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Engine Failure During Takeoff In Twin Engine A/C

Thesis Submitted inPartial Fulfillment of the Requirements for the Degree of Bachelor of Engineering. (BengHonor)

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الآية

قال تعالي:(وَلَوْ يُؤَاخِذُ اللَّهُ النَّاسَ بِمَا كَسَبُوا مَا تَرَكَ عَلَىٰ ظَهْرِهَا مِن دَابَّةٍ وَلَٰكِن يُؤَخِّرُهُمْ إِلَىٰ أَجَلٍ مُّسَمًّى ۖ فَإِذَا جَاءَ أَجَلُهُمْ فَإِنَّ اللَّهَ كَانَ بِعِبَادِهِ بَصِيرًا)

سورة فاطر (45)

ABSTRACT

This project study the condition of twin engine air craft during takeoff , at one engine failure ,This causes several negative effects on A/C, in addition to the loss of engine thrust ,the performance and stability are changes.

A simple ,uncomplicated ,high resolution system has been proposed ,operating automatically without outside interference , where it works to determine the balance of the plane when the malfunction occurs, calculated the angles of the required control surfaces and execute the desired for balance of A/C , the angles and moments required for the plane equilibrium was calculated by scientific steps, computer applications were used to explain the relation between the variables required to operation of the system the results of the calculations were acceptable in comparison to the results required for the balance of the aircraft .

التجريد

يهدف المشروع لدراسة حالة الطائره ذات المحركين اثناء الاقلاع في حالة حدوث فشل لأحد المحركين(انهيار المحرك)، وهذا يسبب العديد من الاثار السالبه ، فبالإضافة الي فقدان دفع المحرك فإن أداء واستقرارية الطائره تتغير .

تم اقتراح نظام بسيط وغير معقدوذو دقه عاليه وآمن ، يعمل آليا دون تدخل خارجي ، حيث يعمل علي تحديد الخلل في اتزان الطائره عندما يحدث العطل ،وحساب زوايا اسطح التحكم المطلوبه، وتنفيذالمطلوب ،حيثتم حساب الزوايا والعزوم اللازمه لإتزان الطائره وذلك بخطوات علميه، وتم استخدام تطبيقات الحاسوب لتوضيح العلاقات بين المتغيرات المطلوبه لعمل هذا النظام ،وكانت نتائج الحسابات مقبوله بالمقارنه مع النتائج اللازمه لإتزان الطائره

ACKNOWLEDGMENT

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DEDICATION

Every challenging work needs self efforts as well as guidance of elders especially those who were very close to our heart.

My humble effort I dedicate to my sweet and loving

Father &Mother

Whose affection ,love ,encouragement

Along with all hard working and respected

Teachers

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List of Abbreviations

FAR	Federal Aviation Regulations
JAR	Joint Aviation Authority
FCS	Flight Control System
OEI	One Engine Inoperative
AFM	Airplane Flight Manual

List of Symbols

A	aspect ratio
B	wing span
$Bvtail$	vertical tail span
$CDewm$	drag coefficient due to wind milling of failed engine
CL	lift coefficient
$CLahtail$	lift curve slope of the horizontal tail
$Clavtail$	section lift curve slope of vertical tail
$Clavtaileff$	effective lift curve slope of vertical tail
$CLawb$	lift curve slope of the wing and body
$Cnavail$	available yawing moment coefficient at the engine-out flight condition
$Cnreq$	required yawing moment coefficient at the engine-out flight condition
Cyb	variation of sideforce coefficient with yaw angle
Clb	variation of rolling moment coefficient with yaw angle
Cnb	variation of yawing moment coefficient with yaw angle
$Dewm$	drag due to windmilling of failed engine
$Dfuse$	maximum fuselage diameter
$Dfusevtail$	depth of the fuselage at the vertical tail quarter-chord position
Di	engine inlet diameter
$Dnacelle$	nacelle diameter
L	horizontal distance between CG and vertical surface
Le	butt line of outboard engine
$Lext$	external rolling moment
KCybv	empirical factor for vertical tail sideslip derivative estimation
K'	empirical correction factor for large control deflections
Kb	flap span factor
KH	factor accounting for the relative size of the horizontal and vertical tails
KMG	compressibility correction to dihedral
KN	empirical factor for body and body + wing effects
KRl	Reynold's number factor for the fuselage

*KM*L	compressibility correction to sweep
Kwb	factor for fuselage loss in the lift curve slope
Kwbi	wing-body interference factor
Ltv	horizontal distance between CG and engine nozzle
Lvtail	horizontal distance between CG and aerodynamic center of vertical tail
v	
M	Mach number
Nengines	number of engines
Nreq	required yawing moment
Nmax	maximum attainable yawing moment
Qeo	dynamic pressure at the engine-out flight condition
Shtail	horizontal tail area
So	cross-sectional area of fuselage
Sref	wing reference area
Svtail	vertical tail area
T	maximum available thrust at given mach and altitude
To	static thrust at sea level
$\frac{V_n}{V}$	ratio of mean nozzle exit velocity to freestream velocity
Yext	external sideforce
Ztv	vertical distance between CG and engine nozzle
Zvtail	vertical distance between CG and aerodynamic center of vertical tail
D*CLcc*	change in vertical tail CL due to circulation control
A	angle of attack (rad)
B	sideslip angle (positive with relative wind from right)
B*M*	compressibility factor = 1 - *M*2
D*a*	aileron deflection (positive for right up, left down)
D*r*	rudder deflection (positive right)
H*htail*	dynamic pressure ratio at the horizontal tail
F	bank angle (positive right roll)
G	dihedral angle (deg)
K	ratio of actual lift curve slope to 2p

L*c*/2	half-chord sweep angle
L*c*/4	quarter-chord sweep angle
S	ratio of density at a given altitude to density at sea level

Subscripts

Avail	available
Bs	body side
Cc	circulation control
Eff	effective
Fuse	fuselage
Htail	horizontal tail
Req	required

CHAPTER ONE

INTRODUCTION

1.1 Overview

This project discusses issues concerning of One Engine failure During takeoff in twin engine A/C. Thrust reduction and asymmetric thrust are two important considerations in determining aircraft stability under OEF circumstances as the resulting unbalanced state of the aircraft needs to be counteracted by systematic control from new system auto correct the balance of A/C.

1.2 Aims and Objectives

1.2.1 Aims

1. Increase the safety of aircraft
2. In future , Show this idea and testing

1.2.2 Objectives

1. Study and Calculate the take off distances
2. Calculate the side slip angle due to one engine failure in twin engine A/C and control surfaces deflection (aileron and rudder) required to eliminate it .
3. Plot the curve show relation between side slip angle and rudder deflection , side slip angle and aileron deflection.
4. Proposing and show overview automatic system to correct degrees of aileron and rudder at engine failure (one) in twin engine aircraft

1.3 Problem Statement

Engine failure in twin engine aircraft during flight .

1.4 Proposed solution

Increase the ability of control of A\C after engine failure by automatic system to correct the angles of aileron and rudder after engine failure

1.5Methodology

Firstly collect data from the sources and discussed this data with supervisor and use Microsoft applications to calculation and show the results

1.6 Out line

Chapter one : introduction

Chapter tow : literature review

Chapter three : methodology

Chapter four : results and discussion

Chapter five : conclusion and recommendation

CHAPTER TWO

LITRITURE REVIEW

2.1 Takeoff Distances

The takeoff part of a flight is the distance from the brake release point to the point at which the aircraft reaches a defined height over the surface. For any particular takeoff it must be shown that the distance required for takeoff in the prevailing conditions does not exceed the takeoff distance available at the aerodrome. During the takeoff roll, lift is created on the wings to overcome the aircraft weight. This is done by forward acceleration of the aircraft produced by greater thrust force drag.

Following speeds are determined or, on modern aircraft, obtained from the FMS:

1. V1 – speed beyond which the takeoff should no longer be aborted ,also called (decision speed), at which in case of engine failure the continued takeoff distance required, will not exceed the takeoff distance available.
2. VR – rotation speed, at which aircraft nose is lifted from the ground (rotated) for takeoff
3. V2 – takeoff safety speed with critical engine inoperative, at which the aircraft can take of safely with critical engine inoperative. [1]

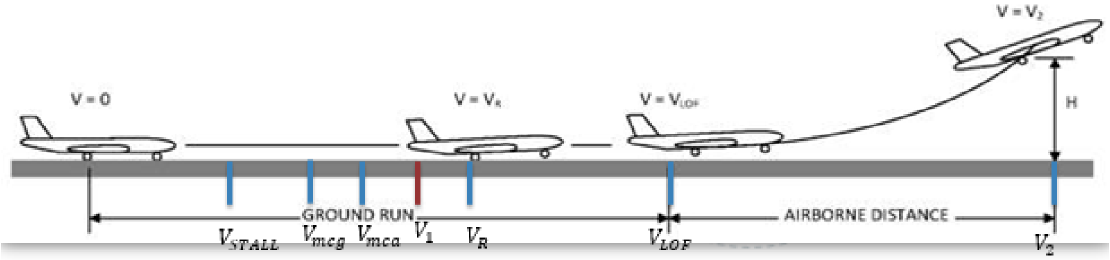

Fig. (2. 1) Takeoff distances and velocities

[2]

2.1.1 Accelerate GO/STOP Distances

Accelerate/Stop Distance – The total distance required to accelerate the Seminole to a specified speed (Vmca), and assuming failure of an engine immediately at Vmca, to bring the airplane to a stop on the remaining runway.

Accelerate/Go Distance – The total distance required to accelerate the engine to a specified speed, and assuming engine failure at the instant that speed is attained, continue takeoff on the remaining engine to a height of 50 feet at Vyse with no obstacles and Vxse with an obstacle on the end of the runway

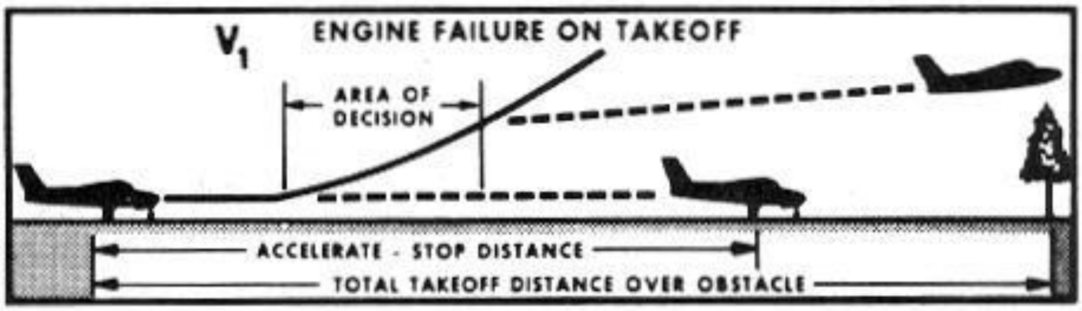

Fig. (2. 2) Accelerate GO/STOP distances

2.1.2 Influence Of Various Factors On Take-off Distance

1 – Higher take-off mass, which means higher take-off weight, results in longer take-off distance.

2 – Higher thrust-to-weight ratio (T/W) results in shorter take-off distance.

3 – Lower air density, which means higher temperature or higher runway elevation, results in longer take-off distance. Lower density also causes lower thrust, which leads to further extension of take-off distance.

4 –Higher maximum lift coefficient up to a certain extent can lead to a shorter take-off distance. However, higher maximum lift coefficients may cause higher drag coefficients for some flap settings, and this can result in longer take-off distance.

5 – For similar thrust-to-weight (T/W) and ${}^{C_D}\!/_{C_{L_{max}}}$ ratios, airborne distances of Class B airplanes are always longer compared to Class A airplanes.[3]

NOTE

"In the event of an engine failure prior to lift off, I will close both throttles, maintain the center line with rudder and bring the aircraft to a stop using full brakes"

"In the event of an engine failure immediately after takeoff, I will counter the yaw with rudder and use aileron to raise the dead engine. I will raise the undercarriage and lower the nose to maintain airspeed. I will then positively identify the failure and feather the failed engine..."

2.1.3Can Airplane Takeoff Automatic?

the answer is no. Not because a plane can't configure itself for takeoff and power up the engines , also because there is no system in place to electronically guide an aircraft through a series of taxiways all the way to the base of the runway so that it can line up to take off in the first place. , ATC gives a lot of instructions for ground operations, funneling aircraft this way and that via taxiway A through Z. They'd have no way of telling an auto-pilot about these directions, there's no computer to send out signals and there is no voice recognition build into the plane, they would have no way to input the instructions into the autopilot, nor would the autopilot know what to do if it ever received such instructions. It just isn't designed to follow taxiways. Also beyond just taxiway layout, there are a lot of planes in close proximity on the ground, plus bunches of other important vehicles (fire trucks, fuel trucks, deicers, etc.) Steering around all of those, faultlessly, would be quite the feat. [4]

2.1.4 Engine Out Obstacle Clearance Profile

The Net Takeoff Flight Path for the engine failure case is divided into four segments. Three of these are climbing segments with specified minimum gradients which are dependent upon the number of engines installed on the aircraft and one is a level acceleration segment. A brief description of the four segments is as follows:

1. First Segment - depending upon the regulations under which the aircraft is certified, the first segment begins either at lift-off or at the end of the takeoff distance at a screen height of 35' and a speed of V_2. On a wet runway, the screen height is reduced to 15'. Operating engines are at takeoff thrust, the flaps/slats are in takeoff configuration and landing gear retraction is initiated once safely airborne with positive climb. The first segment ends when the landing gear is fully retracted.
2. Second Segment - begins when the landing gear is fully retracted. Engines are at takeoff thrust and the flaps/slats are in the takeoff configuration. This segment ends at the higher of 400' or specified acceleration altitude. In most cases, the second segment is the performance limiting segment of the climb.
3. Third or Acceleration Segment- begins at the higher of 400' or specified acceleration altitude. Engines are at takeoff thrust and the aircraft is

accelerated in level flight. Slats/flaps are retracted on speed. The segment ends when aircraft is in clean configuration and a speed of V_{FS} has been achieved. Note that the third segment must be completed prior to exceeding the maximum time allowed for engines at takeoff thrust.

