and altitudes. Typically, the flight envelope is more restricted for commercial aircraft compared to transport and military aircraft, as each type is designed for different missions. Consequently, their maneuvering characteristics vary. To achieve equilibrium and perform maneuvers, airplane must be equipped with efficient aerodynamic and propulsive controls. Commercial aircrafts have relatively quite less maneuverability in comparison to the fighter aircrafts ensuring the sufficient stability of the aircraft to make sure of the safety of the passengers during the whole mission , while fighter aircrafts rated in the order of the ease of performing the large scale tactical exercise under simulated conditions of war [3]. Usually, pilots form opinions about the airplanes on the basis of its handling characteristics. Airplanes with poor maneuverability are difficult to fly and an attempt to handle them can be fatal for both the aircraft and the pilot.

### *1.1 Datasets*

For the level turn experiment was performed on a two Seater aircraft of weight *W*= 6300 Kg, surface area of wing *s* = 25.08 $m^2$, aspect ratio= 10.017 in Cranfield Jetstream laboratory for the following data listed in the table below.
Unit of velocity is m/$sec^2$, bank angle and angle of attack is radians; and pitch rate is rad/sec. [4]

**Table1.** Velocity versus bank angle (2)

| V(velocity) | μ(bank angle) |
|---|---|
| 51.5 | 15.00 |
| 59.2 | 10.41 |
| 66.9 | 7.94 |
| 74.7 | 5.41 |
| 82.4 | 4.33 |
| 90.1 | 3.11 |
| 97.8 | 2.30 |
| 105.5 | 1.55 |
| 113.3 | 1.05 |
| 121.0 | 32.3 |
| 128.7 | 44.1 |

While for pull up and pull down maneuvers the data listed in the tables 2&3 below, relates to the changes in velocity with angle of attack at different pitch rates, performed for a two Seater aircraft Hansa of weight, *W* = 9500 kg, surface area of wing s = 10.47$m^2$ in IIT Kanpur flight Laboratory. [5]

**Table 2.** Pitch rate versus velocity at different angle of attack for pull up maneuver.

| Q(pitch rate) | V(velocity) | α angle of attack |
|---|---|---|
| 0.16 | 44 | 0 |
| 0.29 | 47 | 0.5 |
| 0.41 | 51 | 0.7 |
| 0.59 | 53 | 1.2 |
| 0.78 | 56 | 1.8 |
| 1.00 | 57 | 2.2 |
| 1.08 | 59 | 2.8 |
| 1.47 | 60 | 3.0 |

**Table 3.** Pitch rate versus velocity at different angle of attacks for pull down maneuver.

| Q(pitch rate) | V(velocity) | A angle of attack |
|---|---|---|
| 1.08 | 41.4 | -2 |
| 1.20 | 41.8 | -3 |
| 1.33 | 42.3 | -4 |
| 1.42 | 43.5 | -5 |
| 1.51 | 45.8 | -6 |
| 1.72 | 46.3 | -7 |
| 1.84 | 46.9 | -8 |
| 1.92 | 47.2 | -9 |
| 2.00 | 49.6 | -10 |
| 2.12 | 51.7 | -11 |
| 2.20 | 52.4 | -12 |

## 2. Methodology

### *2.1. Level turn*

By definition, A level turn is a maneuver where the curved flight path is in a horizontal plane parallel to the ground, maintaining a constant altitude [4]. The two most crucial performance characteristics in turning are the turn radius (R) and the turn rate, which is the local angular velocity of the airplane along the curved flight path. The roll angle is determined solely by the load factor; knowing one allows you to determine the other [5], [6]. The turn performance of an aircraft depends on the load factor. To achieve the smallest possible turn radius and the highest possible turn rate, the goal is to have the highest load factor and the lowest velocity. Using the below equations with corresponding values for a two Seater commercial aircraft tested in Cranfield Jetstream laboratories [2], the dataset for velocity and bank angle mentioned in table 1 and corresponding plot shown in Figures we obtain the drag polar performance , load factor envelope, drag-velocity values and thrust requirements for exhibiting a level turn. [7], [8]

$$C_L = \frac{L}{0.5\rho s v^2} \quad \ldots\ldots\ldots\ldots (1)$$

$$D = 0.5\rho v^2 s C_d \quad \ldots\ldots\ldots\ldots (2)$$

$$C_d = C_{d0} + k.C_L{}^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where $C_{d0} = 0.03$; $k$= 0.045;

