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A-320 BASED VIRTUAL FLIGHT TEST BED

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Abstract

A Flight Test Bed (FTB) is a dedicated experimental aircraft with extensive instrumentation and is used for evaluation of modification proposals e.g. integration of a new sub system to improve operational deployment of the existing aircraft. Flight testing on the FTB is an involved process comprising of lengthy and expensive experimentation procedures using physical prototypes. Reference [1] contains descriptive procedure to realise virtual environment of an aircraft for evaluating various modification options. The research methodology does facilitate visualisation and immersion into a virtual aircraft along with modification scheme thereby evaluating functional aspects of the modification proposal. The main challenge is however to simultaneously compute and assess relevant aerodynamic parameters affecting flight safety, performance, stability and control of the modified aircraft. This research paper deals with integrating a flight dynamics computational application, JSB Sim for transporting results of the calculations undertaken on the dynamics of the aircraft into virtual realisation software, Unreal Engine that was used to develop the virtual environment. In this paper, Airbus A 320 based FTB has been used as a virtual platform on which a hypothetical modification proposal to fit three modification racks in the cargo compartment for utilising this aircraft in Electronic Warfare role has been experimented. The flight dynamics computational engine is programmed to compute trim conditions of the modified aircraft during cruise conditions of flight.

Keywords: *Flight Test Bed . Integration . Flight Dynamics . Virtual . JSB Sim . Trim . Modification Proposal . Simulation .*

1. Introduction

The flying characteristics of an aircraft largely depend on its response to aerodynamic, propulsive, and gravitational forces, and to control inputs from the pilot. The force of gravity continuously attempts to pull an aircraft down toward Earth. The force of lift counteracts weight and sustains an aircraft in flight. The amount of lift produced by an aircraft is limited by the airfoil design, angle of attack (AOA), airspeed, and air density. To assure that the lift generated is sufficient to balance weight, the mod evaluation process need to ascertain the critical parameters of weight and CG for all configurations of the aircraft being attempted for modification. If the weight is greater than the lift generated, the aircraft may be incapable of flight. In the same manner, if the CG is not within the CG margin, the aircraft may become unstable or uncontrollable. A flight dynamic computational software like JSB Sim can be utilised to evaluate various stability and control derivatives to evaluate the trim parameters of the modified configuration.

2 Scope

The scope of the current research has been to develop programming and integration algorithms of the flight dynamics computation engine for realising a virtual FTB based on Airbus A 320 aircraft. This involves software programming to :-

- Calculate and display centre of gravity in 3 dimension of the modified option in the virtual environment of the Airbus A 320 based FTB.
- Programming JSB Sim for calculations of trim characteristics of the Airbus A 320 aircraft fitted with CFM 56-5B aero engine and an empty cargo compartment with no seats fitted.
- Transmission of the revised CG position of FTB as per calculations in the Unreal engine for flight dynamics computations of the trim conditions during cruise flight by the JSB Sim application software.
- Obtain feedback from JSB Sim and display trim analysis results in terms of Pass Fail criteria of

the flight vehicle translational and rotational accelerations about the body axes along with stabilised control positions.

3 Theory Of Flight Dynamics

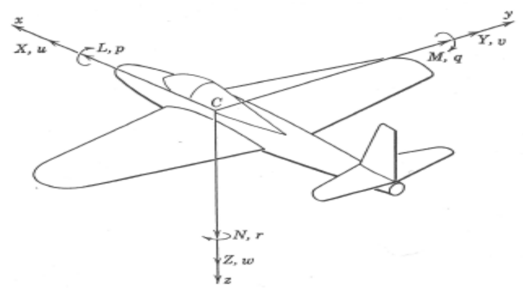

Fig. 1. *Standard notation for aerodynamic forces and moments*

3.1. The standard notation for describing the motion of, and the aerodynamic forces and moments acting upon, an aircraft are indicated in Fig. 1 above.