4. Fourth or Final Segment - begins when the aircraft is in clean configuration and at a speed of V_{FS}. Climb is re-established and thrust is reduced to maximum continuous (MCT). The segment ends at a minimum of 1500' above airport elevation or when the criteria for reroute obstacle clearance have been met.

Each segment of the one engine inoperative takeoff flight path has a mandated climb gradient requirement. For example, a gross second segment climb gradient capability of 2.4%, 2.7% or 3.0% is required for two, three and four engine aircraft respectively. Similarly, the required gross gradients for the fourth segment are 1.2%, 1.5% and 1.7% respectively.

To ensure obstacle clearance while allowing for aircraft performance degradation and less than optimum pilot technique, the gross gradients are reduced by 0.8%, 0.9% and 1.0% respectively to calculate a net gradient. The obstacle identification surface (OIS), or obstruction envelope, starts at runway elevation at a point directly beneath the end of the takeoff distance (TOD) and parallels the net gradient profile of the climb segments. If an obstacle in the departure path penetrates the OIS, the slope of the OIS must be increased and both the net and the gross gradient slopes of the corresponding segment must also be increased to ensure that the minimum obstacle clearance criteria is met.

The aircraft net gradient capability, correctable for temperature, altitude and pressure, is published in the AFM performance data and, in actual operations, must ensure that the limiting obstacle in the departure path can be cleared by a minimum of 35'. If there is an obstacle within the departure path that cannot be avoided and would not be cleared by 35', the planned takeoff weight must be reduced until minimum obstacle clearance can be achieved. Note that, by regulation, turns immediately after takeoff cannot be initiated below the greater of 50'AGL or one half of the aircraft wingspan and, that during the initial climb, turns are limited to 15° of bank. Turning will result in a reduction in aircraft climb capability.

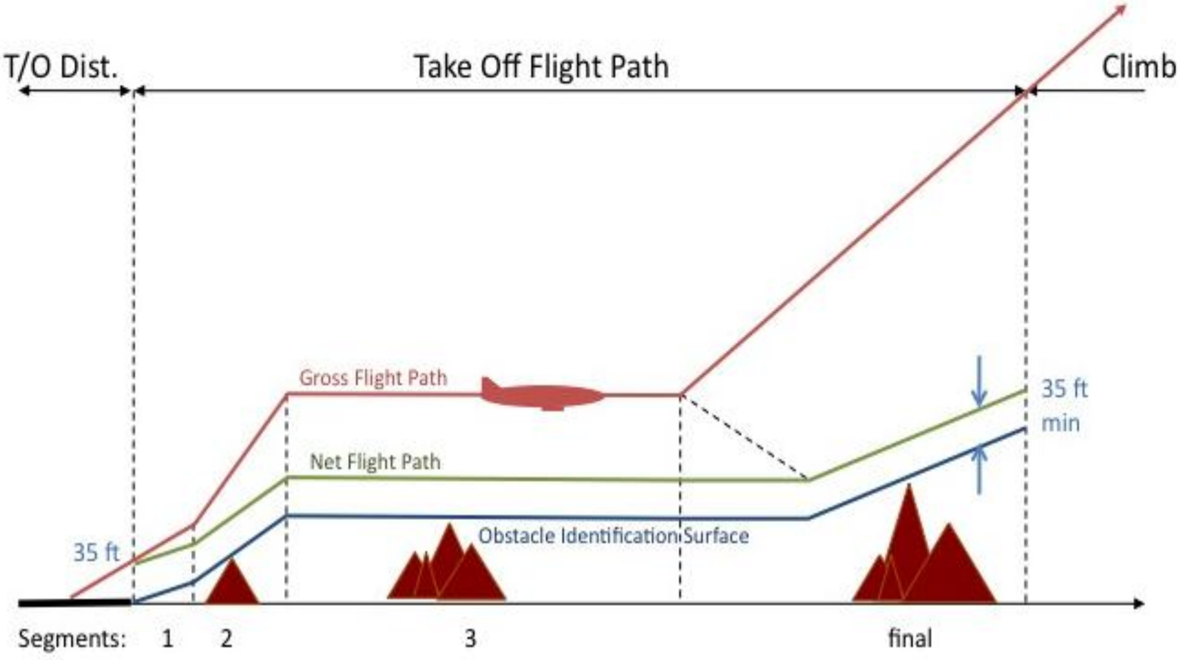

Fig. (2. 3) Take off flight path

To maximize the payload capability from any given runway, most operators develop and utilize emergency turn procedures. These procedures follow a specified ground track which minimizes the affects of local obstacles and a specified vertical profile which complies with the more restrictive of certification or actual obstacle climb requirements.

2.2 Engine Failure On Take-off (EFTO)

2.2.1 Background

In modern aviation, the widespread application of multi-engine aircraft has resulted in marked improvement of flight safety as well as operational efficiency. However, at the same time, the probability of having an engine failure in multi-engine operations has increased consequently.

An aircraft requires “a carefully designed synthesis of various aerodynamic components- the wings, fuselage, horizontal and vertical tail, and other appendages which are working harmoniously with one another to produce the lift necessary to sustain the airplane in the air while creating the smallest possible amount of drag When the surface area of the airplane is subject to airflow, pressure and sheer stress exert on the surface. The pressure acts locally perpendicular to the surface, and shear stress acts locally parallel to the surface .[5]

The net aerodynamic force is the resultant aerodynamic force due to the pressure and shear stress distributions over the total exposed surface area.

In order to produce the airflow and hence the lift, the aircraft requires airspeed- it needs to propel through air at a certain speed. A consequence of this lift/speed requirement for flight is a retarding force called drag. The required force to overcome drag is called thrust and produced by power plants. These forces acting on the aircraft must be in equilibrium to maintain straight and level flight. The aerodynamic force acting on the aircraft depends on the velocity of the aircraft through air, the density of the ambient air, the size of the aircraft and the angle of attack: the angle between the relative wind and a reference line on the aircraft or wing.[6]

An airplane just like any body , is in equilibrium ,if the sum of forces and the sum of moments that act on the airplane are zero ,when one of the engines of multi-engine air plane failed ,the balance of forces and moments is disturbed .Then causes yawing and most airplane start rolling .

If multiengine A/C lost one of the engine during flight , a fatal accident happened due to the pilot delay control action .after reviewing many accident investigation it was notice that , most pilots and cabin crew misunderstanding at engine failure , for example :

1. Shutting the operating engine instead of failure one.
2. Delay the reaction of pilot control to balance the A/C forces and moments when one of the engine fails.
3. Some of A/C fitted with engine control system to increase the operated engine over max mainly at engine fails during takeoff for short time.

After reviewing many accident investigation reports, it was noticed that most instructors, pilots and accident investigators explain and apply the minimum control speed in the air (Vmca) of the air-plane in a different way than airplane design engineers, experimental test pilots and flight test engineers do. This difference in interpretation has, to the opinion of AvioConsult, led to many catastrophic accidents caused by the loss of control and/or performance after engine failure and also to incorrect and incomplete conclusions and recommendations in accident investigation reports. [7]

This article is for all multi-engine rated pilots and accident investigators. Briefly discussed are the design of the vertical tail of a multi-engine airplane, the flight test techniques that are used to determine Vmca and a factual error in the Vmca definition in most Airplane Flight Manuals (AFM). After reading this article, the real value of Vmca that is listed in the AFM of multi-engine airplanes and the conditions for which this Vmca is valid will have become much clearer, which is of vital importance for getting home safely after engine failure and for preventing engine failure related accidents. Accident Investigations will also improve.

2.2.2 One Engine Failure During Takeoff

Is a situation, when flying an aircraft, where is an engine has failed, or is not delivering sufficient power, at any time between brake release and the wheels leaving the ground /V_2. The phases of flight are de-lineated to allow simplified standard procedures for different aircraft types to be developed. If an aircraft suffered engine failure on takeoff, the standard procedure for most aircraft would be to abort the takeoff In small airplanes, if the engine failure occurs before (Vr)Rotation Speed , the pilot should reduce throttles to idle, deploy speed brakes (if equipped), and brake as necessary. If the engine failure occurs just after liftoff, the pilot must make a decision if there is enough runway to achieve an emergency runway landing, or if an off field landing is required. One of the biggest mistakes a pilot can make is attempting to turn around and return to the airport for an emergency landing. If altitude permits, this could be an option but most pilots are trained to avoid the obvious tendency to turn around and instead land the plane straight forward.

2.2.3 Engine Malfunctions(causes)

1. Compressor surge

   occurs during high power at takeoff, , this has led to a rejected takeoff above V1. These high-speed rejected takeoffs have sometimes resulted in injuries, loss of the airplane, and even passenger fatalities.
2. Bird ingestion(FOD)

Airplane engines ingest birds most often in the vicinity of airports, either during takeoff or during landing. Encounters with birds occur during both daytime and nighttime flights.

3. Engine Separation
4. Fuel System Problems
5. Oil System Problems

2.2.4 Aerodynamic Effects Of An Engine Failure

When an engine failure occurs in a multi-engine aircraft, asymmetric thrust and drag produce the following effects on the aircraft's axes of rotation

1. Pitch down along the lateral axis – loss of accelerated slipstream over the horizontal stabilizer produces less negative lift.
2. Roll down toward the inoperative engine along the longitudinal axis – wing produces less lift on side of failed engine due to loss of accelerated slipstream
3. Yaw toward the inoperative engine along the vertical axis – loss of thrust and increased drag from the wind milling propeller

To compensate for these effects, a pilot must add additional back pressure, deflect the ailerons into the operating engine, and apply rudder pressure on the side of the operating engine.