$$T\cos\beta - D = 0 \quad \ldots\ldots\ldots\ldots (4)$$

$$L\cos\mu - W = 0 \quad \ldots\ldots\ldots\ldots (5)$$

$$T\sin\beta + l\sin\mu = Wv^2/gR \quad \ldots\ldots (6)$$

$$n = L/W \quad \ldots\ldots\ldots\ldots (7)$$

$$V = \sqrt[2]{[(2n*w)/(\rho*s*C_L)]} \quad \ldots. (8)$$

$$R = (v^2/g(\tan\mu + T\sin\beta/W) \quad .. (9)$$

$$\tan\mu = (v^2/Rg) - (T\sin\beta/W) \quad (10)$$

$R =$ Radius of turn;
$C_L$ = coefficient of lift;
$\rho$ =density;
$v$ = flight velocity;
$C_d$ =drag coefficient;
$T$ =thrust;
$\beta$ =side slip;
$W$ =Weight;
$\mu$ =bank angle;
$k$= induced drag factor;
$C_{d0}$ = induced drag factor.

### *2.2. Pull-up maneuver*

It is the curved flight in the vertical plane normal to ground plane marked by increasing angle of attack. In the pull-up During a maneuver, the change in an aircraft's angle of attack can be related to its lift coefficient. In a pull-up maneuver at constant velocity, the aircraft's angle of attack changes to achieve the required load factor. This change in lift coefficient, necessary for maneuvering at high load factors with constant velocity, arises from two sources: the increase in load factor and elevator deflection [9]. Although the change in lift due to elevator deflection is often considered minor compared to the total lift, it will be included for a more comprehensive analysis. The aircraft maintains equilibrium at a certain lift coefficient before the elevator is deflected to initiate the pull-up. If the elevator is treated as a flap, its deflection will alter the lift curve as follows: when the elevator is deflected upward, the lift curve shifts downward without changing its slope, indicating an initial loss of lift. [10] This loss in lift due to elevator deflection is designated. The aircraft continues to pitch upward and increase its angle of attack until it reaches a new lift coefficient and an equilibrium load factor. Using the below equations with corresponding values for a two Seater commercial aircraft tested in IIT Kanpur flight laboratory, we obtain the drag polar performance , load factor envelope, drag-velocity values and thrust requirements for exhibiting a pull up maneuver. [11]

Turn radius=$R$; pitch rate $q = \partial\theta/\partial t$ ; Roll angle $\phi = 0$ ; $\theta = 0$ instantaneous pull up starting from straight and level flight

$$Mv^2 / R = L - W \quad \text{.................. (11)}$$

$$L = [(v^2 / Rg) + 1]W \quad \text{.................. (12)}$$

$$n = 1 + v^2 / Rg \quad \text{......................... (13)}$$

$$q_{PULLUP} = g(n-1)/v \quad \text{..................(14)}$$

***2.3. Pull down maneuver***

In straight and level flight, lift (L) equals weight (W). When the pilot suddenly pitches the airplane down to a lower angle of attack, the lift decreases sharply, and the flight path becomes inverted in the vertical plane with a turn radius (R) and turn rate. This is known as a pull-down maneuver. In a pull-down maneuver, the roll angle is zero. The main difference between pull-up and pull-down maneuvers is the sign in the equations; otherwise, they are similar. Additionally, as with a level turn, the turn radius and turn rate for both pull-up and pull-down maneuvers depend solely on the flight characteristics of velocity and load factor. Using the below equations with corresponding values for a two Seater commercial aircraft tested in IIT Kanpur flight laboratory, we obtain the drag polar performance, load factor envelope, drag-velocity values and thrust requirements for exhibiting a pull down maneuver. [12]

$$L = W(v^2 / Rg - 1) \quad \text{............ (15)}$$

$$n = v^2 / Rg - 1 \quad \text{............. (16)}$$

$$q_{PULLDOWN} = g(n+1)/v \quad \text{....... (17)}$$

## 3. Results

**3.1 Result 1: Cranfield Jetstream laboratory**

The results obtained for level turn performed in Cranfield Jetstream laboratories are as follows:

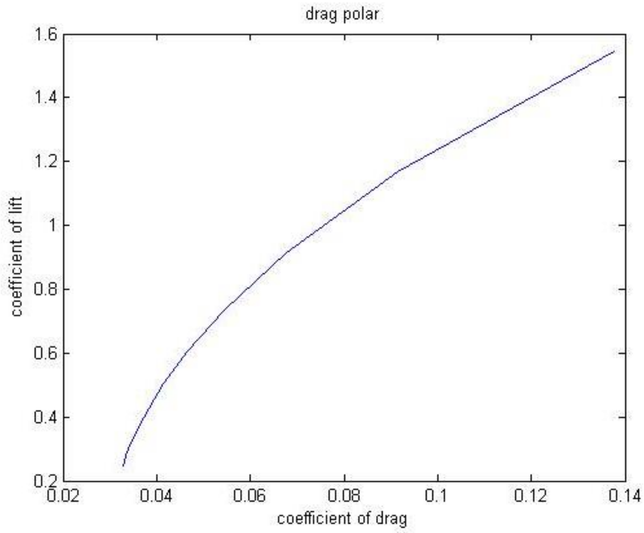


**Figure.1.** Drag polar: $C_L$ versus $C_d$ for level turns.

The drag polar estimation curve exhibits the standard shapes same as exhibited by aircrafts under straight and level flight. The drag polar estimation curve shows the typical shapes seen in aircraft during straight and level flight.

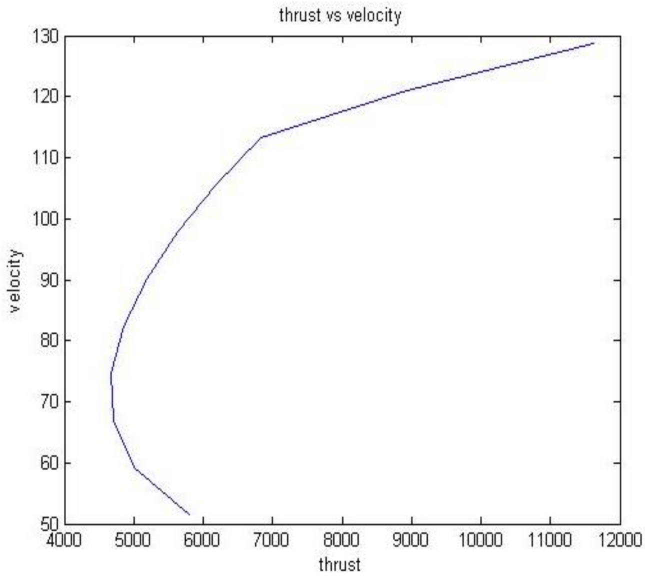


**Figure.2.** Thrust versus velocity variation for level turn.

With increase in velocities the thrust keeps on decreasing. But when aircraft turns, then due to sideslip a component of thrust balances the drag produced hence thrust increases. As velocities increase, the thrust decreases. However, when the aircraft turns, the sideslip causes a component of thrust to balance the drag produced, resulting in an increase in thrust. [13]

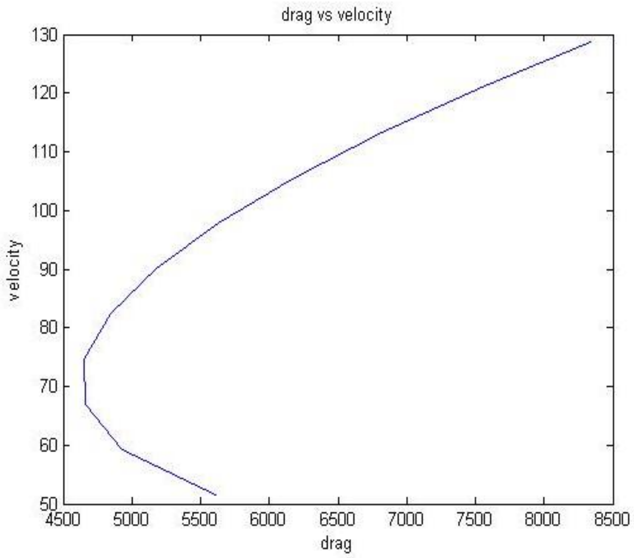


**Figure.3.** Velocity versus drag graph for level turns.

With increase in velocity drag first decreases to a minimum then rises drastically in a level turn.
As velocity increases, drag initially decreases to a minimum and then rises sharply during a level turn.