- The variables u, v, w represent the instantaneous components of linear velocity in the directions of the x, y, and z axes, respectively.
- The variables X, Y , Z represent the components of aerodynamic force in the directions of the x, y, and z axes, respectively.
- The variables p, q, r represent the instantaneous components of rotational velocity about the x, y, and z axes, respectively.
- The variables L, M, N represent the components of aerodynamic moments about the x, y, and z axes, respectively.

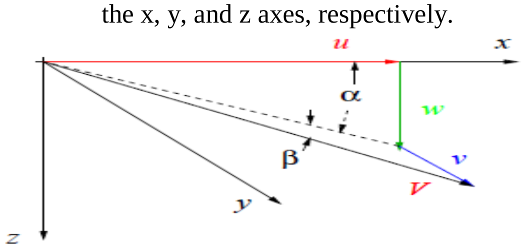

Fig. 2. *Standard notations of angular motion*

3.2. Stevens and Lewis [3] have expressed the aircraft state equations in general terms by the following implicit system in terms of the aircraft *state* vector (x) with g as a vector of *ns* scalar nonlinear functions *gi* resulting from aircraft nonlinear, six-degree-of freedom state equations projected onto a convenient reference frame.

$$g(\dot{\mathbf{x}},\mathbf{x},\mathbf{u}) = 0 \qquad (1)$$

In the above equation, u is the column of n_c control variables

3.3. Trimmed states

Marco and Berndt [4] have analysed a variety of trim conditions that have proved useful. The general steady-state flight conditions concluded in this research are as under :

- Accelerations: $\dot{u}, \dot{v}, \dot{w} \equiv 0$ & $\dot{p}, \dot{q}, \dot{r} \equiv 0$
- Linear Velocities: *u, v,w* (or *V, α, β*) = prescribed constant values ,
- Angular Velocities: *p, q, r* = prescribed constant values
- Aircraft Controls :*δT , δe, δa, δr* = appropriate constant values

4 Realisation of Flight Test Bed

Fig 3 below gives a schematic block diagram to illustrate the methodology followed for realising the Airbus A-320 based flight test bed complete software at a high-level.

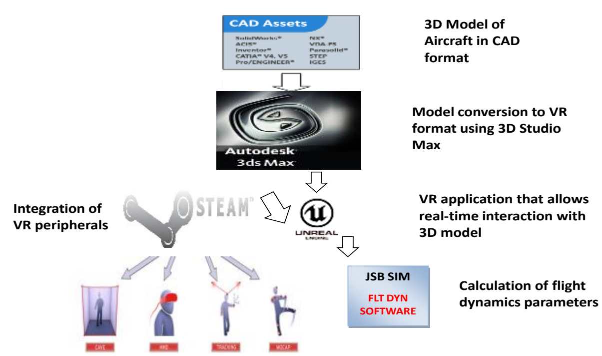

Fig 3. *Integration Diagram of Application Softwares*

With significant ongoing research on Virtual and Augmented reality for aviation use, a large number of 3 D models of various aircraft are available in the open domain. These are however heavy with too many engineering details and were simplified for

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efficient rendering. For realistic visualization of the virtual environment of the FTB, the simplified model was converted into VR format on 3D Studio Max by suitable texturing and lighting of the model and then the virtual A320 model was transported and programmed on Unreal Engine with the following functionalities incorporated:

i. Import of 3D models

ii. Interactive creation, editing and assembly of parts, components and sub systems for virtual realisation of modification items.

iii. Computation of Physics parameters (cg & weight) associated with the modification process during moving of various parts, components and sub systems of the modification proposal.

iv. Integration of helmat mounted display and wands through the Steam application software for full immersion into the virtual environment.

v. Navigation and manipulation of various parameters using the VR peripherals for association with the modification proposal in the virtual environment.