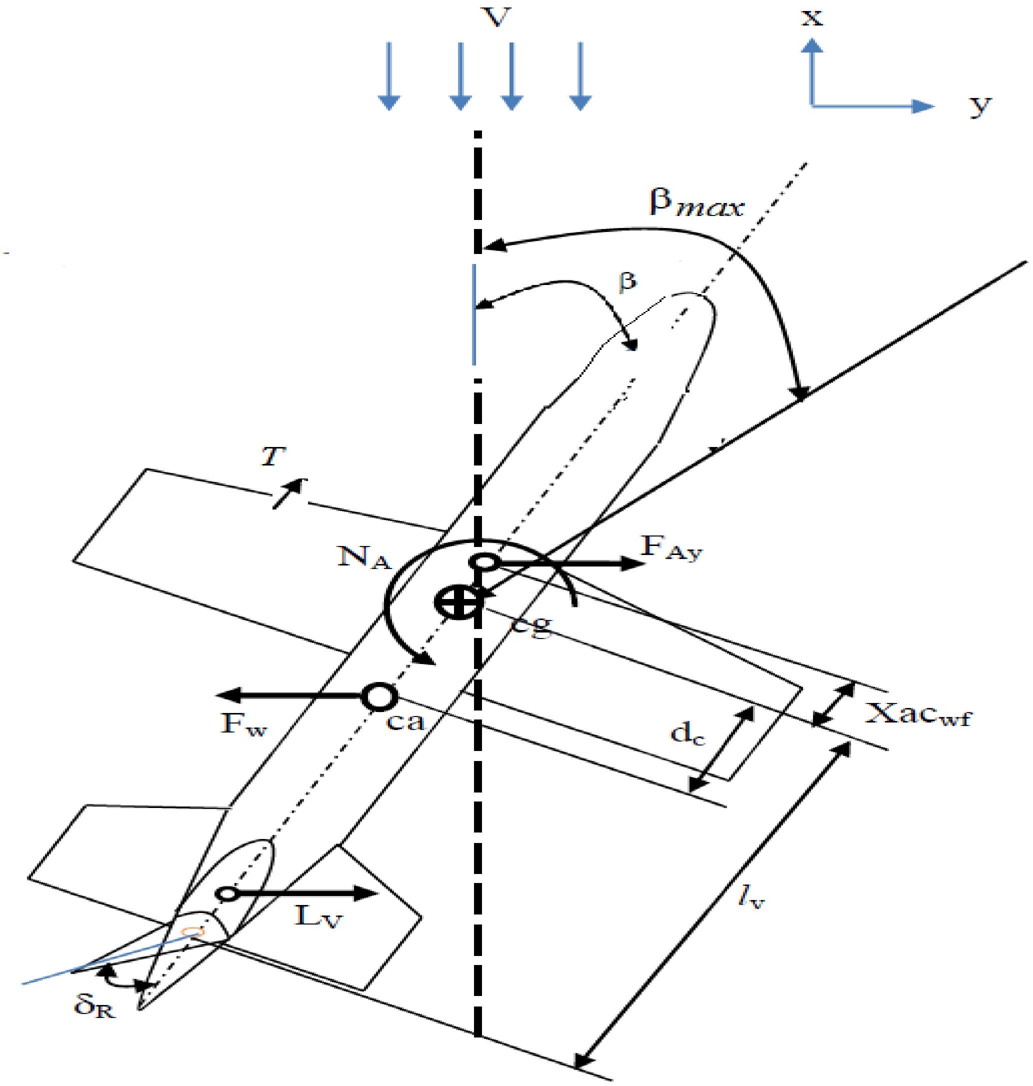

Fig. (2. 4) Forces and moments the aircraft subjected to with OEI and side slip

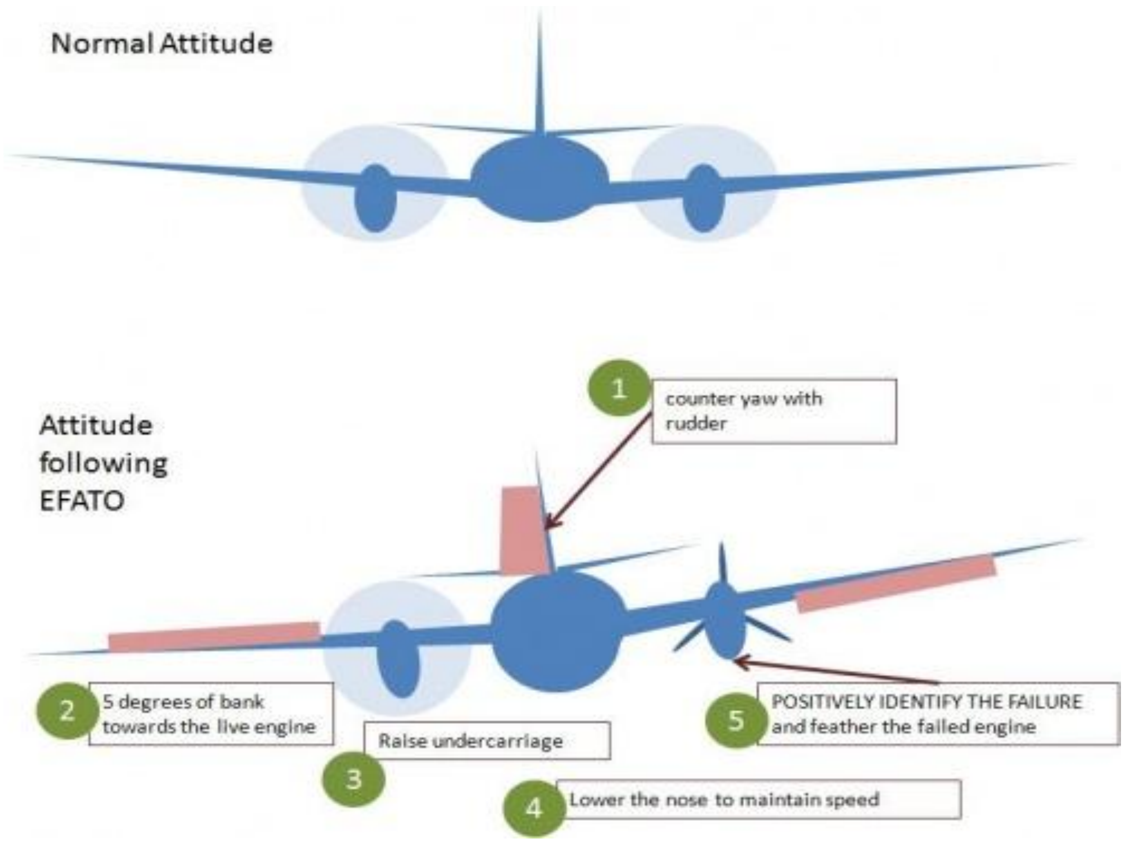

Fig. (2. 5) Engine failure after takeoff

2.3 Tail Design

The vertical tail of any multiengine airplane is designed and sized to provide for the required side force (and hence yawing moment) to counter asymmetrical thrust down to certain speed and to maintain straight flight after engine failure.

the most important forces and moments are shown that act on a multi-engine airplane during steady straight flight when one engine is inoperative and the wings are kept level. As for anybody, an airplane is in equilibrium if both the sum of the forces and the sum of the moments that act on the airplane are zero.[7]

A deflected rudder (δr) generates a side force (Yδr) that causes a yawing moment (Nδr) to counter the asymmetrical thrust yawing moment (NT). Yδr also causes acceleration to the dead engine side; a sideslip develops. The acceleration continues and the sideslip increases, until the sum of the side forces is zero. The aerodynamic side force Yδr is proportional to the (squre of the) airspeed (V2). The lowest airspeed at which straight flight can just be maintained while either the rudder or the ailerons are maximum deflected, is called Vmca, but sometimes also incompletely as Vmca. Sideslip causes drag which reduces the remaining climb performance significantly and should therefore be kept to a minimum. This is impossible without banking (unless the opposite engine is also shut down). When banking, a component of the weight, leads to a side force due to bank angle (Wsinϕ) , that can re-place the side force Y_β due to sideslip that was required for balance with the wings level. The small bank angle decreases the sideslip angle to a minimum, decreasing the total drag and, hence, increasing climb performance. Side force(Wsinϕ) acts in the centre of gravity and therefore does not cause any adverse yawing moments.[8]

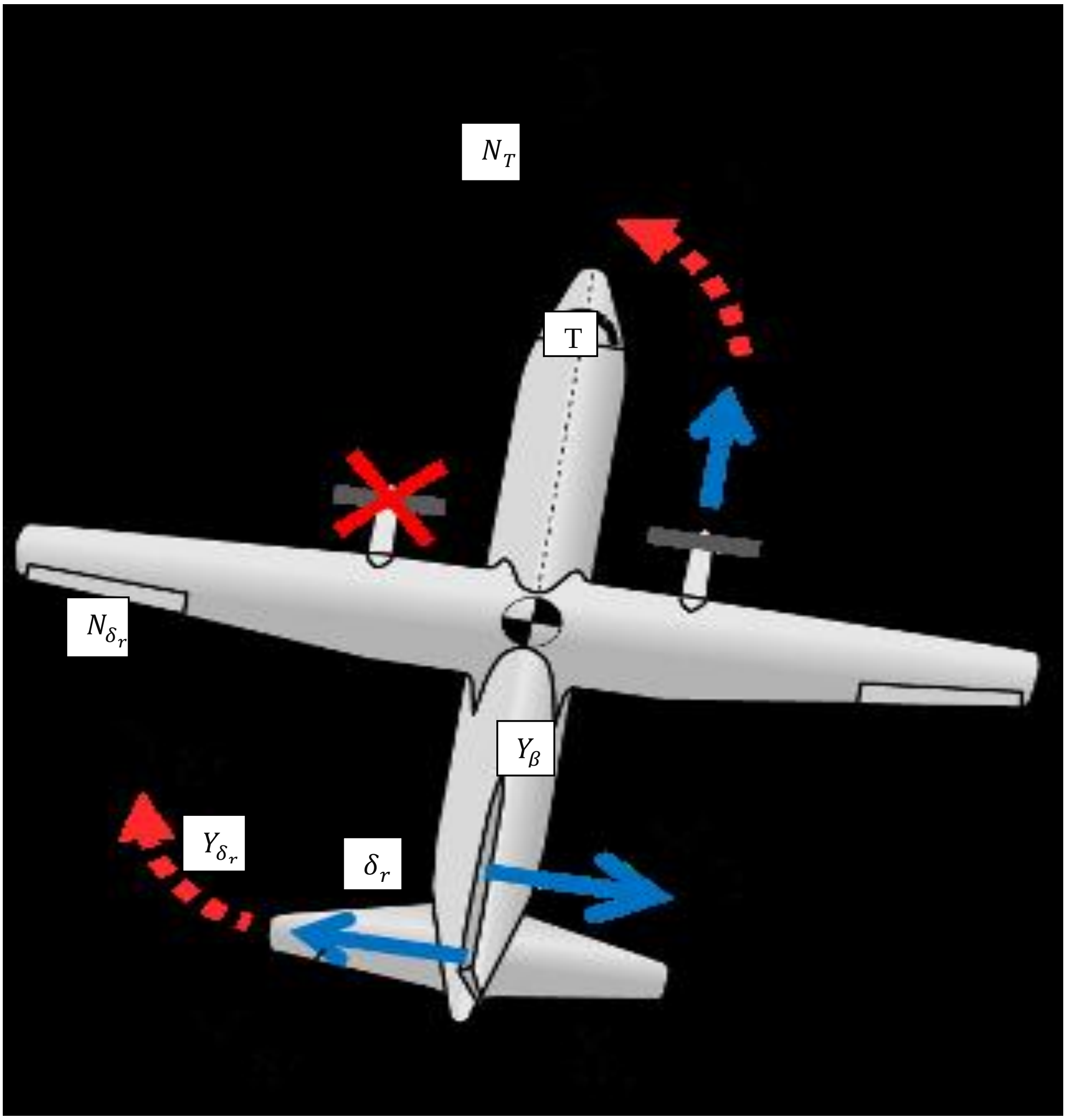

Fig. (2. 6) Forces and moments wing kept level

2.4 Minimum Control Speed _ (Vmca)

Because of the limited size of the vertical tail, there is a minimum airspeed below which the vertical tail with rudder does not generate a high enough aerodynamic force (Y_{δ_r}) any more to counter the yawing moments (N) caused by asymmetrical thrust NT (and propeller drag)

The motions of the airplane below this minimum airspeed can no longer be controlled; the rudder and /or ailerons seem not effective anymore. This airspeed is called minimum control speed in the air

Also the VMCA The VMC(A) definition in an AFM is often:

"Minimum control speed is the minimum flight speed at which the airplane is controllable with a bank angle of not more than 5 degrees when the critical engine suddenly becomes inoperative and the remaining engine is operating at takeoff power".[8]

2.4.1 Effect Of Bank Angle And Weight On Minimum Control Speed

When, during the design phase of the airplane, the size of the vertical tail is either known or assumed, graphs can be calculated using the stability derivatives of the airplane that show the effect of bank angle and weight on VMCA during straight equilibrium flight while both the asymmetrical thrust and the rudder deflection are maximal. The graphs presented in Fig-ures 2-8 and 2-9 below are calculated using B707/DC-8 type air-plane data. The shape of the plots is valid for all multi-engine airplane types, though.

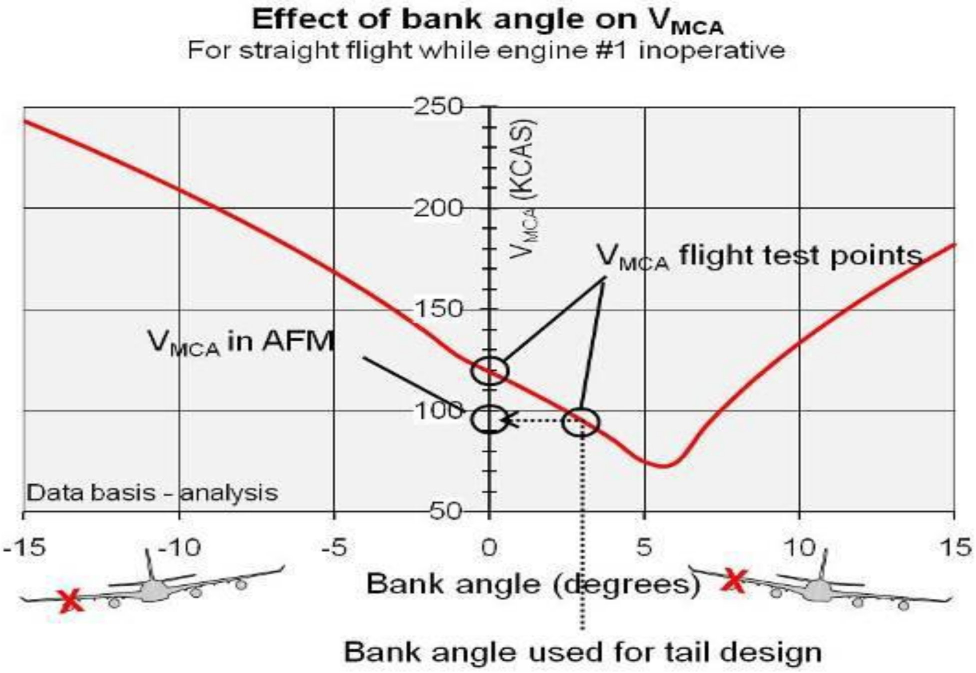

Fig. (2. 7) The effect of bank angle on minimum control speed

The manufacturer of this sample airplane has calculated that the sideslip angle is near zero, i.e. the drag is minimal, if the bank angle is 3 degrees away from the inoperative engine. For that reason, this bank angle is often included as a condition in the legend of engine inoperative performance diagrams for the presented data to be valid.

Bank angle however, not only has effect on sideslip and drag.