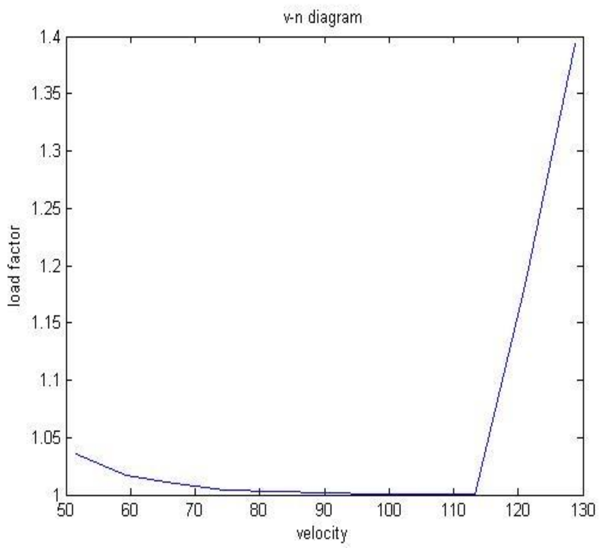


**Figure.4.** *V-n* diagram for level turn flight.

With increase in velocity the load factor first decreases, but then after a certain velocity a drastic increment in load factor value is observed. As velocity increases, the load factor initially decreases, but beyond a certain speed, a significant rise in the load factor is noted.

### *3.2 Results 2: IIT Kanpur Flight Laboratory (pull up maneuver)*

The results obtained for pull up performed for *Hansa aircraft* in IIT Kanpur flight laboratory are as follows:

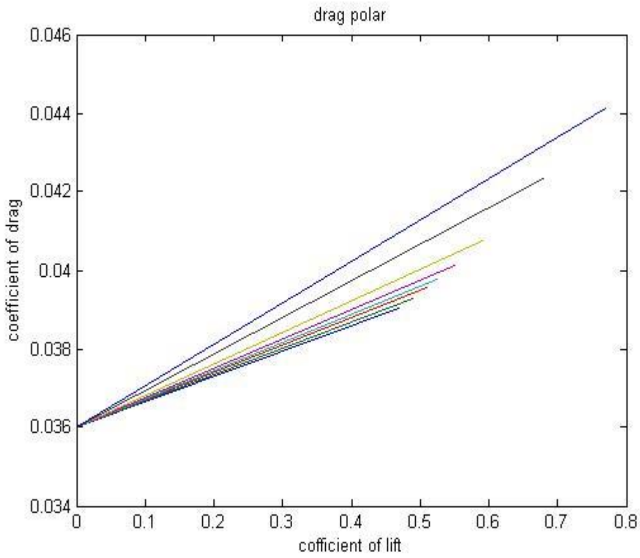


**Figure.5.** $C_L$ versus $C_d$ at different angle of attacks for the pull up maneuver.

The $C_L$ / $C_d$ ratio increases with increase in the pitch rate for pull up maneuver.

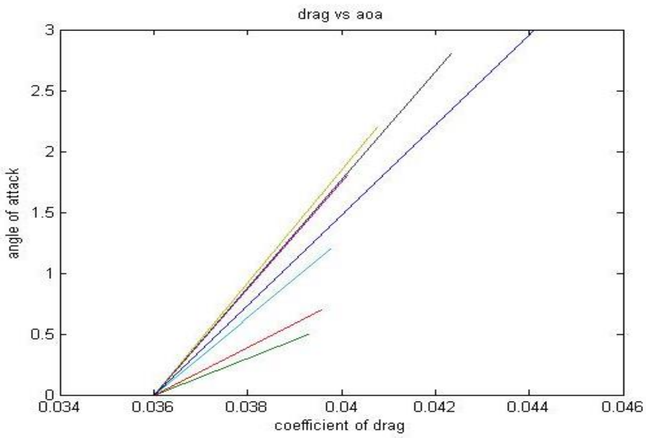


**Figure .6.** $C_d$ versus angle of attack for pull up maneuver at different pitch rates.

As the angle of attack increases the amount of coefficient of drag also increases.