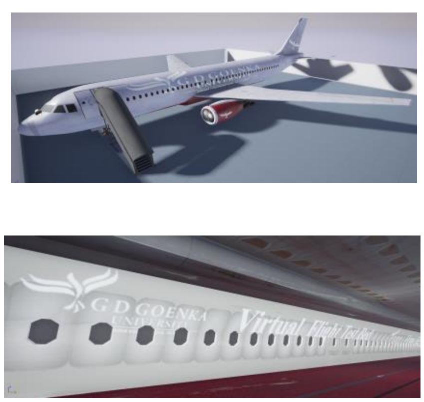

Fig. 4. *Screen shots of virtual environment*

The research project uses Head Mounted Display (Vivo HTC) for visualization and navigation. The wands (see fig 5 below) are used for interactive placement of objects inside the aircraft. The simulated environment also depicts collision and enables visual depiction of these parameters. In [5], an interactive virtual model of an aircraft galley is described to illustrate as to how a 3 D interactive visualization can support multi disciplinary meetings of the design teams. Design of the virtual FTB in the instant case additionally enables computation of cg coordinate in body axis system based on the modification objects location and passed on to the mathematical simulation model (JSBSim). With the feedback coming from JSB Sim, the software facilitate visual depiction of simulated trim results.

Fig. 5. *Sketch of VR peripherals (HMD & Wand)*

5. Configuring Flight Dynamics Application

David W Babka in [6] have considered two simulators, X-Plane 9 by Laminar Research and Flight Simulator X from Microsoft and conducted three tests (Stall, Stability & Steady turns) on a Cessna 172SP & noted that the simulation produced data very similar to the actual flight test results. Considering the requirement of testing modification proposals, we have utilized JSBSim, an open source Flight Dynamics computational software that is utilized by various flight simulators to model the flight dynamics of an aircraft. It has been in development and use since 1996. The code is written in C++ and uses XML configuration files. The trim conditions can be used to evaluate aircraft performance within the OEM defined flight envelope. In the instant case, the linearization of the aircraft dynamics has been used to evaluate the effect of aircraft modifications on its control systems. Input files that contain the description of an aerospace vehicle, engines, scripts, etc. in XML file format, are given as input to JSBSim, which in turn computes various performance parameters and control characteristics to analyse performance and dynamics of the vehicle being simulated. Following scripts are used :-

- Aircraft Model : describes the configuration of the aircraft used.

- Init file : set the initial condition for the aircraft
- Engine file : description of the engine used in the aircraft
- Main file : used to define what has to be done e.g trimming, start engines etc.

1.1 5.1 Geometric configuration of aircraft

The metric module of the config file contains the relevant geometric parameters of the aircraft and the relative position of various components affecting aerodynamic of the aircraft being simulated. For simulating Airbus A 320, following broad geometric parameters were used :

(a) Wing area unit 1171.00 sq feet
(b) Wing span 94.70 feet
(c) Relative location of wing in inches from reference point
<x> 625 </x>
<y> 0 </y>
<z> 24 </z>

1.1.1 **Weight and CG.** On this module, the mass properties of the Airbus A 320 have been specified. The section contains data on the empty weight of the aircraft, the mass moments of inertia, cg position in space with reference to flight reference point, and relative location of the modification of items proposed to be evaluated.

1.1.2 Take off and Landing. Ground reaction due to transfer of the aircraft weight on ground is modelled in JSB Sim for realistic simulation of take off and landing characteristics. This module can also be used to model the ground reaction of any other part of the aircraft structure due to .

1.1.3 **Aeroengine.** The propulsive module contains information on the aeroengine powering the aircraft and its location with specific reference to the thruster that converts the engine power into a thrust, and also the fuel tanks , their location and the fuel consumption sequence. In the instant research work the propulsion system used was the CFM aero engine for A 320 aircraft.

1.1.4 Control Laws. This module comprises of information on the controllability parameters of the aircraft and defines the permissible flight envelope of the aircraft. Typical parameters could be pitch rate, roll rate, flight altitude and the governing atmospheric conditions. These component properties are set here such as

- Summer Component
- Aerospace Scaling Component
- Kinematics Component.
- Scheduled Gain Component

Aerodynamics. The forces and moments experienced by the aircraft by virtue of its motion in the atmosphere are defined in the 'aerodynamics' section of an aircraft configuration file. This module has the governing laws and corresponding coefficients for all the six degrees of freedom. All the six sub sections corresponding to three translational and three rotational axes have independent and comprehensive formulations to compute the forces and moments wich are then summed up in the summer component .