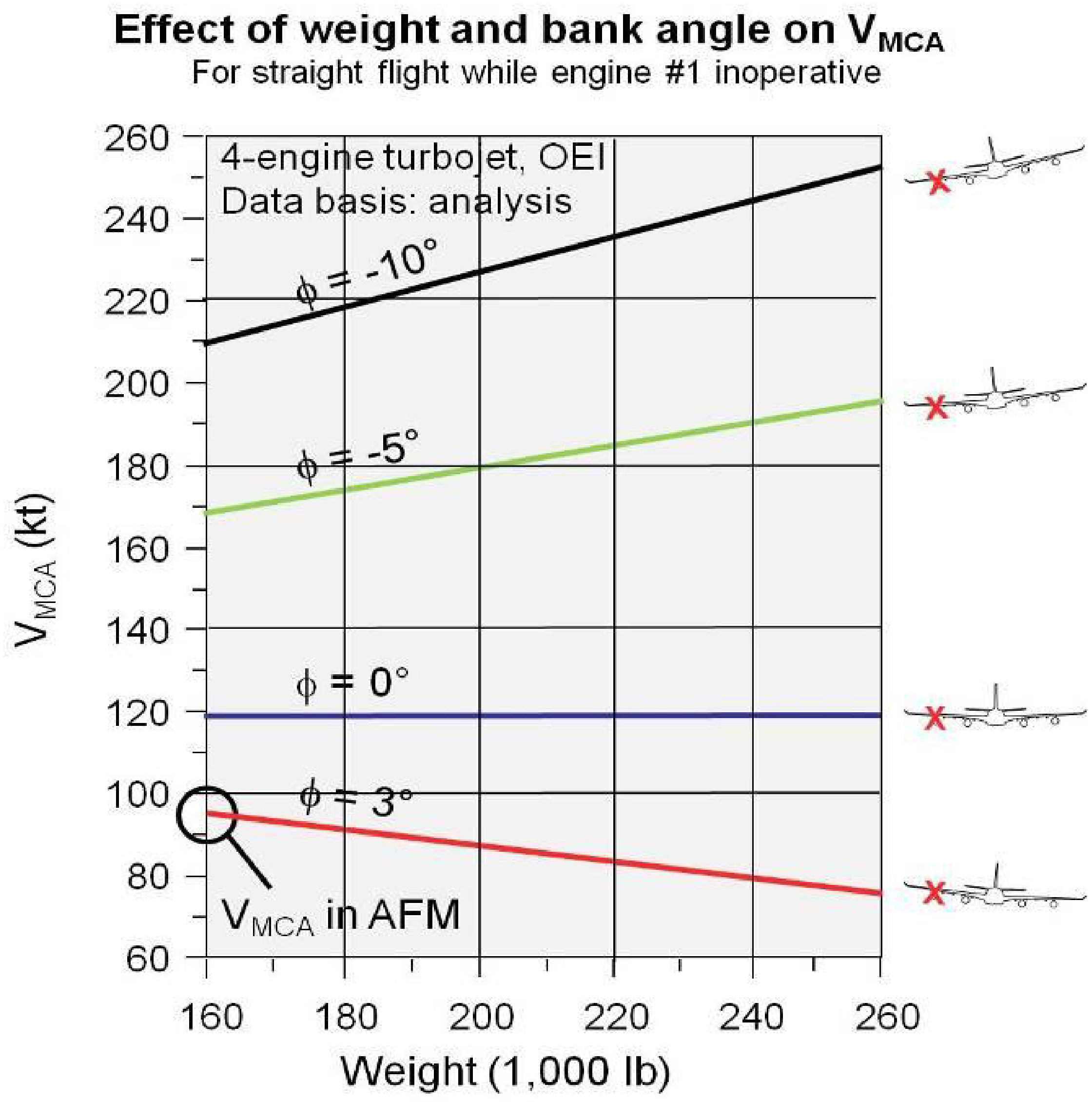

Fig. (2. 8) The effect of weight and bank angle on minimum control speed

Weight (W) and bank angle (ϕ) both have great influence on the *actual* VMCA of the airplane via side force(Wsin ϕ), as is illustrated in Figure (2-9). The *standardized* VMCA that is listed in the AFM will in this case be 95 kt.

As shown in Figures (2-8) and (2-9), the *actual* VMCA of this sample airplane increases to 120 kt if the wings are kept level. In addition, keeping the wings level or turning to either side leads to a sideslip for the balance of side forces (Figure 1). This increases the drag and hence, reduces the climb performance or leaves no positive climb performance at all.

It will be clear that the requirement for maintaining a small bank angle must be made known to the pilots of multi-engine airplanes; the saved weight and manufacturing cost of a smaller vertical tail needs to be replaced by a quite 'heavy' condition/ warning in AFMs for maintaining the mandatory small bank angle while an engine is inoperative, the airspeed is low and the power setting is high. This condition is regrettably not presented anymore in AFMs, with the exception of Lockheed manuals.[8]

2.5 Thrust Asymmetry Effect

The engine and fin locations affect the asymmetric thrust due to OEI. There is a more pronounced thrust asymmetry effect in the aircraft which have wing mounted engines than those which have the rear mounted engines in OEI. This is because the greater lateral distance of the thrust line of the wing mounted engines from the centre of gravity creates the greater moment arm.

The asymmetric thrust causes the aircraft to develop yaw rate towards the direction of failed engine which needs to be corrected by application of rudder. This thrust asymmetry also induces asymmetric lift as one wing produces more lift than the other which creates roll.

The dihedral and wing blanking effects in combination with resulting side slip also play their role in contributing towards the rolling moment towards the direction of the dead engine. "On propeller airplanes, an additional rolling moment develops due to the loss of propulsive lift of the wing section behind the failed propulsion system. Turbojet/ -fan airplanes do not have blown wing sections because the engines are mounted below or above the wings, but the sideslip angle reduces the frontal area of the downwind swept wing considerably, increasing the rolling moment". There is also a roll due to the rudder deflection. A certain amount of aileron deflection is required to achieve zero rolling moment.[5]

2.6 Spillage Drag

In addition to this asymmetric yaw caused by loss of thrust from one engine, there is a drag due to an inoperative engine which is known as spillage drag which adds to the yawing moment.

The spillage drag is a propulsion performance penalty of turbo fanor jet engines which occurs when inlet of the engine spills air around the outside instead of conducting the air to the compressor. However, this drag is partially cancelled out by the phenomenon known as lip suction effect produced by passing of spilled air over the external cowl lip which makes the air accelerate and the pressure decreases.

When an engine is shutdown or fails, the difference between the actual engine airflow and the maximum air flow demanded by the inlet of the engine is great, producing the spillage drag.

The drag from the engine can be minimized by reducing the spillage through allowing a Wind milling engine, which passes more air through it. In modeling the drag for OEI ,the wind milling drag can be estimated based on the inlet diameter of the engine, Mach number, mean nozzle exit velocity and free stream velocity using Torenbeek's method.[5]

2.7 Critical Engine

A critical engine is the engine which most adversely affects the performance and controllability of the aircraft when it fails. Not all multi-engine airplanes have a critical engine. Specifically, planes with counter rotating propellers, like the Piper Seminole, do not have one. That said, most high-performance multi-engine aircraft have a critical engine, and it is a topic with which you should be familiar.

What makes one engine have more effect on control and performance than the other? Remember **P-A-S-T**:

1. **P** - P-factor
2. **A** - Accelerated slipstream
3. **S** - Slipstream
4. **T**– Torque

P-Factor

The descending blade of a propeller produces more thrust. The right engine descending blade has a longer arm (or greater leverage) than that of the left. Thus, P-factor from the right engine produces more asymmetric thrust when the left fails, making the left the critical engine. See image below.

Accelerated slipstream (Roll)

The center of lift on the right engine is farther from the longitudinal axis, and it is closer on left side. This results in less negative lift on the tail which produces roll. Roll produced by loss of the left engine will be greater than that produced by loss of the right.

Spiraling Slipstream (Yaw)

The right engine slipstream spirals away from the tail, while that of the left engine hits the vertical stabilizer. Thus, when we lose the left engine there are more directional control problems, making it critical.

Torque (Roll)

Since propellers rotate clockwise, the aircraft will roll counterclockwise. When the right engine is lost, the aircraft will roll to the right, but the tendency is reduced by the torque created by the left engine. When the left engine is lost, the aircraft rolls to left and the torque produced by the right engine will add to left rolling tendency. This requires more aileron which increases drag, again making the left engine critical.

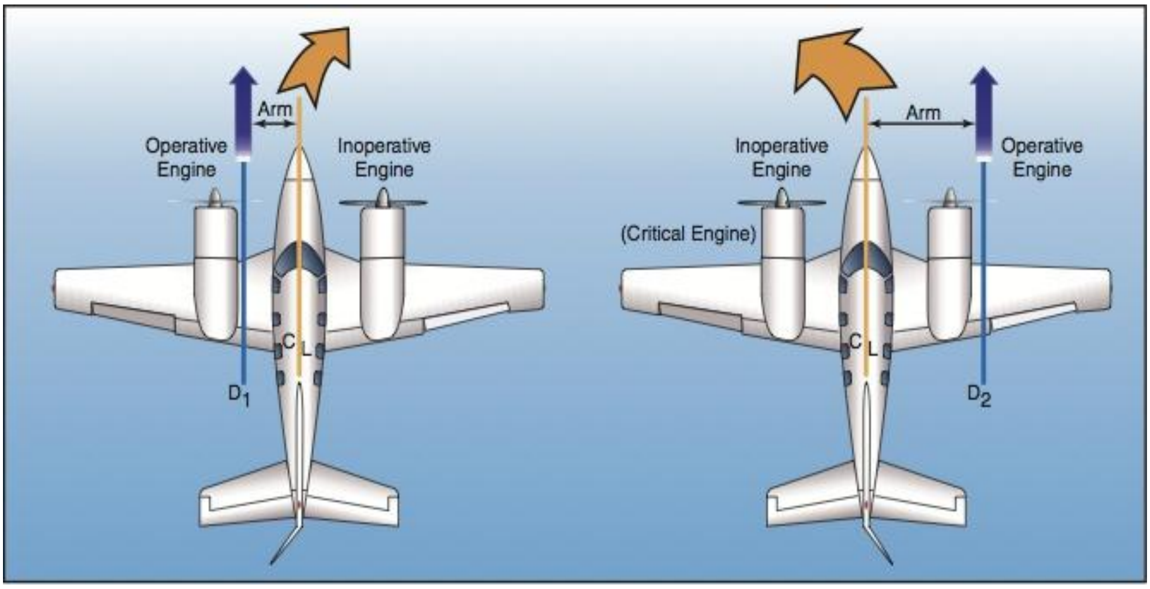

Fig. (2.9) The critical engine

2.8The System Of Regime During a Failure Of engine At T/O

the gas-turbine engine equipped with a safe (EMERGENCY REGIME).

Provides a safe A/O for A/C , at failure of one engine at T/O.

For switching on the emergency regime in the A/C and engine the flowing steps should be carried out :

1-the mechanism of switching the control of emergency regime fitted on the port side of the pilot in front of the engine throttle.

2-electro mechanism solenoid controlling the emergency regime located the upper of medium casing of the engine compressor . (each engine has it own solenoid)

3-relay located on the panel of port pilot.

b-the mechanism of switching on the control of emergency regime :

1-the mechanism casing contains the emergency lever (3) was fixed by (4) the bolts on the panel down the left pilot .

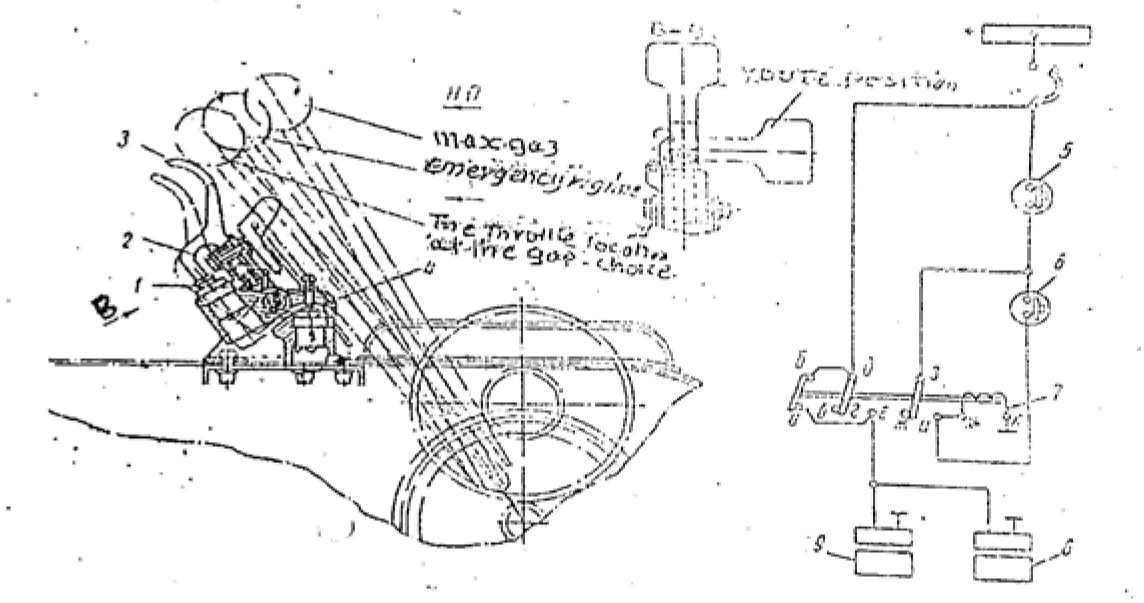

Fig. (2.10) The control mechanism of emergency regime engine failure

Fig 2-10 shows the control mechanism of emergency regime at engine failure at T/O regime : 1-spring 2-ball 3-emergency lever 4-casing –(5-6)knobs-7-relay . (8-9)solenoid In the casing fixed two knobs (5and6) , the lever 3 can inclined at an angle of 90 degs . in the port side , and at it far end a ball (2) and spring (1).

On ground and during flight the lever 3 should be inclined at 90 degs .fixed in route position . in this case the knobs 5 . and 6 switched off . before flight the lever 3 should be fixed vertically in ready operation at emergency regime . at the action of spring 1, the casing with lever inclined for ward till the fixer , switching on the knob 5 , andoff6 . therefore for switching on the control of emergency regime , at the position of the throttle in the limiter of max regime , it is required to pull the lever 3 to the throttle in the direction of (B) FIG 4-1 , switching on the contact of knob 6 . and then switching on throw the relay 7 the solenoids 8-9 , which moves the throttle in the left pilot side forward to the position of emergency regime .[9]

2.9 Is One Engine Able To Fly The Aircraft?

twin engine plane can fly perfectly well on one engine. In fact it can even take-off and land with just one engine. Losing an engine in flight is not a particularly serious problem, the pilots are trained to fly the aircraft should an engine fail. If an engine did A fail in flight, the pilots would carry out a number of checklists to ensure the engine is secure and safe, and then as a precaution, land at a nearby suitable airport – unfortunately this is unlikely to be your destination!

