Design of Air Traffic Control Operation System

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***5th International Workshop on Numerical Modelling in Aerospace Sciences, NMAS 2017**, 17-18 May 2017, Bucharest, Romania, (held at INCAS, B-dul Iuliu Maniu 220, sector 6) Section 2 – Flight dynamics simulation*

***Abstract:** This paper presents a numerical simulation for a different aircraft, based on the specific aircraft data that can be incorporated in the model and the equations of motions which can be consequently solved. The aircraft flight design involves various technical steps and requires the use of sophisticated software having modeling and simulation capabilities. Within the flight simulation model, the aerodynamic model can be regarded as the most complex and most important. With appropriate aerodynamic modeling the aerodynamic forces and moments acting on the aircraft's center of gravity can be numerically solved with accuracy. These forces and moments are further used to solve the equations of motion. The development of control and computing technology makes it possible for advanced flight control strategy. The advanced control techniques tend to make the control design and their implementation much more complicated with more control loops or channels; in this line, the autopilot of modern aircrafts includes a variety of automatic control systems that aid and support the flight navigation, flight management, and perform the enhancing and/or augmenting of the stability characteristics of the airplane. Therefore in this context it is very important to choose the dynamic that will satisfy the performance and robustness specifications.*

***Key Words:** Air Traffic Control, control design, robustness, simulation capabilities.*

1. INTRODUCTION

Aircrafts are usually controlled by basic control surfaces like ailerons, elevators and rudders, supported by additional control surfaces: stabilizer, spoilers, flaps and by control of the engine thrust. Aircraft motion for various degrees of freedom is controlled by single or multiple control surfaces. The conventional operation of control surfaces has various design limitations. Several methods and algorithms are available for the implementing reconfiguration of automatic flight control system, [9, 11].

Navigation, communication, radar, and other special equipment are severely limited if the pilot has to work continually on the physical manipulation of the controls. In high-performance aircraft capable of supersonic flight, the aircraft speed is so great that the pilot's normal response time is far too slow. By the time the pilot reacts to an indicator to position a control surface, the aircraft may already be out of control, [9, 11].

Automatic flight control and stabilization systems ease the pilot's workload and provide aircraft stability at all speeds. Automatic Flight Control Systems are capable of flying the aircraft by radio navigation aids, correcting for wind, and making pilot unaided landings, [9].

Boeing and Airbus each embrace automation but their philosophies differ with regard to the most appropriate way to apply it. Both companies say their designs give ultimate control of the aircraft to the pilots. Yet fundamentally, Airbus' philosophy is automation-centric while Boeing's is human-centric. Airbus focuses more on avoiding pilot error than on taking advantage of human capabilities. It does so from the outside by allowing automation at times to override the pilot and his decision making. This can be seen in Airbus' publicly available philosophy statement, which says that "all aircraft have physical limits that they must not exceed" and that such flight-envelope limits "are not to be exceeded during normal operations." Boeing, in contrast, focuses more on taking advantage of human performance or the pilots' collective physiological and psychological performance capabilities rather than avoiding human error. Boeing does so from the inside out by using automation to aid the pilot in his decision making. According to Boeing philosophy, automation implies "to assist, but not replace, the flight crew member responsible for safe operation of the airplane." In short, Boeing guides the pilot; Airbus limits the pilot, [12].

Answering the question of which philosophy is better can be as complex as the software code that drives the industry's state-of-the-art automation.

2. FLIGHT CONTROL SYSTEM

Let's note some basic operational similarities between Airbus and Boeing's automation implementation. Pilots aboard both aircraft can generally disengage the autopilot and auto throttles simply by using disconnect buttons. This gives manual control of the flight controls and throttles back to the pilot. But the pilot of a Boeing aircraft can also disengage the autopilot by applying sufficient force to the center control yoke. This can be an advantage in the event of a sudden traffic conflict avoidance maneuver, for instance. Yet in an Airbus aircraft, a push on the side stick controller, no matter the force or rate, will not disconnect the autopilot, [12]. The autopilot is only a portion of the automation control. It is in the flight control computers that the philosophical difference between the two manufacturers is most noticeable operationally. Both manufacturers provide flight envelope protection by way of software-defined limitations in the Flight Control Computer - FCC. The difference between the two, though, is that Airbus defines hard flight envelope limits, beyond which the pilot cannot go regardless of circumstance. Only some pitch and roll limitations, but not load-factor limitations, are shed during a dual FCC failure in "alternate law" mode. More, but still not all, limitations are shed if all three FCCs fail, termed "direct law" mode, [12].

By contrast, Boeing sets soft limits that pilots can go beyond if they deem it necessary. This would typically occur during abnormal and emergency operations, but it is available during normal operations as well. And unlike the autopilots and auto throttles, the FCCs in either Boeing or Airbus aircraft cannot be disconnected by a pilot in a normal operational manner. This means in the Airbus design some flight envelope limitations are always present, even during abnormal or emergency operations, [12].

Airbus's philosophy appears to be that automation generally knows better than the pilot and should, under most circumstances, have the final decision authority. Boeing takes the view that the pilot is best able to evaluate individual, and possibly unique, operational circumstances and should make the ultimate decision. While Airbus' design protects the aircraft from inadvertent pilot error during normal flight, Boeing's more directly addresses abnormal and emergency operations, in the belief that under some circumstances it is better to allow the pilot to "bend" the aircraft than to potentially increase the risk of a crash, [12].