1.2 5.2 Initialization file

This sub routine sets up the aircraft to start off and fly as per requirement. In the instant case, the research work has been accomplished for cruise conditions at following flight parameters..

(a) Flight Altitude 30000 feet
(b) Indicated Air speed 750 feet /sec
(c) Roll Rate 0 deg /sec
(d) Pitch Rate 0 deg /sec
(e) Yaw rate 0 deg /sec
(f) latitude 47.0 deg
(g) longitude 122 deg
(h) Phi 0 d
(i) Psi 0 deg
(j) Beta 0 deg

1.3 5.3. Engine File

This module caters for the required type and parameters of the aero engine such as thrust, specific fuel consumption, fuel flow rate, bypass ratio, rpm at idle and max rating etc.

1.4 *5.4. Main File*

In the main file, the JSB Sim was given commands using the input file in XML format. The input file was generated by the physics computation of the Un real Engine. Various trim conditions of Airbus A 320 aircraft are programmed in the main file to run the flight simulation module for a finite time with increments in the form of step or ramp function. The simulation was performed using step function with time interval of 0.008333 seconds over 100 iterations.

6. Implementation of Trim Algorithm for Flight Dynamics Computations

With continous change in weight and CG characteristics which were computed in the physics module of Unreal, we are solving trimming problem of the Airbus 320 aircraft under cruise flight by using the JSB Sim library to set up a trim. The trim algorithm calculates the equilibrium states of the aircraft with CFM 56 aero engines powering the aircraft at an altitude of 30000 feet and runs out to 100 seconds with the steady state flight data of various parameters like speed, altitude, control inputs etc printed out at 0.008333 second intervals.

6.1. Integration. For integration of the Unreal engine, a simple batch file was scripted to launch the python script and JSBSim. The output of the physics module of Unreal engine is configured to store cg and weight parameters during modification process in a csv file named input.csv. The Python script essentially takes this input.csv and generates output.csv based on JSBSim results which are projected in the virtual environment.

6.2. Results. The simulation was initially run with no modifications to the aircraft galley equipment. Result shows that trimming was successful (Fig. 6).

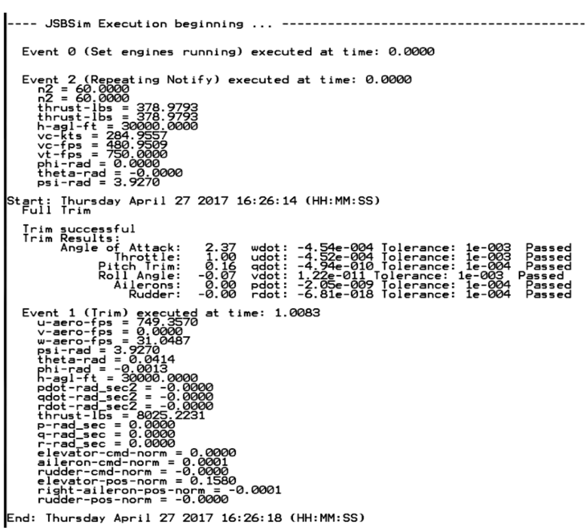
```
---- JSBSim Execution beginning ... ----------------------------------------

  Event 0 (Set engines running) executed at time: 0.0000

  Event 2 (Repeating Notify) executed at time: 0.0000
    n2 = 60.0000
    n2 = 60.0000
    thrust-lbs = 378.9793
    thrust-lbs = 378.9793
    h-agl-ft = 30000.0000
    vc-kts = 284.9557
    vc-fps = 480.9509
    vt-fps = 750.0000
    phi-rad = 0.0000
    theta-rad = -0.0000
    psi-rad = 3.9270
Start: Thursday April 27 2017 16:26:14 (HH:MM:SS)
  Full Trim

  Trim successful
  Trim Results:
       Angle of Attack:   2.37  wdot: -4.54e-004 Tolerance: 1e-003  Passed
              Throttle:   1.00  udot: -4.52e-004 Tolerance: 1e-003  Passed
            Pitch Trim:   0.16  qdot: -4.94e-010 Tolerance: 1e-004  Passed
            Roll Angle:  -0.07  vdot: 1.22e-011 Tolerance: 1e-003  Passed
              Ailerons:   0.00  pdot: -2.05e-009 Tolerance: 1e-004  Passed
                Rudder:  -0.00  rdot: -6.81e-018 Tolerance: 1e-004  Passed

  Event 1 (Trim) executed at time: 1.0083
    u-aero-fps = 749.3570
    v-aero-fps = 0.0000
    w-aero-fps = 31.0487
    psi-rad = 3.9270
    theta-rad = 0.0414
    phi-rad = -0.0013
    h-agl-ft = 30000.0000
    pdot-rad_sec2 = -0.0000
    qdot-rad_sec2 = -0.0000
    rdot-rad_sec2 = -0.0000
    thrust-lbs = 8025.2231
    p-rad_sec = 0.0000
    q-rad_sec = 0.0000
    r-rad_sec = 0.0000
    elevator-cmd-norm = 0.0000
    aileron-cmd-norm = 0.0001
    rudder-cmd-norm = -0.0000
    elevator-pos-norm = 0.1580
    right-aileron-pos-norm = -0.0001
    rudder-pos-norm = -0.0000

End: Thursday April 27 2017 16:26:18 (HH:MM:SS)
```