2.10 Automatic System Of The project

2.10.1 The New System

The new systems changes the flight control system after engine failure from mechanical to digital balance of A/C by wire , utilizing smart actuators sensors with remote electronic control It has several advantages over mechanical system, must be safe and available and very low probability of losing A/C balance system of during one engine fails.

2.10.2 Description Of (FCS) Of Engine Failure

Connecting the compressors of two engines with pipe to microproccers , which operate by pressure of operate engine compressed air, sending signal to the pilot to indicate the failure engine, and to the smart actuators to all control system for automatic selection of the failed engine and action for balance the A/C.

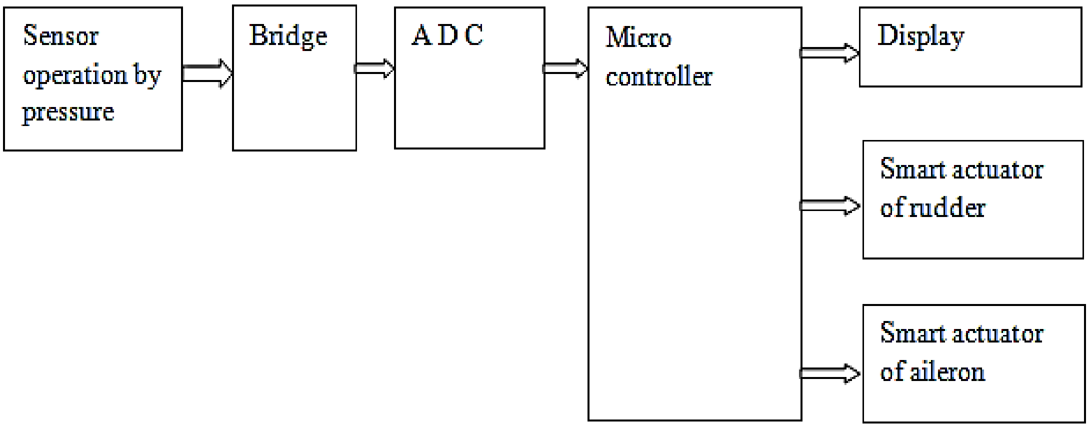

Fig. (2.11) block diagram of the new system

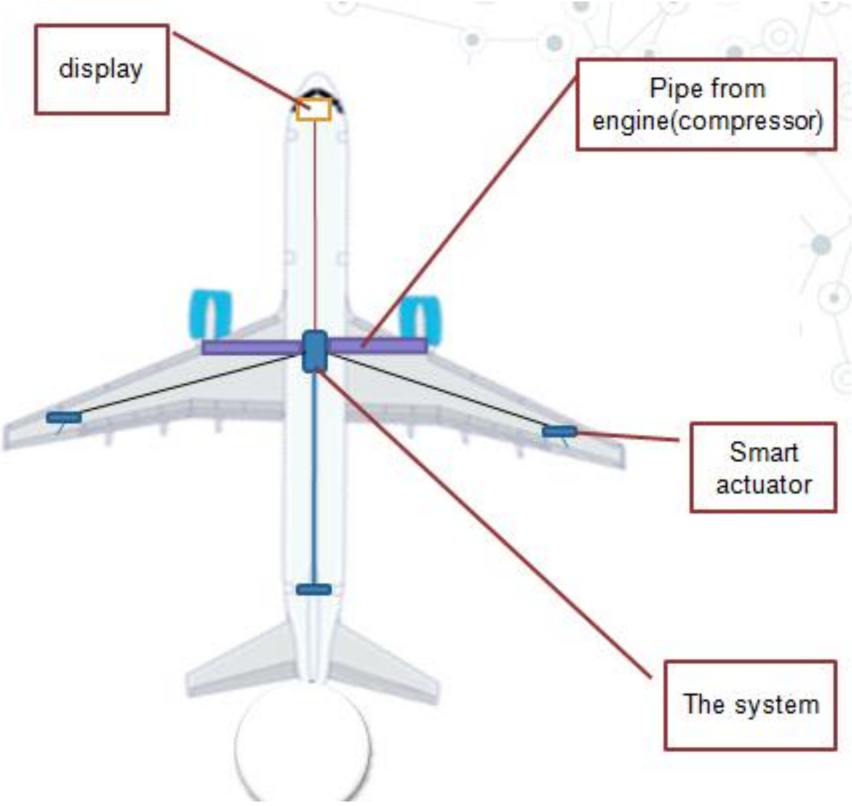

Fig. (2.12) The construction of the system

2.10.3 Requirement Of System

1. Failsafe design are required by civil aviation regulation
2. The system to meet the FAR/JAR 25
3. The system is robust any considerable failure or combination of failure[10]

CHAPTER THREE

CALCULATIONS

3.1 Givens and Calculations

Table (3. 1) input (givens) values

INPUT	**VALUES**
$C_{y_{\delta r}}$	-0.118
C_{y_β}	-1.54
$C_{y_{\delta a}}$	0
K_{cy_β}	0.57
$K_{w_{bi}}$	1.5
S_o	18.9
q	397.3
b_i	9.5
b_o	12.6
Aileron effectiveness	0.5
Rudder effectiveness	0.52
V.tail lift slope	0.1
$C_{l_{\delta r}}$	-0.034
C_{l_β}	0.034

The data in this table used in the equation to calculate the required values

Table (3. 2) Calculation of takeoff distances

62820	Kg	WTO
2.16		Clmax
105.4	m2	S
0.436111	Rad	Sweep
0.104667	Rad	dihedral
0.04		Delta
0.961538		E
9.16		AR
0.048091		K
0.016		CD0
0.240371		CD
98100	N	T
84695.98	N	D
66.47881	m/s	Vs
76.45063	m/s	VLO
0.021752	rad	theta
1747.561	M	Sg
689.6412	M	Sa
2437.202	M	ST

Table (3. 3) calculations of (Me) and (Mr)

V (m/s)	T	T2	Cm del r	del r	MR	Me	P	m	d
0	196200	98100	-0.118	-25	=	588600	0	0	0
10	196200	98100	-0.118	-25	4283.784	588600	981000	0.2	1032.92
20	196200	98100	-0.118	-25	17135.14	588600	1962000	0.4	4131.68
30	196200	98100	-0.118	-25	38554.06	588600	2943000	0.6	9296.28
40	196200	98100	-0.118	-25	68540.55	588600	3924000	0.8	16526.72
50	196200	98100	-0.118	-25	107094.6	588600	4905000	1	25823
60	196200	98100	-0.118	-25	154216.2	588600	5886000	1.2	37185.12
70	196200	98100	-0.118	-25	209905.4	588600	6867000	1.4	50613.08
80	196200	98100	-0.118	-25	274162.2	588600	7848000	1.6	66106.88
90	196200	98100	-0.118	-25	346986.5	588600	8829000	1.8	83666.52
100	196200	98100	-0.118	-25	428378.4	588600	9810000	2	103292
110	196200	98100	-0.118	-25	518337.9	588600	10791000	2.2	124983.3
120	196200	98100	-0.118	-25	616865	588600	11772000	2.4	148740.5
130	196200	98100	-0.118	-25	723959.6	588600	12753000	2.6	174563.5

3.2 Takeoff Calculations

This equation to calculate stall speed

$V_S = \sqrt{\frac{2w}{\rho s C_{lmax}}}$ ……………………………..(3_1)

$V_S =$ 66.5 m/s

This equation To calculate liftoff speed

$V_{LOF=}$1.2 V_S...(3_2)

$V_{LOF=}$76.4 m/s

This equation to calculate takeoff angle

$\theta = \sin^{-1}\left[\frac{T-D}{W}\right]$……………………………(3_3)

$\theta=$ 0.021 (rad)

This equation to calculate ground distance

$S_{g=}\frac{1.235\ W^2}{\rho g C_{max} T}$……………………………….(3_4)

$S_{g=}$ = 1747.5 m

This equation to calculate airborne distance

$S_a = \frac{HW}{T-D}$ ………………………………..(3_5)

$S_a =$ 689.6 m

This equation to calculate total takeoff distance

$S_{TOTAL} = S_g + S_a$…………………………… (3_6)

$S_{TOTAL} =$ 2437.1 m

3.3 Stability Calculations

3.2.1 Introduction

This part describes the estimation of stability and control derivatives using the method of Reference (which is essentially DATCOM), and the establishment of the engine-out constraint based on the required yawing moment coefficient. The use of thrust vectoring and circulation control to provide additional yawing moment is also described.

3.2.2 Control Surface Sign Conventions

The control surface sign conventions are defined such that a positive control deflection generates a positive roll or yaw moment according to the right hand rule with a conventional body axis coordinate system, as shown in Figure 3-1.

A positive aileron deflection is defined with the right aileron up and the left aileron down. The aileron deflection is the average deflection of the two surfaces from the neutral position. A positive rudder deflection is defined with the trailing edge to the right, as viewed from above.

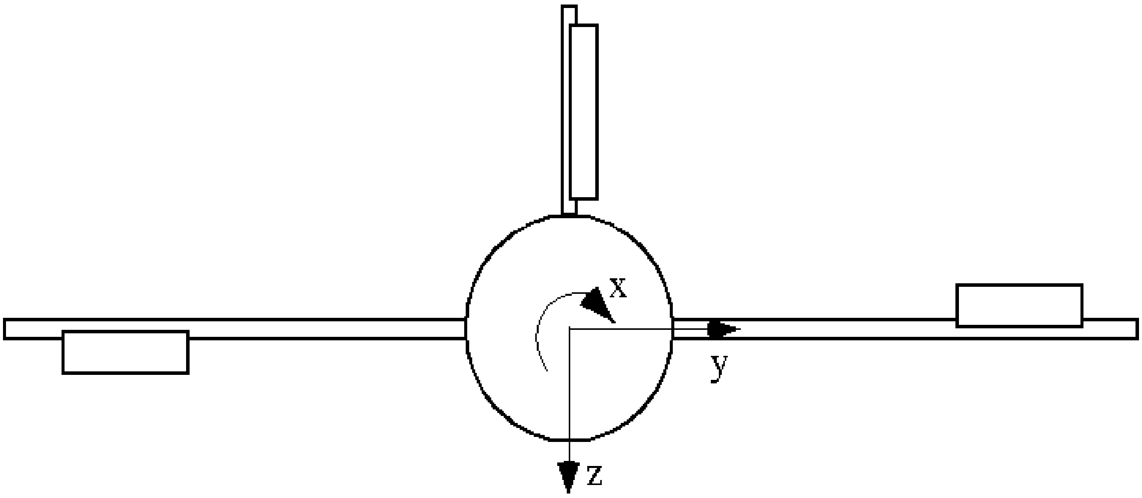

Fig. (3. 1) shows control surfaces sign convention

3.3 Engine-out Methodology

The engine-out constraint is established by constraining the maximum available yawing moment coefficient ($C_{n_{avail}}$) to be greater than the required yawing moment coefficient($C_{n_{req}}$) for the engine-out flight condition:

$C_{n_{avail}} \geq C_{n_{req}}$ ……………………………(3_7)

The required yawing moment coefficient is the yawing moment coefficient required to maintain steady flight with one failed outboard engine at 1.2 times the stall speed, as specified by FAR 25.149. The remaining outboard engine must be at the maximum available thrust, and the bank angle cannot be larger than 5°.

Figure 3-1 shows the engine-out geometry for a twin-engine configuration. The yawing moment coefficient required to maintain steady flight with an inoperative engine is given by:

$C_{n_{req}} = \frac{(T + D_{ewm})Le}{q S_{ref}\, b}$ …………………………..(3_8)

Where :

T is the maximum available thrust at the given Mach number and altitude

(D_{ewm}) is the drag due to the wind milling of the failed engine.

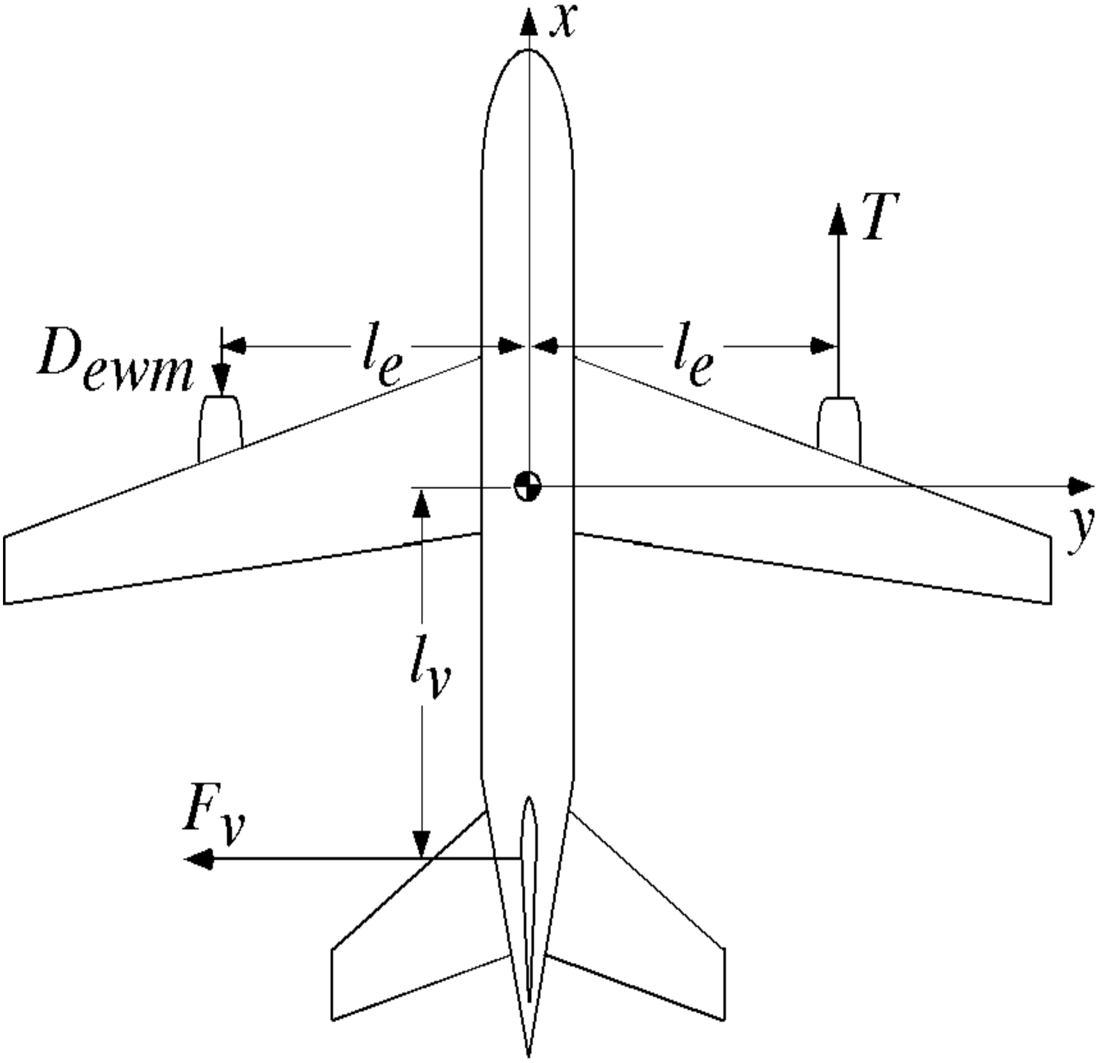

Fig. (3. 2) shows Engine out geometry

The drag due to the wind milling of the failed engine is calculated using the method described in Appendix G-8 of Torenbeek