In the Airbus design, one pilot does not see the other pilot's side stick inputs reflected in movement of his own side stick; instead, the side sticks move independently of each other. By contrast, when one pilot of a Boeing aircraft moves his yoke, the movement is mirrored by the other yoke, [12].

Also in the Airbus design, autopilot inputs go unseen by the pilots because the side sticks do not move in response to the autopilot commands. Similarly, auto throttle inputs do not move the throttle levers, designs that collectively contribute to lack of automation transparency. In Boeing's fly-by-wire design, autopilot and auto throttle inputs are also seen in yoke and throttle lever movements. Also, the Boeing design adds artificial forces and electromechanical systems to retain the traditional "feel," or aerodynamic feedback, of flying the airplane, something Airbus lacks. All this provides the Boeing pilot with a more intuitive insight into what the aircraft is doing improving automation transparency and situational awareness, [12].

More complex automation systems, such as Airbus, can lead to degradation of human performance. Automation complexity requires more analytically demanding decision making by pilots, which in turn increases cognitive workloads, [12].

Thus, Boeing's philosophy of automation simplicity is a distinct advantage. While computers may be gaining on the human brain, it remains the most capable, flexible and adaptable complex processor in the world.

Construction of avionics systems requires large teams of engineers from a wide variety of disciplines, including computer and software engineering.

The construction costs, maintenance costs, and operational weight of all the different mechanical elements made them targets for replacement with digital technology, and that led to the introduction of fly-by-wire control. The term fly-by-wire usually refers to the combination of the communication of control signals over a digital data bus and the use of those signals by computers within the aircraft structure for adjustment of the control surfaces and the engine settings. As airplanes have thus become flying computer systems, avionics has assumed an increasingly significant role in their development and production, [13-14].

The ATC is responsible for scheduling aircraft to use runways and assigns runways in a way that will maintain sufficient separation between aircraft, [14-15].

The Terminal Radar Control Center or TRACON controllers are responsible for managing aircraft in the airspace around airport (terminal) using airport radar. In addition to their primary task of maintaining separation between aircraft, TRACON controllers assign arrival and departure routes to aircraft landing at and taking off from the terminal, respectively. Upon notification from the local controller that a runway is clear, the TRACON controller will give clearance to descend and approach the runway to the next aircraft waiting to land. Each TRACON controller monitors some of the sectors of the airspace, where the size and number of sectors are dependent on the volume of air traffic in the area (sectors are larger or a controller will monitor several sectors at night, for instance), [14-15].

En route flight is generally restricted to specific routes, called airways, where aircraft are assigned to routes and flight levels by ATC. Air route traffic control centers (ARTCCs) divide covered airspace into sectors, with 1-2 controllers monitoring each sector to ensure adequate separation. The required separation between aircraft is generally higher than in the terminal area because of imprecision in radar coverage, faster travel speeds, and lower volumes of traffic in non-terminal airspace, [14-15].

As the aircraft progresses along its route, it is handed off to other controllers as it passes from one area to the next. In some remote areas - primarily oceanic regions - no radar coverage exists, so no standard ATC coverage exists. Instead, controllers in specific coastal centers are responsible for communicating with pilots flying in those regions to determine an aircraft's position and intent, [14-15].

With increasing volumes of air traffic, the time dimension of the flight plan becomes more and more important. En route controllers attempt to direct flights to their destination TRACONs as quickly as possible without forcing them to wait for landing clearance, [14].

Navigation systems that monitor signals from continuous-wave radio stations are able to follow lanes that can be counted to keep track of course. Fine positioning can be achieved through phase measurement. If a gap in radio coverage occurs, the system must be reinitialized. The most recent inertial navigation systems have been able to reduce drift rates to less than 0.1 degrees per hour by using evacuated cavities or optical fibers that contain counter-rotating laser beams. The phases of these lasers are compared in order to derive acceleration, [14-15]. Navigation software is embedded in either a central processor, with other aviation software, or in navigation computers. It is the job of the software to process sensor data using well-established algorithms. In order to accomplish this, the software utilizes calibration constants, initialization sequences, self-test algorithms, and reasonability tests. The software is also responsible for providing alternate processing schema for handling situations in which sensors fail or are not receiving data, [14-15].

In order to address CNS/ATM, Airbus created a program called Airbus Interoperable Modular Future Air Navigation System (AIM-FANS). AIM-FANS was charged with finding a means of implementing CNS/ATM in Airbus aircraft that would be easy to install and upgrade, reducing the costs and complications of future changes. [14-15].

The Flight Control System - FCS in an aircraft provides the basic interface between the pilot and the aircraft's control surfaces. This interface is the pilot's most direct means of flying the aircraft and is also used by higher-level control systems such as the autopilot and Flight Management System. Traditionally, FCSs have not been avionics systems but rather mechanical or hydraulic systems. The Digital Flight Control Systems have become nearly ubiquitous in modern commercial aircraft, most notably in the Airbus A 320/330/340 and Boeing 777 jetliners. These systems, in which pilot commands are processed by computers and relayed to control surfaces via electrical cables, offer significant benefits over their traditional counterparts. Digital Flight Control Systems carry lower production and maintenance costs, alleviate pilot workload by automatically handling certain aspects of flight, and can improve flight safety and passenger comfort by limiting the pilot's ability to overstress the aircraft. Serious technical and philosophical challenges accompany these benefits, however, such as assuring the dependability of the computer systems required for Digital Flight Control and deciding to what extent the pilot should have authority over the automation. Flight control has been, and continues to be, one of the most critical design considerations for the development of commercial aircraft, [13-15].