Fig. 6. *Screen shot of unmodified aircraft results*

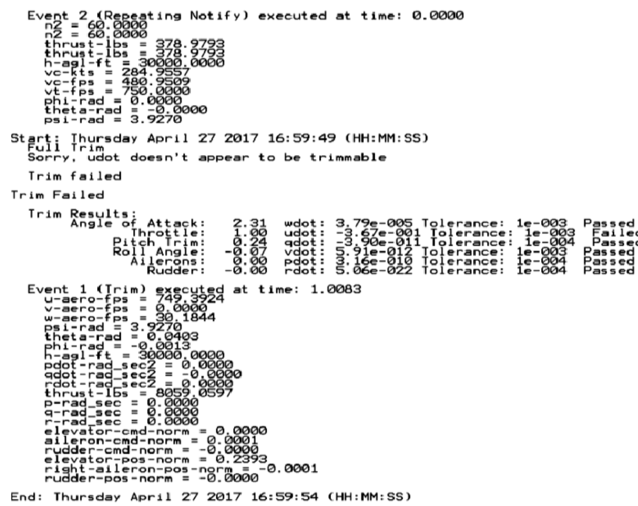
```
  Event 2 (Repeating Notify) executed at time: 0.0000
    n2 = 60.0000
    n2 = 60.0000
    thrust-lbs = 378.9793
    thrust-lbs = 378.9793
    h-agl-ft = 30000.0000
    vc-kts = 284.9557
    vc-fps = 480.9509
    vt-fps = 750.0000
    phi-rad = 0.0000
    theta-rad = -0.0000
    psi-rad = 3.9270
Start: Thursday April 27 2017 16:59:49 (HH:MM:SS)
  Full Trim
  Sorry, udot doesn't appear to be trimmable

  Trim failed

Trim Failed

  Trim Results:
       Angle of Attack:   2.31  wdot: 3.79e-005 Tolerance: 1e-003  Passed
              Throttle:   1.00  udot: -3.67e-001 Tolerance: 1e-003  Failed
            Pitch Trim:   0.24  qdot: -3.90e-011 Tolerance: 1e-004  Passed
            Roll Angle:  -0.07  vdot: 5.91e-012 Tolerance: 1e-003  Passed
              Ailerons:   0.00  pdot: 3.16e-010 Tolerance: 1e-004  Passed
                Rudder:  -0.00  rdot: 5.06e-022 Tolerance: 1e-004  Passed

  Event 1 (Trim) executed at time: 1.0083
    u-aero-fps = 749.3924
    v-aero-fps = 0.0000
    w-aero-fps = 30.1844
    psi-rad = 3.9270
    theta-rad = 0.0403
    phi-rad = -0.0013
    h-agl-ft = 30000.0000
    pdot-rad_sec2 = 0.0000
    qdot-rad_sec2 = -0.0000
    rdot-rad_sec2 = 0.0000
    thrust-lbs = 8059.0597
    p-rad_sec = 0.0000
    q-rad_sec = 0.0000
    r-rad_sec = 0.0000
    elevator-cmd-norm = 0.0000
    aileron-cmd-norm = 0.0001
    rudder-cmd-norm = -0.0000
    elevator-pos-norm = 0.2393
    right-aileron-pos-norm = -0.0001
    rudder-pos-norm = -0.0000
End: Thursday April 27 2017 16:59:54 (HH:MM:SS)
```