$D_{ewm=} q\ S_{ref}\ C_{D_{ewm}}$ ………………………(3_9)

$D_{ewm=}$ -256.7 kn

Where:

$$C_{D_{ewm}} = \frac{d_i^2\left[0.0785 + \frac{2}{1+0.16M^2}\frac{\pi V_n}{4\;V}\left(1-\frac{V_n}{V}\right)\right]}{S_{ref}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots(3\_10)$$

$CSS_{D_{ewm}}$ = -6.13

Where:

Di	is the engine inlet diameter
M	is the Mach number
Vn	is the nozzle exit velocity
$\frac{V_n}{V}$	is bypass ratio engines

3.4 Maximum Available Yawing Moment Coefficient

The maximum available yawing moment coefficient is obtained at an equilibrium flight condition with a given bank angle (ϕ) and a given maximum rudder deflection (δr). The bank angle is limited to a maximum of 5° by FAR 25.149, and the aircraft is allowed to have some sideslip (β).The sideslip angle is found by summing the forces along the y-axis

3.4.1Sideforce Equation

$$C_{y_{\delta a}}\delta_a + C_{y_{\delta r}}\delta r + C_{y_\beta}\beta + C_l \sin\emptyset - \frac{T\sin\varepsilon}{q\,S_{ref}} - \Delta C_{L_{CC}}\frac{S_{v.tail}}{S_{ref}} = -\frac{Y_{ext}}{q\,S_{ref}} \ldots\ldots\ldots\ldots\ldots\ldots(3.11)$$

The fifth term in the equation above ($\frac{T\sin\varepsilon}{q\,S_{ref}}$) is due to the thrust being vectored at an angle ε to the centerline, and the sixth term ($\Delta C_{L_{CC}}\frac{S_{v.tail}}{S_{ref}}$) is due to the change in CL at the vertical tail due to circulation control. Since the external sideforce ($Yext$) is zero, and $Cy\delta a$ is assumed to bezero, this equation can be simplified and solved for the sideslip angle

$$\beta = \frac{-C_{y_{\delta r}}\delta r - C_l\sin\emptyset + \frac{T\sin\varepsilon}{q\,S_{ref}} + \Delta C_{L_{CC}}\frac{S_{v.tail}}{S_{ref}}}{C_{y_\beta}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.12)$$

β = 6 (degree)

3.5 Rolling Moment Equation

The aileron deflection required to maintain equilibrium flight is obtained by summing the rolling moments about the x-axis:

$$C_{l_{\delta a}}\delta_a + C_{l_{\delta r}}\delta r + C_{l_\beta}\beta - \frac{T\sin\varepsilon}{q\,S_{ref}}\frac{Z_{v.t}}{b} - \Delta C_{L_{CC}}\frac{S_{v.tail}}{S_{ref}}\frac{Z_{v.t}}{b} = -\frac{L_{ext}}{q\,S_{ref}} \text{.........}(3.13)$$

By setting the external rolling moment (L_{ext}) equal to zero, this equation can be solved for the aileron deflection:

$$\delta_a = \frac{-C_{l_{\delta r}}\delta r - C_{l_\beta}\beta + \frac{T\sin\varepsilon Z_{v.t}}{q\,S_{ref}\ \ b} + \Delta C_{L_{CC}}\frac{S_{v.tail}Z_{v.t}}{S_{ref}\ \ b}}{C_{l_{\delta a}}} \text{.............}(3.14)$$

δ_a =11 (deg)

3.6 Yawing Moment Equation

The rudder deflection is initially set to the given maximum allowable steady-state value, and the sideslip angle and aileron deflection for equilibrium flight are determined byEqs. (2-6) and (2-8). The maximum allowable steady-state deflection is typically 20°-25°. This allows for an additional 5° of deflection for maneuvering. A warning statement is printed if the calculated deflection exceeds the maximum allowable deflection.

The maximum available yawing moment is found by summing the contributions due to the ailerons, rudder, and sideslip

$$C_{n_{avail}} = C_{n_{\delta a}}\delta_a + C_{n_{\delta r}}\delta r + C_{n_\beta}\beta + \frac{T\sin\varepsilon}{q\,S_{ref}}\frac{L_{v.t}}{b} + \Delta C_{L_{CC}}\frac{S_{v.tail}}{S_{ref}}\frac{L_{v.t}}{b} \text{................}(3.15)$$

This value of the available yawing moment coefficient is then constrained in the optimization problem to be greater than the required yawing moment coefficient, as shown in Equation (3.15).

To calculate the rudder deflection

$$\delta r = \frac{T_{l}\,L_{s}}{-q\,A_{w}\,b\,m_{y\,\delta_r}} = 25(\mathrm{deg}) \ldots\ldots\ldots\ldots\ldots\ldots (3.16)$$

3.7Why Can’t The Vertical Tail achieve Its Maximum Lift Coefficient?

The maximum available yawing moment is achieved with a bank angle of 5° and a sideslip angle of 3°. This orientation would be used for a failure of the left engine. The pilot or automatic flight control system would roll the aircraft 5° in the direction of the operating engine and yaw slightly away from it.

Note that in this flight condition, the vertical tail is only flying at an angle of attack of 3°,which is far below the angle of attack corresponding to the maximum lift coefficient of atypical vertical tail. One might expect that the maximum available yawing moment is obtained when the vertical tail is flying at its maximum lift coefficient, but this is not true because the equilibrium equations above must always be satisfied for steady flight. To illustrate this point, Eq. (2-5) has been solved for the bank angle with no thrust vectoring and no circulation control:

$$\emptyset = \sin^{-1}\left[\frac{(C_{l_{\delta r}}\,\delta r + C_{y_{\beta}}\,\beta)}{C_L}\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.17)$$

$\emptyset = 5$ (degree)

3.8 Stability and Control Derivative Estimation

The stability and control derivatives are estimated using the method of Roskam,which was adapted from the USAF Stability and Control DATCOM .

MacMillin used a similar approach for the High-Speed Civil Transport. InMacMillin’s work, however, the baseline stability and control derivatives were estimatedusing a vortex-lattice method, and the DATCOM method was only used to augment thesebaseline values with the effects due to changing the geometry of the vertical tail.The Fortran source code for the stability subroutine is shown in the Appendix.

3.8.1 Angle Of Sideslip Derivatives

3.8.1.1 Side Force Coefficient

The variation of side force coefficient with sideslip angle has contributions from the wing ,fuselage, and vertical tail. Note that all of the stability and control derivatives have units of rad-1.

C_{y_β}=$C_{y\beta_{wing}}+C_{y\beta_{fuse}}+C_{y\beta_{v.tail}}$ -1.54……………………………(3.18)

3.8.1.2 Rolling Moment Coefficient

The variation of rolling moment coefficient with sideslip angle has contributions from the

wing-body, horizontal tail, and vertical tail.

C_{l_β}=$C_{l\beta_{wb}}+C_{l\beta_{h.tail}}+C_{l\beta_{v.tail}}$= -0.29………………………………..(3.19)

3.8.1.3. Yawing Moment Coefficient

The variation of yawing moment coefficient with sideslip angle has contributions from

the wing, fuselage, and vertical tail.

$C_{n_\beta=}C_{n\beta_{wing}}+C_{n\beta_{fuse}}+C_{n\beta_{v.tai}}$ = 0.0019 …………………………………(3.20)

CHAPTER FOUR

RESULTS AND DISCOUSION

4.1 Results

Table (4. 1) shows the results

Variables	***Results***
V_S **(m/s)**	66.4
V_{lof} **(m/s)**	76.4
θ**(rad)**	0.021
S_g**(m)**	1747.5
S_a(m)	689.6
S_T(m)	2437.1
Side slip angle (β**) (deg)**	6
Banking angle ($\emptyset$**)(deg)**	5
Deflection Rudder(δ_r**) (deg)**	25
Deflection Aileron(δ_a**)(deg)**	8
Minimum control speed(m/s)	120

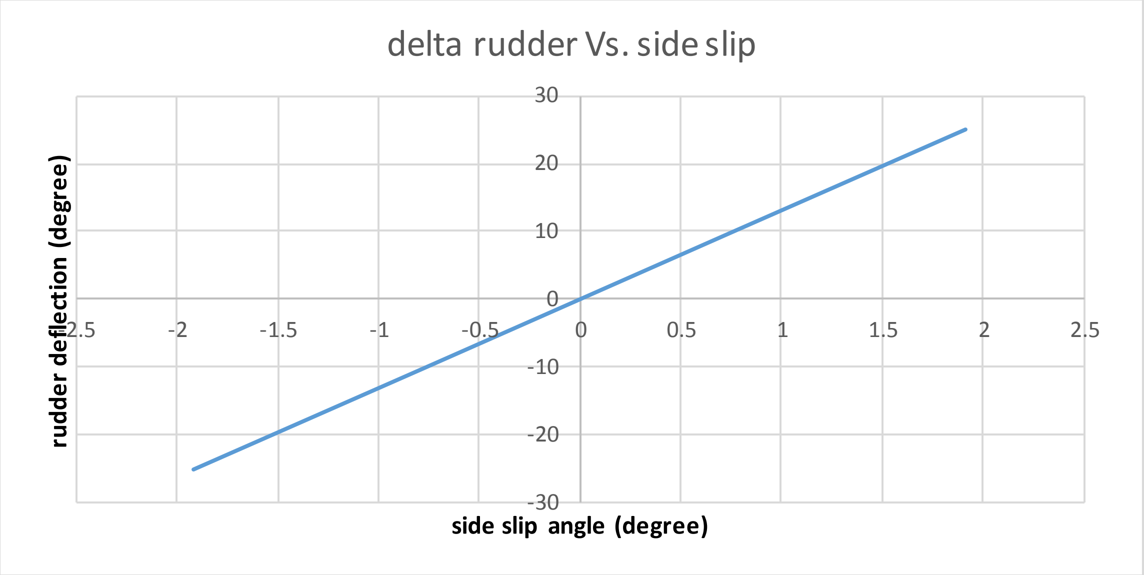

Fig. (4. 1) The relation between side slip angle and rudder deflection at steady flight

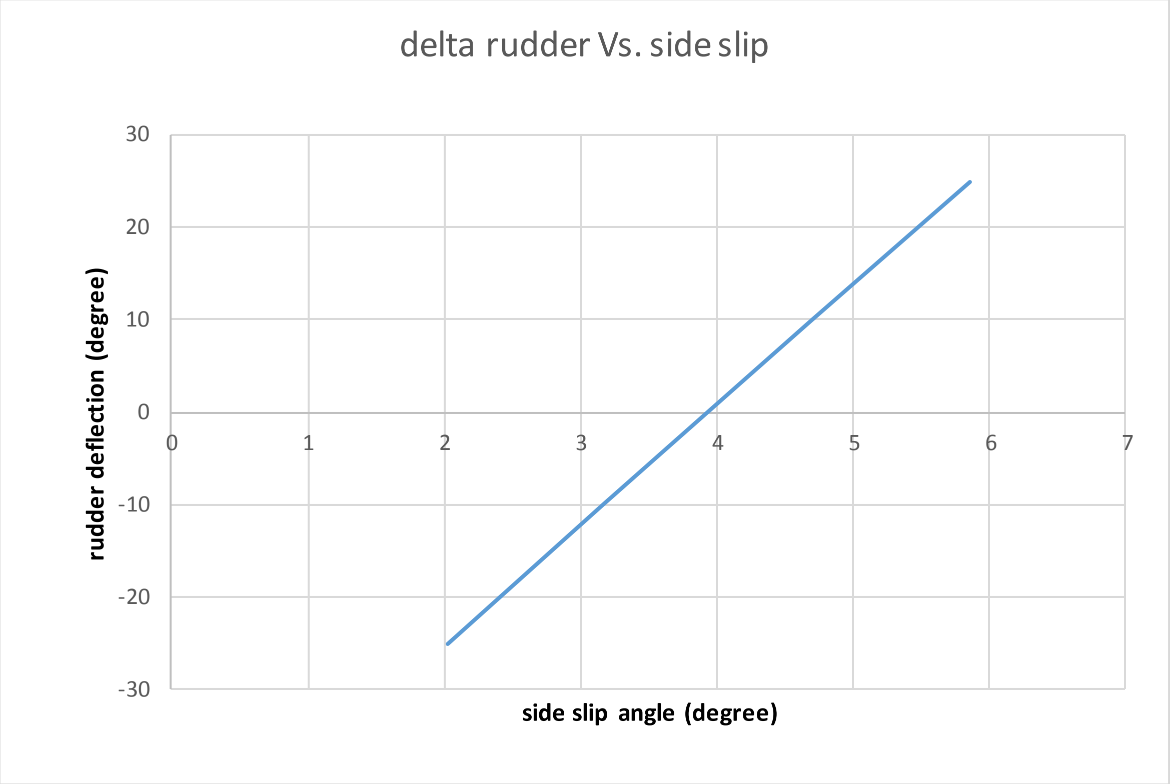

Fig. (4. 2) The relation between side slip angle and rudder deflection at one engine failure