The differential equations describe the time evolution of the position of the aircraft C.G. relative to earth axes ([4-6]):

$$\begin{aligned}\dot{x_E} &= u\cos\Psi\cos\theta + v(\cos\Psi\sin\theta\sin\emptyset - \sin\Psi\cos\emptyset) + \\ &\quad + w(\cos\Psi\sin\theta\cos\emptyset + \sin\Psi\sin\emptyset)\end{aligned} \tag{1}$$

$$\dot{y_E} = u\,\sin\Psi\cos\theta + v(\sin\Psi\sin\theta\sin\emptyset + \cos\Psi\cos\emptyset) + \\ +w(\sin\Psi\sin\theta\cos\emptyset - \cos\Psi\sin\emptyset) \tag{2}$$

$$\dot{h} = u\,\sin\theta - v\cos\theta\sin\emptyset - w\,\cos\theta\cos\emptyset \tag{3}$$

$$a_X = \frac{\bar{q}SC_X + T}{mg} \tag{4}$$

$$a_y = \frac{\bar{q}SC_Y}{mg} \tag{5}$$

$$a_Z = \frac{\bar{q}SC_Z}{mg} \tag{6}$$

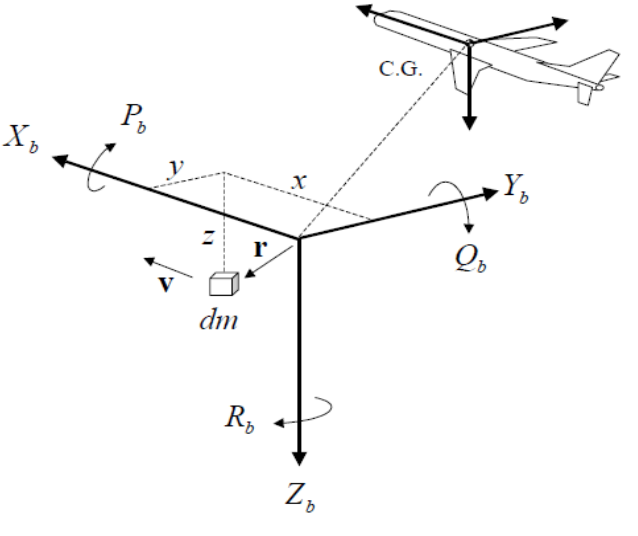

Fig. 1 - Moment of inertia coordinates

The rotational kinematic equations, which relate Euler angular rates to body-axis angular rates, are given by ([4-6]):

$$\dot{\emptyset} = p + \tan\theta(q\,\sin\emptyset + r\,\cos\emptyset) \tag{7}$$

$$\dot{\theta} = q\,\cos\emptyset - r\,\sin\emptyset \tag{8}$$

$$\dot{\Psi} = \frac{q\,\sin\emptyset + r\,\cos\emptyset}{\cos\theta} \tag{9}$$

The nonlinear aircraft dynamics in translational and rotational motion [4-6]:

$$\dot{u} = rv - qw - g\sin\theta + \frac{\bar{q}SC_X + T}{m} \tag{10}$$

$$\dot{v} = pw - ru + g\cos\theta\sin\emptyset + \frac{\bar{q}SC_Y}{m} \tag{11}$$

$$\dot{w} = qu - pv + g\cos\theta\cos\emptyset + \frac{\bar{q}SC_Z}{m} \tag{12}$$

$$\dot{p}I_X - \dot{r}I_{XZ} = \bar{q}SbC_l - qr(I_Z - I_Y) + qpI_{xz} \tag{13}$$

$$\dot{q}I_Y = \bar{q}S\bar{c}C_m - pr(I_X - I_Z) - (p^2 - r^2)I_{XZ} - rh_{eng} \tag{14}$$

$$\dot{r}I_Z - \dot{p}I_{XZ} = \bar{q}SbC_n - pq(I_Y - I_X) - qrI_{XZ} + qh_{eng} \tag{15}$$

$$h_{eng} = [h_{eng} \quad 0 \quad 0]^T = [I_{eng}\cdot\omega_{eng} \quad 0 \quad 0]^T \tag{16}$$

$$V_t = \sqrt{u^2 + v^2 + w^2} \tag{17}$$

$$\propto = \tan^{-1}\left(\frac{w}{u}\right) \tag{18}$$

$$\beta = \sin^{-1}\left(\frac{v}{V_t}\right) \tag{19}$$

$$u = V_t\cos\propto\cos\beta \tag{20}$$

$$v = V_t\sin\beta \tag{21}$$

$$w = V_t\sin\propto\cos\beta \tag{22}$$

$$\dot{V}_t = \frac{u\dot{u}}{V_t} + \frac{v\dot{v}}{V_t} + \frac{w\dot{w}}{V_t} \tag{23}$$

$$\dot{\propto} = \frac{u\dot{w}}{u^2 + w^2} - \frac{w\dot{u}}{u^2 + w^2} \tag{24}$$

$$\dot{\beta} = \frac{V_t\dot{v} - v\dot{V}_t}{V_t^2\sqrt{1 - \left(\frac{v}{V_t}\right)^2}} \tag{25}$$