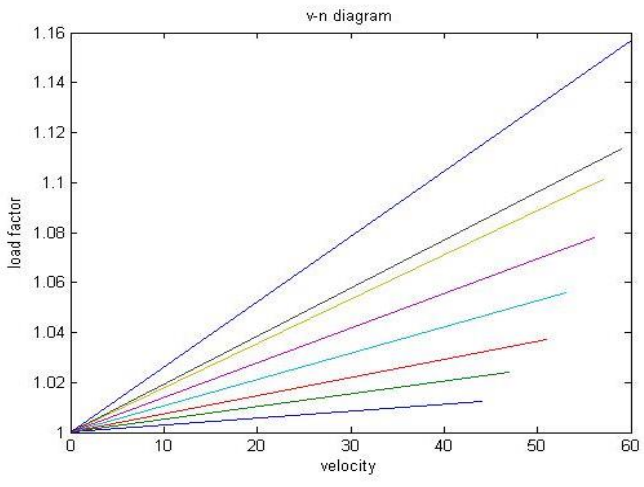


**Figure.7.** *v-n* diagram at different angle of attacks for pull up maneuver.

With increase in velocity for a particular angle of attack , the load factor increases as lift increases and hence the load factor accounting for higher pitch rates and hence high maneuverability under increase in angle of attacks and corresponding velocities.

As velocity increases for a given angle of attack, the load factor rises due to the increase in lift. This results in a higher load factor, considering higher pitch rates and therefore greater maneuverability at increased angles of attack and corresponding velocities.

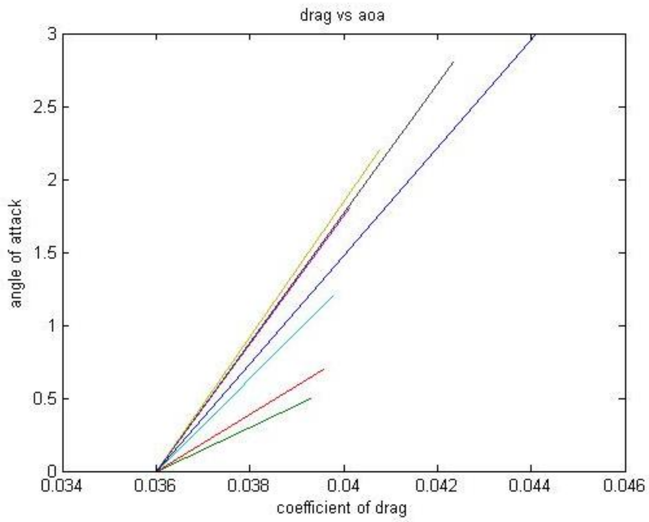


**Figure .8**. $C_d$ versus angle of attack for pull up maneuver at different pitch rates.

As the angle of attack increases the amount of coefficient of drag also increases.

***3.3 Results 3*****:** ***IIT Kanpur Flight Laboratory (pull down maneuver)***

The results obtained for pull down maneuver performed for *Hansa aircraft in IIT Kanpur flight laboratory* are as follows:

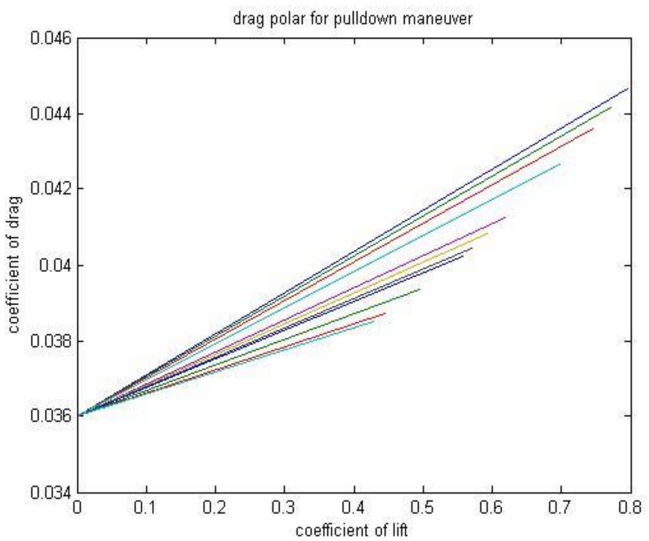


**Figure.9.** $C_L$ versus $C_d$ for different angle of attacks for pull down maneuver at different pitch rates.

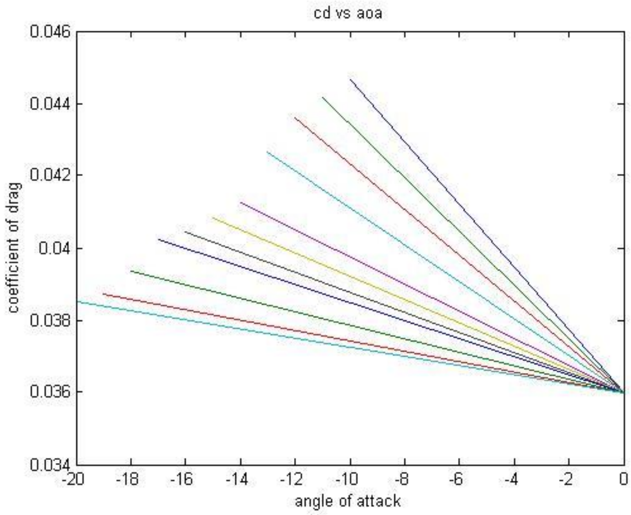


**Figure.10.** $C_d$ versus angle of attack

Coefficient of drag increases with increase in negative lift angle of attacks at different pitch rates.

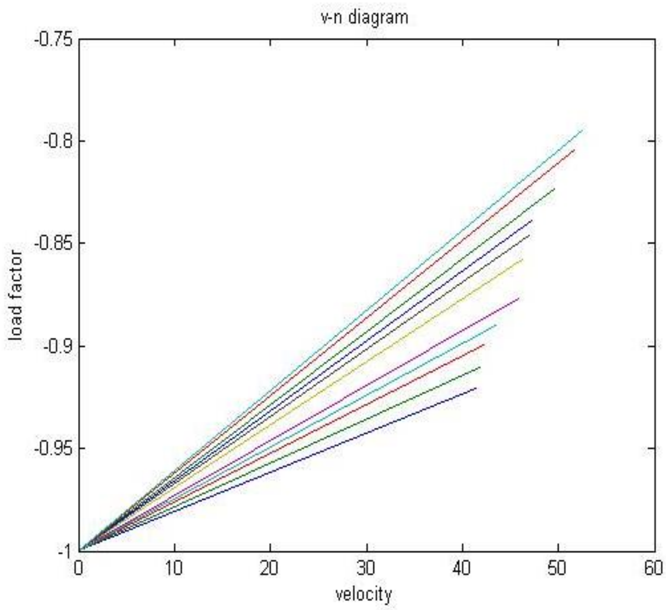


**Figure.11.** *V-n* diagram for pull down maneuver at different angle of attacks.

Hence an increase in negative angle of attack accounts for higher pitch rates.

## 4. Conclusion

In level turn graphs different colours of line depicts for different values of bank angle. While, in pull up and pull down graphs different colours of line depicts the different pitch rates. To obtain the largest possible turn rate, we want the highest possible load factor and the lowest possible velocity. From the graphs of level turn flight for Cranfield jet stream aircraft the minimum turn radius comes out to be 265 meters. For pull up maneuver minimum turn radius of HANSA aircraft in IIT Kanpur laboratory comes out to be 87 meters with corresponding maximum pitch rate of 1.47deg/s. For pull down maneuver minimum turn radius of HANSA aircraft comes out to be 84 meters with corresponding maximum pitch rate of 2.02 degree/s.

Therefore, commercial passenger aircraft are designed to be more stable and less maneuverable compared to commercial transport and military aircraft, with passenger safety and security being the primary focus. Estimating the responses of a commercial aircraft during maneuvers within its operational flight envelope is crucial. This estimation process involves, first, studying these maneuvers and then converting them into a matrix model. Next, the maneuvers are simulated in the Matrix Laboratory to obtain the necessary results for further analysis. The conclusions drawn from the flight simulator include the coefficients of lift and drag, load factor, velocity, and time estimation for a specific maneuver the aircraft can perform.

**Conflict of Interest**
No Conflict of Interest

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**Author's contribution**
Dr Raja Munusamy is contributed the - study conception and design, data collection, analysis
Dr Sudhir Kumar Chaturvedi is contributed the - analysis and interpretation of results
Mrs Kokila Vasudevan - is contributed the Literature review and manuscript preparation

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