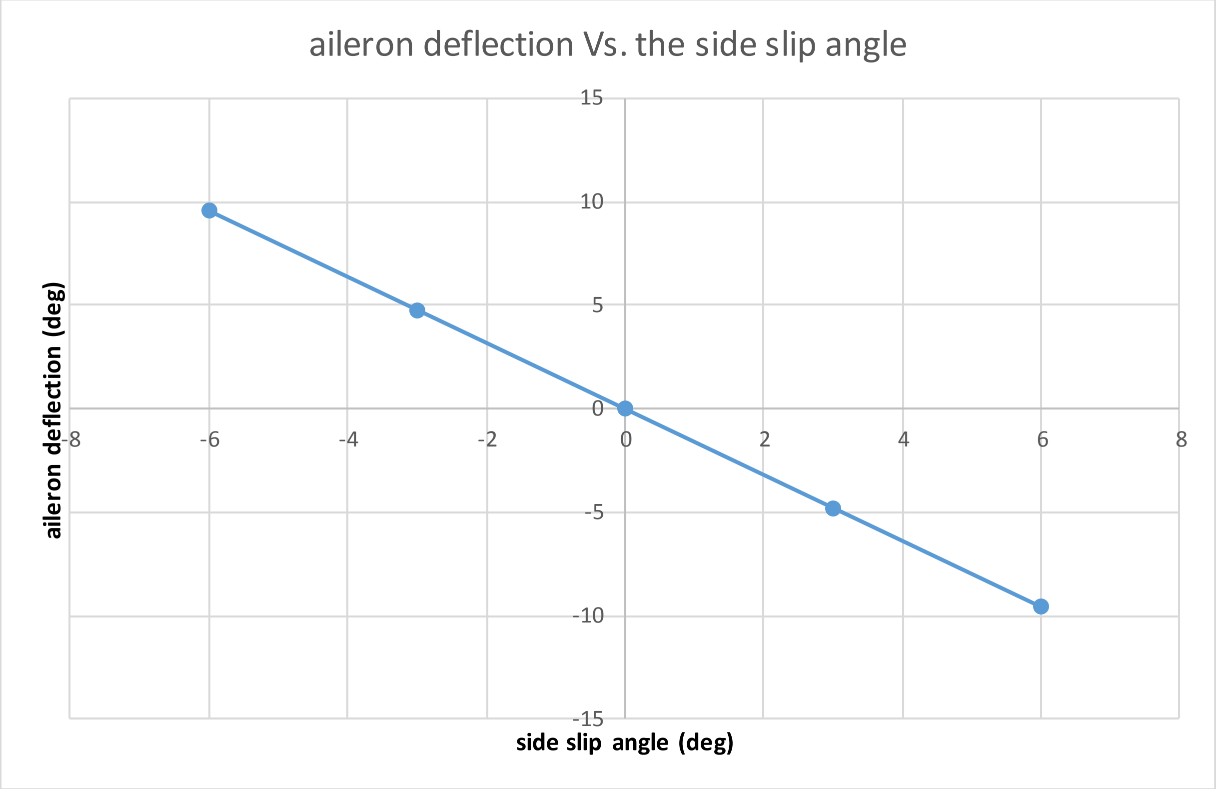

Fig. (4. 3) The relation between side slip angle and aileron deflection without engine failure

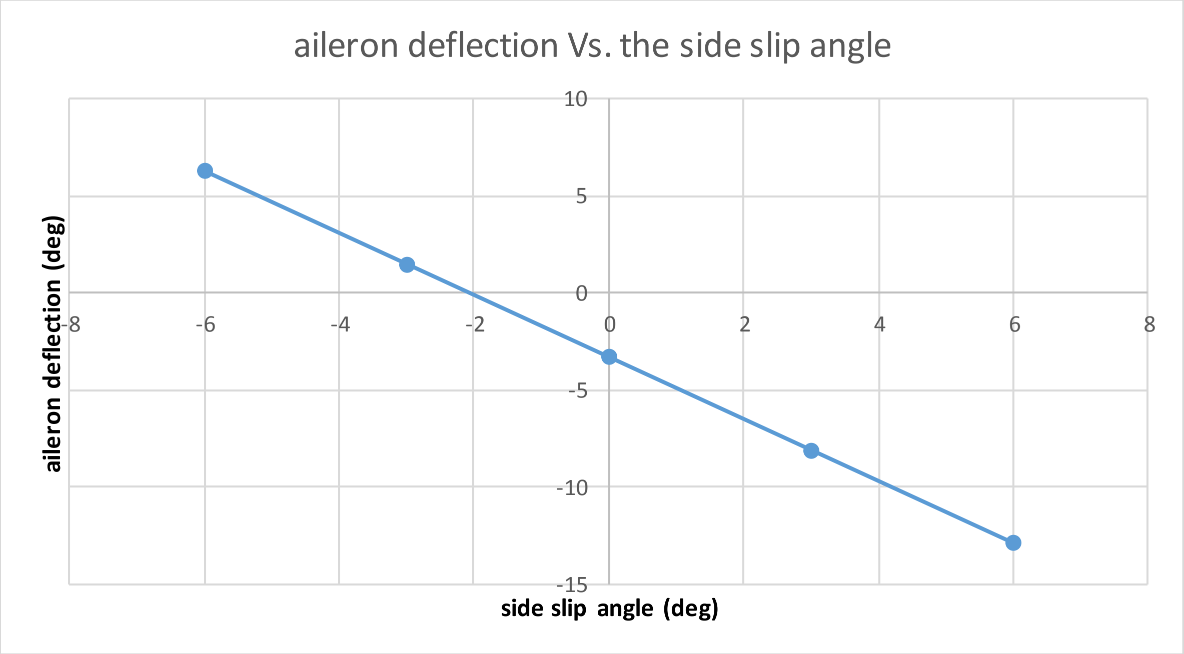

Fig. (4. 4) The relation between side slip angle and aileron deflection at one engine failure

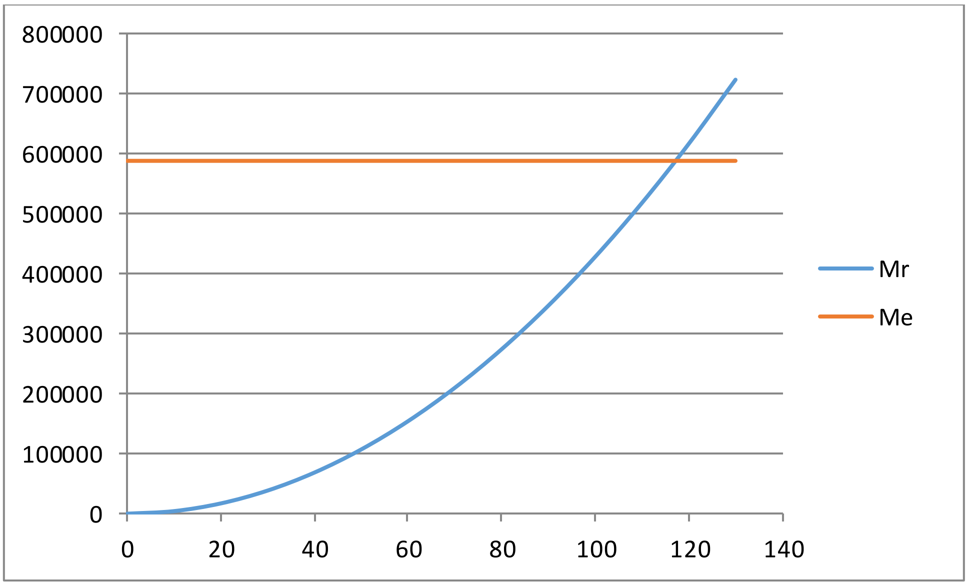

Fig. (4. 5) The relation between engine moment and moment required from rudder deflection

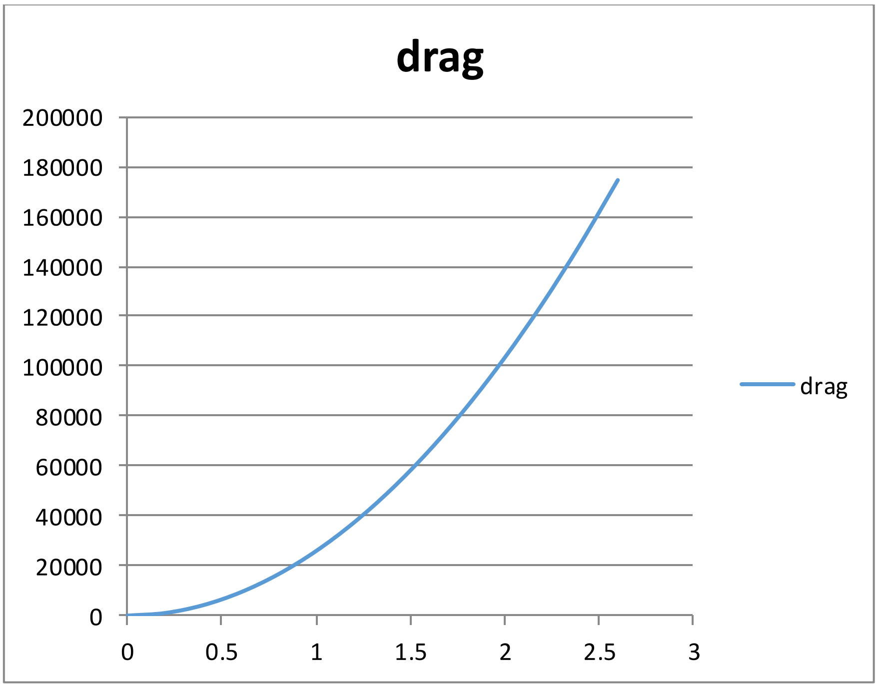

Fig. (4. 6) The relation between wind milling drag and mach number

4.2 Discussion

The graph (4_1)show the relation between side slip angle and rudder deflection , The vertical tail is the main component of static directional stability. When placed at an angle of attack due to the sideslip disturbance, it generates a side force which when multiplied by the moment arm (center of gravity of airplane to aerodynamic center of vertical tail) produces a stabilizing moment that tends to move the airplane back to a zero sideslip or yaw condition. Some observations are useful, however. The vertical tail usually has a low aspect ratio to prevent stalling. If a stall should occur, instability results and a catastrophic sideslip divergence may result. Adding more vertical tail by use of a dorsal fin extension or ventral tail area provides a stable yawing moment at large sideslip angles.

This graph is show the relation at steady flight (normal condition, without engine failure)

the graph(4_2) describe the relation when one engine failure , between side slip angle disturbed and the required rudder deflection to overcome,when the A/C large disturbed side slip angle the A/C required more deflection rudder to generate the adequate yaw moment to release the side angle.

The curve is not going to zero due to contribution of inoperative engine and bank angle.

The graph(4_3)show the relation between side slip angle and aileron deflection at normal condition, it can be clearly seen that , the graph is similar to general condition required to stability of A/C , when side slip angle increased in the positive direction , the aileron deflection will also increase but in negative direction (i.e when side slip angle is positive the aileron deflection is negative (seeControl Surface Sign Conventions)

The graph(4_4) show the same relation , but at one engine failure , it can be clearly seen that the graphs are same but we can observes that, the curve is shift down due to contribution engine operate and rudder deflection

The graph(4_5) show the relation between operative engine moment(Me) ,required moment(Mr) and velocity, the main purposed of graph is determine minimum control speed(Vmca) is that point of an intersection between (Me) and (Mr).

Finally, by compare the results and curve that ,all the results and curves are acceptable and similar of the stability rules

CHAPTER FIVE

CONCLOSION AND RECOMMENDATION

5.1 Conclusion

Through this project all the objective done , and study the condition of A/C when one engine failure during takeoff , we used Microsoft application to calculate side slip angle, banking angle , moment from operative engine(Me) , require moment from rudder to overcome (Me) , rudder and aileron deflections , liftoff speed, total takeoff distance, minimum control speed and other calculation .

In addition , we compare the results with other calculation and it was acceptable.

5.2Recommendation

1. we recommended to continue this study by avionics students for investigation of automatic control by computer in the future .
2. Study and design the automatic system of correct the directional and lateral stability.
3. Simulation for the automatic system.
4. study the performance of aircraft when one engine failure.