$$\dot{p} = \left(c_1 r + c_2 p + c_4 h_{eng}\right)q + \bar{q}Sb(c_3 C_l + c_4 C_n) \tag{26}$$

$$\dot{q} = \left(c_5 p - c_7 h_{eng}\right)r - c_6(p^2 - r^2) + \bar{q}S\bar{c}c_7 C_m \tag{27}$$

$$\dot{r} = \left(c_8 p - c_2 r + c_9 h_{eng}\right)q + \bar{q}Sb(c_4 C_l + c_9 C_n) \tag{28}$$

$$c_1 = \frac{(I_Y - I_Z)I_Z - I_{XZ}^2}{I_X I_Z - I_{XZ}^2} \tag{29}$$

$$c_2 = \frac{(I_X - I_Y + I_Z)I_{XZ}}{I_X I_Z - I_{XZ}^2} \tag{30}$$

$$c_3 = \frac{I_Z}{I_X I_Z - I_{XZ}^2} \tag{31}$$

$$c_4 = \frac{I_{XZ}}{I_X I_Z - I_{XZ}^2} \tag{32}$$

$$c_5 = \frac{I_Z - I_X}{I_Y} \tag{33}$$

$$c_6 = \frac{I_{XZ}}{I_Y} \tag{34}$$

$$c_7 = \frac{1}{I_Y} \tag{35}$$

$$c_8 = \frac{(I_X - I_Y)I_X - I_{XZ}^2}{I_X I_Z - I_{XZ}^2} \tag{36}$$

$$c_9 = \frac{I_X}{I_X I_Z - I_{XZ}^2} \tag{37}$$

3. AIR TRAFFIC CONTROL OPERATION SYSTEM

The longitudinal autopilot controls the pitch orientation of the aircraft. The elevator is the primary pitch control device. The longitudinal autopilot has two major control modes. Vertical Path Control - VPC is used to hold a given altitude during normal flight, [7-8]. Once glide slope is engaged and a final Instrument Landing System - ILS approach begins, the longitudinal autopilot switches to Autoland mode. The glide slope error is used to close the pitch control loop. The autopilot commands pitch down if the aircraft is coming in too high; pitch up if too low. This continues until the altitude where the flare mode begins is attained. Then, a preprogrammed pitch profile for the flare is commanded. Flying aircraft are controlled by autopilots to follow commanded trajectories, [4-6]:

$$\dot{x}_{com} = V_{com}(t) \sin \Psi_{com}\ (t) + \widehat{W}_x\ (t) \tag{38}$$

$$\dot{y}_{com} = V_{com}(t) \cos \Psi_{com}\ (t) + \widehat{W}_y\ (t) \tag{39}$$

$$\begin{bmatrix} \xi \\ \eta \end{bmatrix} = \begin{bmatrix} \sin \Psi_{com} & \cos \Psi_{com} \\ \cos \Psi_{com} & -\sin \Psi_{com} \end{bmatrix} \begin{bmatrix} x - x_{com} \\ y - y_{com} \end{bmatrix} \tag{40}$$

$$\eta = (x - x_{com}) \cos \Psi_{com} - (y - y_{com}) \sin \Psi_{com} \tag{41}$$

$$\xi = (x - x_{com}) \sin \Psi_{com} + (y - y_{com}) \cos \Psi_{com} \tag{42}$$

$$\ddot{h} = \dot{V}\ \sin \gamma + \dot{\gamma}\ \ V \cos \gamma + \dot{W}_h \tag{43}$$

$$x_n(t) = x_{n,0} + W_{x,n} t + \frac{V_{n,0}}{\dot{\Psi}_n} \cos \Psi_{n,0} - \frac{\dot{V}_n}{\left(\dot{\Psi}_n\right)^2} \sin \Psi_{n,0} - \frac{V_{n,0} + \dot{V}_n t}{\dot{\Psi}_n} \cos \Psi_n(t) + \frac{\dot{V}_n}{\left(\dot{\Psi}_n\right)^2} \sin \Psi_n(t) \tag{44}$$

$$y_n(t) = y_{n,0} + W_{y,n} t + \frac{V_{n,0} + \dot{V}_n t}{\dot{\Psi}_n} \sin \Psi_n(t) - \frac{V_{n,0}}{\dot{\Psi}_n} \sin \Psi_{n,0} + \frac{\dot{V}_n}{\left(\dot{\Psi}_n\right)^2} \left[\cos \Psi_n(t) - \cos \Psi_{n,0}\right] \tag{45}$$

$$h_n(t) = h_{n,0} + \dot{h}_n t \tag{46}$$

$$W_{x,n} = \widehat{W_x}\ \ ;\ \ W_{y,n} = \widehat{W_y} \tag{47}$$

$$x_n(t) = x_{n,0} + \left(V_{n,0}\sin\Psi_{n,0} + W_{x,n}\right)t + \frac{1}{2}\left(\dot{V}_n \sin\Psi_{n,0}\right)t^2;\ \dot{\Psi}_n = 0 \tag{48}$$

$$y_n(t) = y_{n,0} + \left(V_{n,0}\cos\Psi_{n,0} + W_{y,n}\right)t + \frac{1}{2}\left(\dot{V}_n \cos\Psi_{n,0}\right)t^2;\ \dot{\Psi}_n = 0 \tag{49}$$