Fig. 7. *Screen shot of modified aircraft* results

After initial proving of the simulation with the original aircraft configuration, a hypothetical modification proposal with large scale addition of unacceptable point masses was simulated and the result shows that full trimming has failed as linear acceleration in the longitudinal direction could not be trimmed within the specified tolerance & was unsuccessful (Fig. 7).

7. Conclusion

This paper deals with undertaking computations for trim analysis of the modified aircraft configuration as a result of trying out different implementation options of the modification scheme utilising JSB Sim application software. The computation results are analysed and rendered simultaneously during qualitative evaluation (subjective tests) in the virtual FTB. The key outcomes of the research activity includes design and development of a Virtual Reality based system that allows real-time modifications of a virtual aircraft model. The software integration also undertakes physics computations that compute various parameters like CG, aircraft weight, etc in real-time and provide necessary feedback to the flight dynamics computation engine. Implementation of the above using commodity Virtual Reality gaming hardware makes this extremely cost effective and highly engaging system very useful for in depth analysis and evaluation of aircraft modification proposals. The key outcome of this research work ensures simultaneous availability of trim analysis results by computing variation in relevant flight parameters governing performance, stability and controllability of the aircraft under modification. Besides the computational analysis, the Virtual FTB also facilitates subjective evaluation of the modification in terms of Aesthetic, functional aspect, maintainability considerations etc. The virtual flight test bed therefore results in tremendous saving in cost, time and effort as compared to Flight evaluation on the actual aircraft used for Flight Testing requirements.

References

1. DEVENDER SHARMA & DR SUDEEP SHARMA, 2017, Virtual aircraft environment to evaluate mod proposals, *http://www.asianssr.org/AJCTjournal.php*

2. RAKESH GUPTA, DANIEL WHITNEY & DAVID, 1996 MIT, Cambridge, USA, Prototyping & Design for Assembly analysis using multimodal virtual environments.

3. STEVENS B.L., LEWIS F.L, 1992, Aircraft Control and Simulations, John Wily and Sons.

4. AGOSTINO DE MARCO AND JON S BERNDT, A general solution to the aircraft trim problem, Research Gate , https://www.researchgate.ne/publication/228877995

5. JP THALEN AND MC VANDERVOOT, 2012, Facilitating user ionvolvement in product design through virtual reality http://dx.doi.org/10.5772/48602

6. DAVID W BABKA, 2013, Flight testing in a simulation based environment, American Institute of Aeronautics and Astronautics

7. ADELAIDE MARZANO, INELDA FREL & others, , 2015, School of Mechanical & Aerospace Engineering, Queens University, North Ireland, Design of a VR framework for maintainability and assemblability test of complex systems.

8. X WANG, SK ONG & AYC NU, 2016, National University of Singapore, Real Virtual components interaction for assembly simulation & planning.

9. XIAOYONG LEI, SHULING DAI & others, 2005, Study of virtual manipulation technology in Virtual Reality systems.

10. SANKAR JAYARAM, HUGH & KEVIN WLYONS, 1997, Virtual Assembly using Virtual Reality Techniques School of Mechanical & Materials Engineering, Washington State University.

11. GABRIEL ZACHMANN, July 2000, Dissertation on Virtual Reality in Assembly Simulation- collision, detection, simulation Algorithms & Interaction Techniques by.

12. AUGSTER S.R. VEDAM, 1996 – Virtual Environment for design & manufacturing, Ph D Dissertation, school of Mechanical & Materials Engg, Washington State University, Pullman, W.A..