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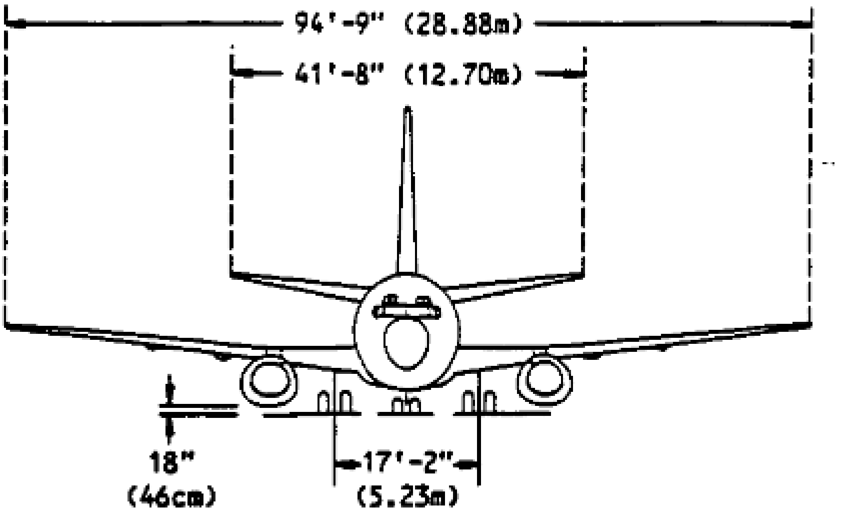
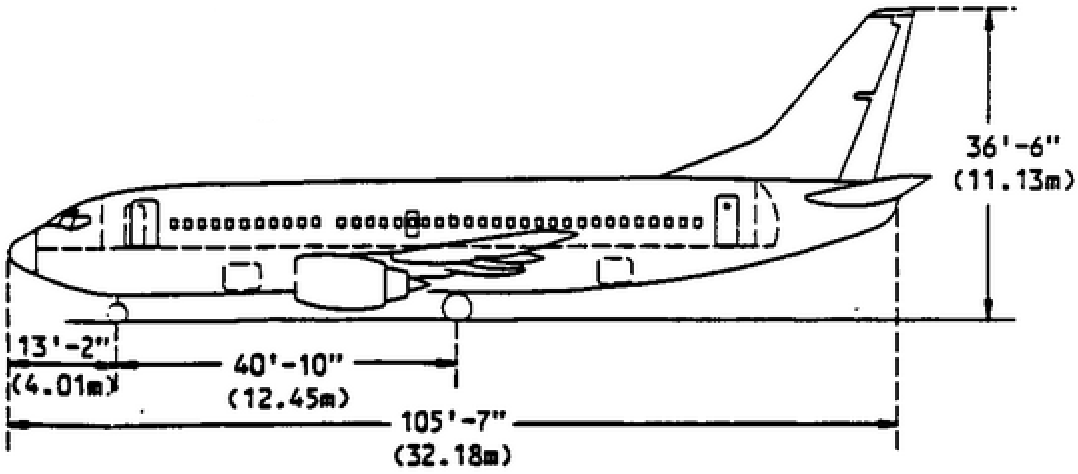
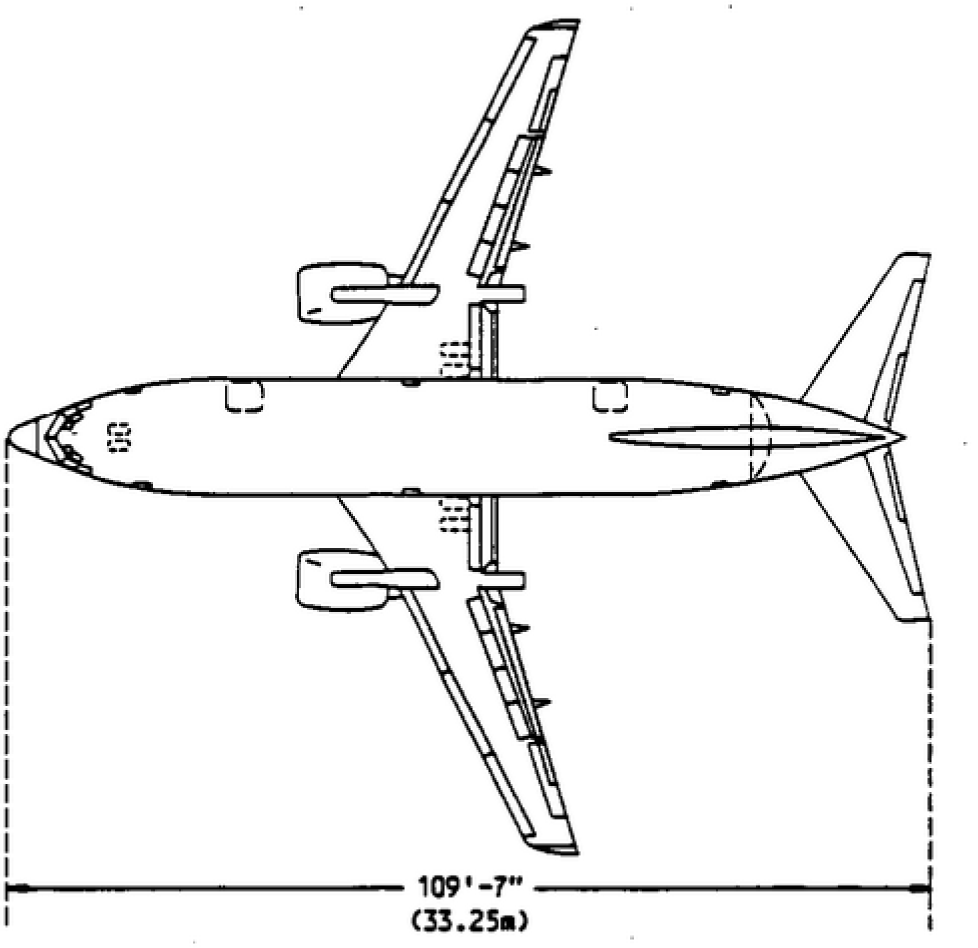
APPENDEX

Aircraft Schematics

Three view schematic drawings of the Boeing 737-300 aircraft can be seen in below figuresThey provide overall dimensions of the aircraft which are very useful in estimating parameters relevant to the research and analysis presented in the subsequent sections.







Aircraft Details

The details of the aircraft: powerplant specifications, aircraft geometry, weights and performance parameters are presented in the following sections.

Powerplant Details

The powerplant deployed for the -300 variant of the Boeing 737 aircraft is of CFM56-3.Its performance specifications can be referred below:

Model	CFM56-3
Type	-B2
Takeoff Thrust (kN)	98.1
Cruising Thrust (N)	22419
Bypass Ratio	5.9
SFC (cruise) lb/lb.hr	0.67
Engine Length (m)	2.36

Engine weight (kg)	1951
Fan diameter (in)	60
No of nacelles	2
Max Nacelle Width (m)	2
Length of Nacelle (m)	3.3
Cross sectional area (m2)	3.14

Wing Geometry

The geometrical details of the main wings used in the Boeing 737-300 aircraft are as follow:

Span (m)	28.88
Gross Area (m2)	105.4
Root Chord (m)	7.32
Tip Chord (m)	1.62
Mean Aerodynamic Chord (m)	3.41
Quarter chord Sweep (deg)	25
Dihedral (deg)	6
Aspect ratio	7.91
Taper ratio	0.240
Wing Twist (deg)	3
Incidence (deg)	1.4

Horizontal Tail Geometry

The details for the Horizontal tail of the aircraft are tabulated as shown below:

Span (m)	12.7
Gross Area (m2)	31.4
Elevators Area (m2)	6.55
Root Chord (m)	3.8
Tip Chord (m)	0.99
Mean Aerodynamic Chord (m)	2.5*
Quarter Chord Sweep (deg)	30
Aspect Ratio	5.14
Taper Ratio	0.260

Vertical Tail Geometry

The vertical tail of the aircraft possesses the following measurements.

Span (m)	6.15
Gross Area (m2)	23.13
Rudder Area (m2)	5.22
Root Chord (m)	5.7
Tip Chord (m)	1.8
Mean Aerodynamic Chord (m)	4.1
Quarter Chord Sweep (deg)	35
Aspect Ratio	1.49
Taper Ratio	0.31

Fuselage Details

The details of the fuselage of the aircraft are presented below.

Length (m) 32.18

Maximum diameter (m) 4.01

Weights

The weight data specified for the Boeing 737-300 aircraft are tabulated below

Maximum take Off weight (kg) 62820

Maximum landing weight (kg) 51710

Maximum zero-fuel weight (kg) 47625

Maximum ramp weight (kg) 56700

Fuel capacity (kg) 14410

Max payload (kg) 14805

Performance Details

The performance specifications known for the aircraft are presented below:

Wing Loading (kg/m2) 596.29

Thrust loading (kg/kN) 353.48

Thrust to Weight Ratio 0.2884

C_{Lmax}(T/O) at MTOW 2.16

C_{Lmax}(Landing) at MLW 2.88

Cruise Mach 0.745

Ceiling (ft) 37000

Range with max payload (nm) 2950

betta (deg)	-6	-3	0	3	6
delta _ a (deg)	6.261791005	1.477726	-3.30634	-8.09041	-12.87447057
vertical tail area (m^2)	23.13	23.13	23.13	23.13	23.13
z_tail	4	4	4	4	4
wing span (m)	28.88	28.88	28.88	28.88	28.88
max thrust N	98100	98100	98100	98100	98100
delta_r_max (deg)	-25	-25	-25	-25	-25
m_l_delta_r	-0.003357711	-0.00336	-0.00336	-0.00336	-0.003357711
m_l_betta	-0.295872985	-0.29587	-0.29587	-0.29587	-0.295872985
m_l_delta_a	0.185536543	0.185537	0.185537	0.185537	0.185536543
dynamic pressure	397.3434535	397.3435	397.3435	397.3435	397.3434535
wing area (m^2)	105.4	105.4	105.4	105.4	105.4
KM	1	1	1	1	1
Kf	0.85	0.85	0.85	0.85	0.85
sweep (C/2) deg	20	20	20	20	20
df (m)	4.01	4.01	4.01	4.01	4.01
CL max	2.16	2.16	2.16	2.16	2.16
dihedral (deg)	6	6	6	6	6
Arw	7.91	7.91	7.91	7.91	7.91
Zw (m)	2	2	2	2	2
av (1/deg)	0.1	0.1	0.1	0.1	0.1
aw (1/deg)	0.12	0.12	0.12	0.12	0.12
cybeta (25)	-1.549679339	-1.54968	-1.54968	-1.54968	-1.549679339
lv (m)	15	15	15	15	15
Zv (m)	4.3	4.3	4.3	4.3	4.3
alfa (rad)	0.226777778	0.226778	0.226778	0.226778	0.226777778
eps (deg)	2	2	2	2	2
tapper ratio	0.24	0.24	0.24	0.24	0.24
croot wing (m)	7.32	7.32	7.32	7.32	7.32
aileron effectiveness	0.5	0.5	0.5	0.5	0.5
CL_delta (1/deg)	-0.0018	-0.0018	-0.0018	-0.0018	-0.0018
bi (m)	9.5	9.5	9.5	9.5	9.5
bo (m)	12.6	12.6	12.6	12.6	12.6
ci (m)	4	4	4	4	4
co(m)	3.5	3.5	3.5	3.5	3.5

Input					
delta rudder (deg)	-25	-10	0	10	25
delta aileron (deg)	0	0	0	0	0
banking angle (deg)	0	0	0	0	0
engine max thrust (N)	98100	98100	98100	98100	98100
eps (deg)	0	0	0	0	0
wing area (m^2)	105.4	105.4	105.4	105.4	105.4
vertical tail area (m^2)	23.13	23.13	23.13	23.13	23.13
weight (N)	62820	62820	62820	62820	62820
density (kg/m^3)	1.225	1.225	1.225	1.225	1.225
Clmax	2.16	2.16	2.16	2.16	2.16
V. tail lift curve slope (1/deg)	0.1	0.1	0.1	0.1	0.1
l_v.tail	18	18	18	18	18
wing span (m)	28.88	28.88	28.88	28.88	28.88
V. tail efficiency	0.97	0.97	0.97	0.97	0.97
V. tail span (m)	6.15	6.15	6.15	6.15	6.15
rudder span (m)	1.845	1.845	1.845	1.845	1.845
rudder effectiveness	0.52	0.52	0.52	0.52	0.52
wing dihedral (deg)	6	6	6	6	6
AR	7.91	7.91	7.91	7.91	7.91
zw (m)	2	2	2	2	2
max fuselage depth (m)	4.01	4.01	4.01	4.01	4.01
sweep (c/4)	25.02	25.02	25.02	25.02	25.02
nacelle diameter (m)	2	2	2	2	2
Kwbi	0.85	0.85	0.85	0.85	0.85
Kcyp	0.75	0.75	0.75	0.75	0.75
calculated					
V. tail volume	0.13677614	0.136776138	0.13677614	0.13677614	0.136776138
Cy_delta_a	0	0	0	0	0
Cy_delta_r (1/rad)	-0.118645	-0.11864502	-0.118645	-0.118645	-0.118645024
Cy_beta (1/rad)	-1.5496793	-1.54967934	-1.5496793	-1.5496793	-1.549679339
velocity (m/s)	25.470061	25.47006097	25.470061	25.470061	25.47006097
dynamic pressure	397.343454	397.3434535	397.343454	397.343454	397.3434535
Kwbi	1.49875312	1.498753117	1.49875312	1.49875312	1.498753117
So	18.9028785	18.9028785	18.9028785	18.9028785	18.9028785
the side slipe angle at the test (rad)	-0.0333891	-0.01335564	0	0.01335564	0.03338911
the side slipe angle at the test (deg)	-1.9140254	-0.76561015	0	0.76561015	1.914025386
banking angle (rad)	0.088030338	0.108063803	0.121419447	0.134775	0.154808557
banking angle (deg)	5.046325086	6.194740317	6.960350472	7.725961	8.874375857

banking angle (deg)	5	5	5	5	5
rudder deflection	25	25	25	25	25