$$a(t) = (x - x_n)\sin\Psi_n + (y - y_n)\cos\Psi_n \tag{50}$$

$$b(t) = (x - x_n)\cos\Psi_n - (y - y_n)\sin\Psi_n \tag{51}$$

$$\Delta h = h - h_n(t) = h - h_{com}(t) + h_{com} - h_n = \Delta h_{com}(t) + \Delta h_s + \Delta\dot{h}_s t \tag{52}$$

$$\begin{aligned} a(t) = {} & \xi\cos(\Psi_n - \Psi_{com}) + \eta\sin(\Psi_n - \Psi_{com}) + (x_{com} - x_n)\sin\Psi_n \\ & + (y_{com} - y_n)\cos\Psi_n \end{aligned} \tag{53}$$

$$\begin{aligned} b(t) = {} & -\xi\sin(\Psi_n - \Psi_{com}) + \eta\cos(\Psi_n - \Psi_{com}) + (x_{com} - x_n)\cos\Psi_n \\ & - (y_{com} - y_n)\sin\Psi_n \end{aligned} \tag{54}$$

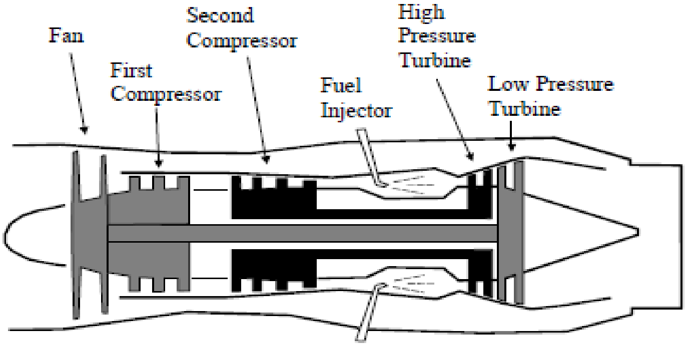

Fig. 2 - Turbofan Engine B-737

The engine used in the B-737 linear Autoland model is Pratt and Whitney JT8D-7. It is an example of the turbofan type of jet engine.

A jet engine works by compressing the air and injecting fuel into a combustion chamber.

The increase in temperature from the burning of the fuel increases the energy content of the air.

This hot air is expanded through a turbine to provide energy to compress new intake air. The energy remaining in the hot air is converted to kinetic energy of motion of the air expelled from the nozzle.

A turbofan engine has two compressors in front of the combustion chamber and two turbines following it.

Some air from the first compressor is ducted around the combustion chamber and turbines and is called “bypass air”.

This is done to increase fuel efficiency by reducing the speed of the nozzle flow but increasing the mass flow. [11]

The primary control parameter of the jet engine is the fuel flow rate into the combustion chamber. The throttle setting controls this fuel flow.

The throttle setting is transferred using a cable arrangement to a Fuel Control Unit Power Lever.

The setting of the Power Lever is called the “Cross Shaft Angle” (CSA). CSA, Cross Shaft Angle is the 'power lever' fuel flow setting on the fuel control unit for the engine, [11].

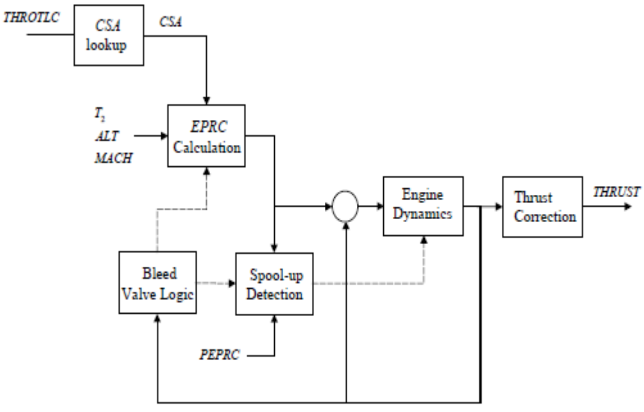

Fig. 3 - Engine model for B-737

Engine pressure ratio is the ratio of the compressor inlet pressure to the nozzle exit pressure. It is the primary feedback parameter that is used to set thrust. It is measured using small pitot tubes in front of the compressor and behind the nozzle. The pressure altitude and ambient air temperature affect EPR settings. The amount of compressor bleed air being used to prevent compressor stall, anti-icing and turbine cooling will also affect the setting, [9-11].

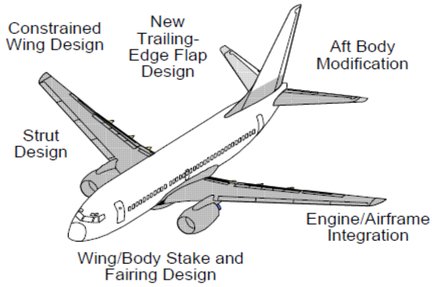

Fig. 4 - Effect of CFD - Computational Fluid Dynamics on the Next Generation B-737

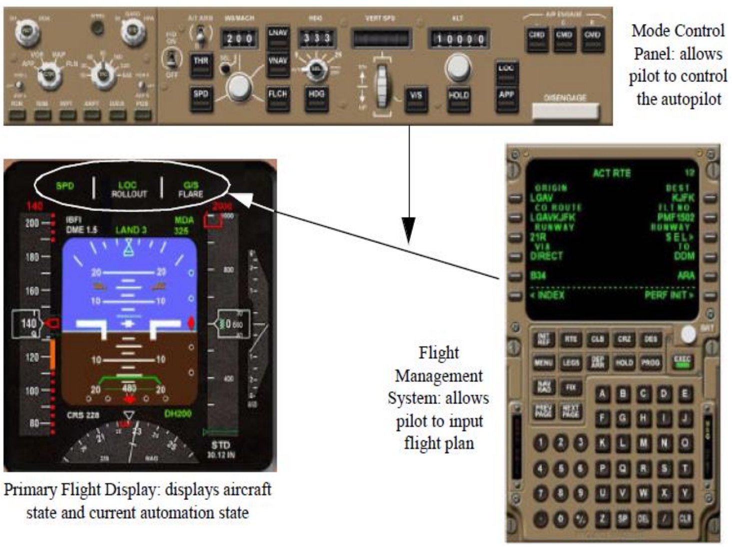

Fig. 5 - MCP, PFD and FMS relationship

The Autopilot Flight Director System - AFDS allows a Digital Flight Guidance Computer to control the aircraft instead of the pilot. The pilot can choose to use the AFDS to follow a Flight Plan- FP entered into the Flight Management System - FMS, or he can enter a specific heading, speed and altitude for the aircraft to maintain, [9-11].

When a pilot wants to use the Autopilot to control speed, he has two options. He can use either the engine thrust or the aircraft pitch. If he decides to use thrust, he would normally engage the basic thrust mode, which maintains a speed specified by the FMS or the speed window on the MCP, [9-11].

Alternatively, if the pilot chooses to control speed by using the aircraft pitch, he would use the basic pitch mode and the FMA would read "Pitch" on the MD-11 and "VNAV SPD" or "FLCH SPD" on the B-737.

The modes in the MD-11 are organized based on what is being controlled: speed, roll, or altitude. Regardless of how the modes are organized on the aircraft, there are three main categories of autopilot modes, based on function. A mode controls either speed, horizontal path, or vertical path, [9-11].

The Autopilot Flight Director System makes it possible for the aircraft to follow a Flight Plan without needing continuous inputs from the pilot.

4. NUMERICAL SIMULATION AND CONCLUSIONS

The most prominent feature of the Primary Flight Display is the Artificial Horizon Located in the center of the display.

The horizon line moves as the B-737 begins to pitch and roll. This allows the pilot to monitor the position of the B-737 relative to the horizon.

The pitch scale, or pitch ladder, marks off degrees of pitch using a number of lines parallel to the horizon.

The current airspeed and altitude can be read from the vertical bars to the left and right of the display, respectively, [1-3].

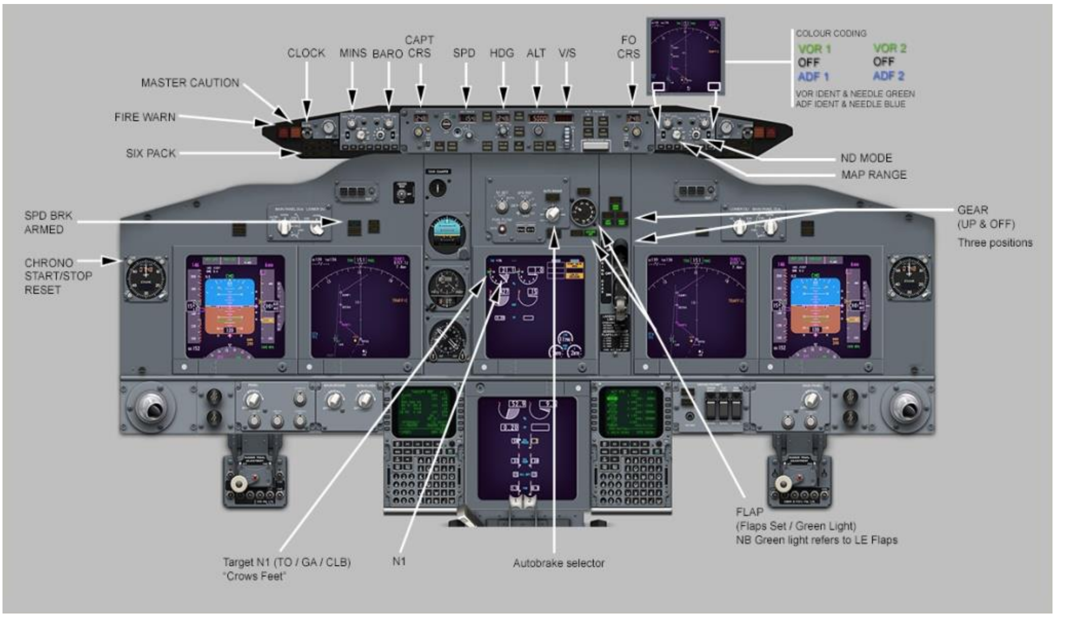

Fig. 6 - Modern PFD_1- B-737 [13]

Fig. 7 - PFD_2 - B-737 [13]

Fig. 8 - PFD_3 - B-737 [13]

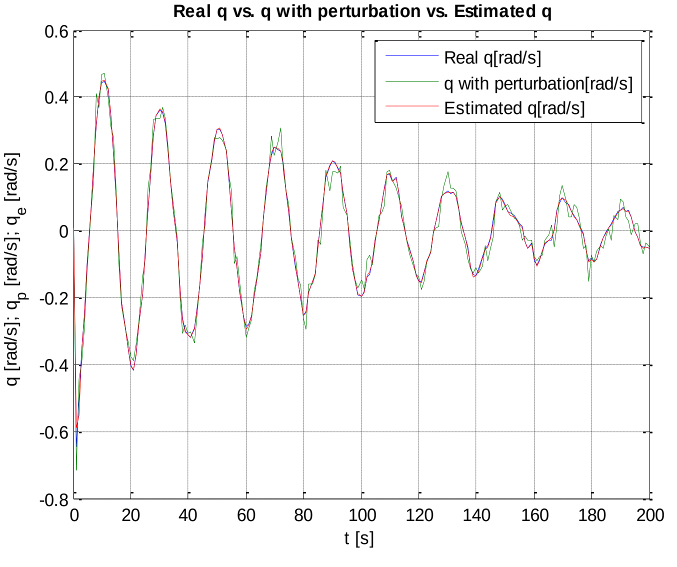

Fig. 9 - Real q vs.q with perturbation vs. estimated q

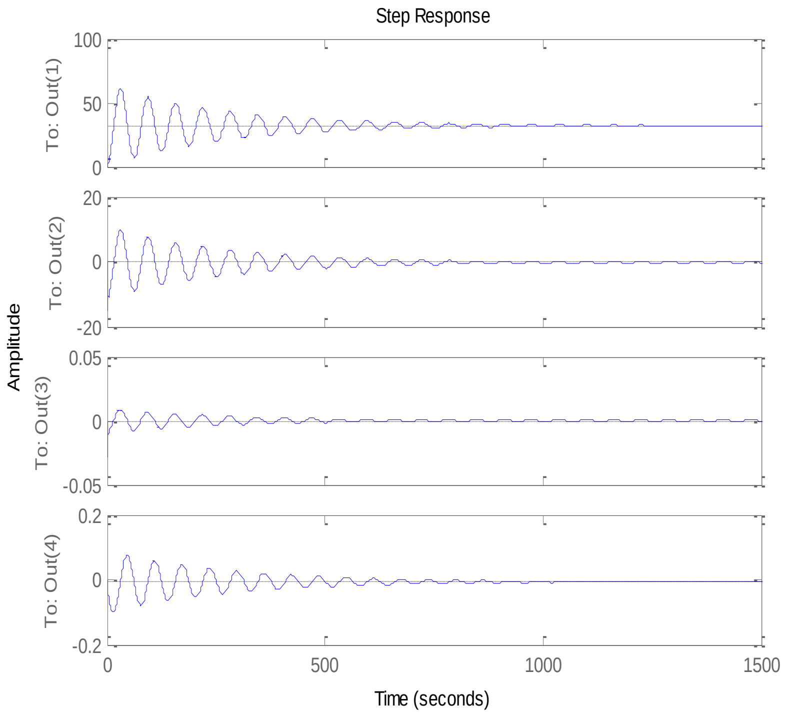

Fig. 10 - Aircraft- Step Response

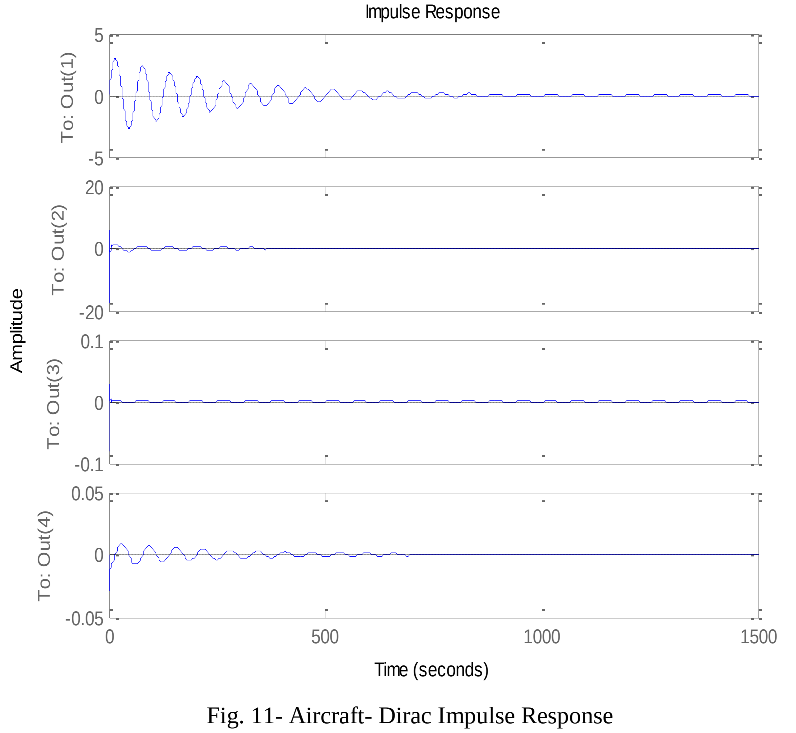

Fig. 11- Aircraft- Dirac Impulse Response

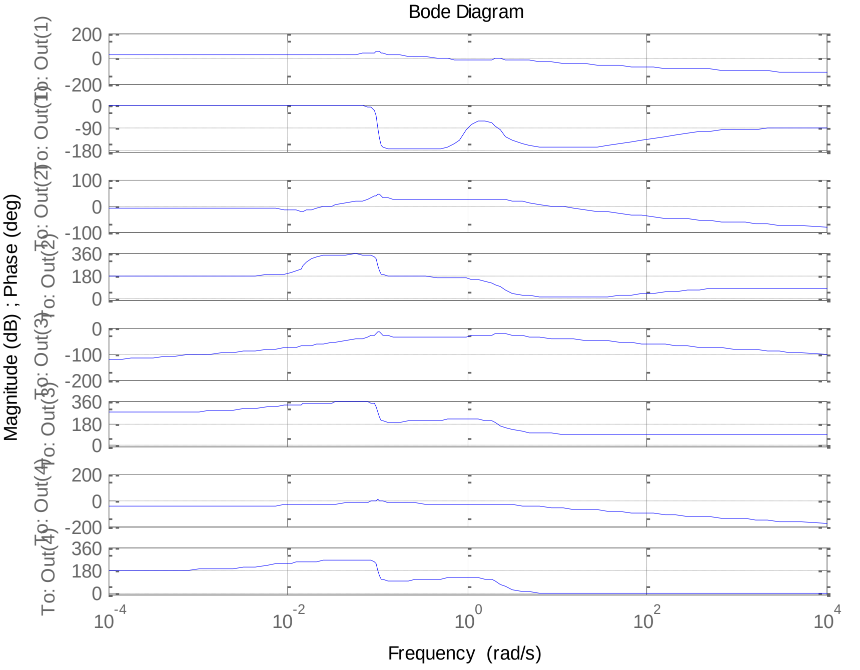

Fig. 12 - Bode Diagram

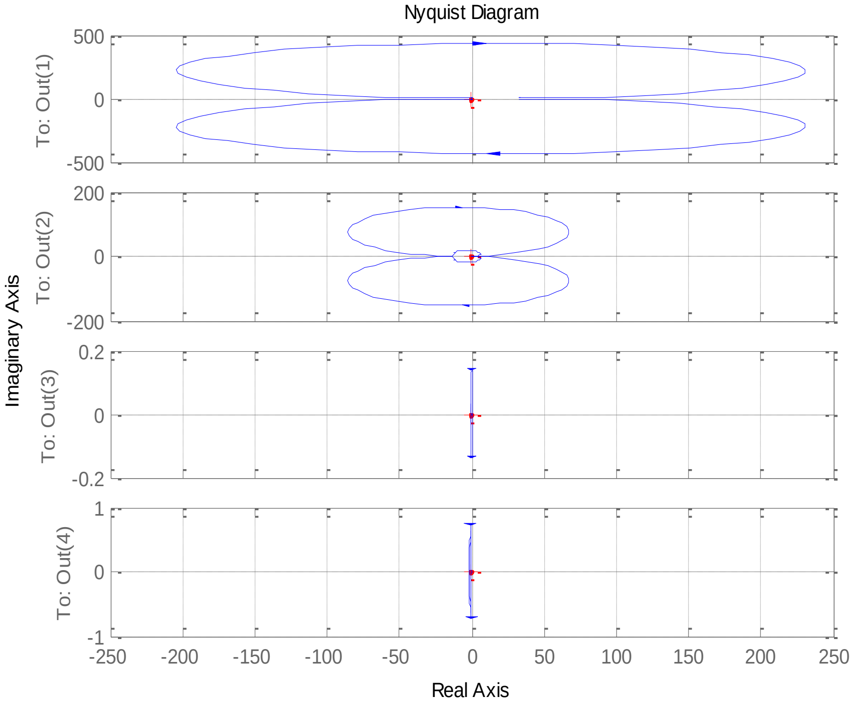

Fig. 13- Nyquist Diagram

Fig. 14- Synthetic Vision

Heading information is presented at the bottom of the display, while mode information is displayed at the top of the PFD. The PFD also displays stall warnings and guidance information. [13]

Boeing is improving the 737 by adding a new onboard network system - ONS to connect airline operations and maintenance with airplane data and software parts. ONS vastly increases data available to the airline, and the ONS connectivity systems provide those data and airplane software to the flight, cabin, and maintenance crews, and the ground. [10]

Together, ONS and ONS connectivity systems consolidate functions typically performed by multiple line replaceable units LRUs. Basic and optional components make ONS scalable to current operational demand as well as flexible enough to grow for future operational needs. Many ONS components are being introduced on the Next-Generation 737, prior to the first 737 MAX delivery.

Changes in the speed of an aircraft also affect the effectiveness of the control surfaces. At a given altitude, slow speeds require more control surface movement than high speeds require accomplishing the same maneuver.

The pilot maintains (or changes) the altitude by referencing the altimeter. The AFCS can also maintain a constant altitude. To accomplish this task the AFCS uses altitude data supplied by an air data sensor or Air Data Computer - ADC as the reference altitude.

Control surface signals are modified by a gain control unit to compensate for changes in airspeed. This unit uses the difference between ram pressure and static pressure.

The flight control surfaces (rudder, aileron, and elevator) are mechanically linked to the electro hydraulic actuators. As the control surface moves, a position transmitter synchro develops a feedback signal having the opposite polarity to the error signal. The magnitude of the feedback signal increases as the control surface displacement increases. When the error signal and feedback signal are equal and opposite in magnitude and polarity, the control surface will no longer move.

However, regardless of how sophisticated the AFCS computer may be, the reasoning power of the pilot cannot be duplicated.

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