Flight Simulation for Wind Shear Encounter

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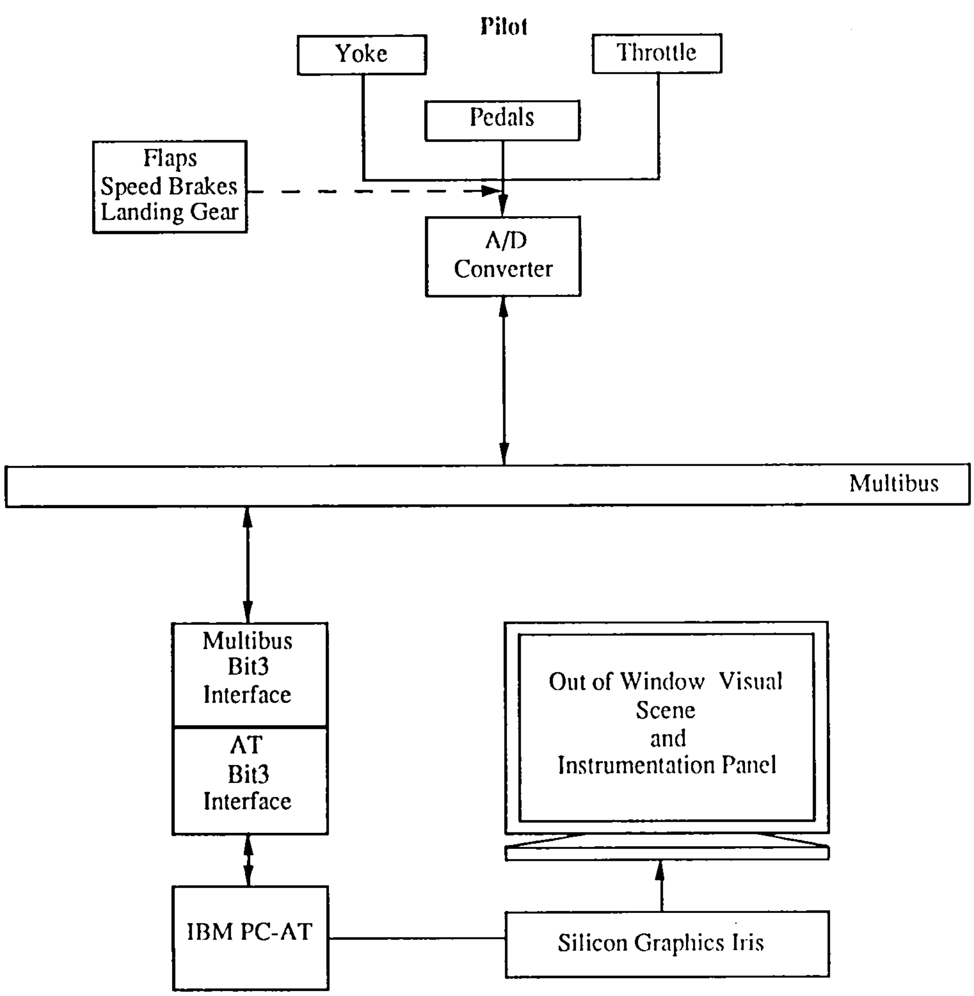
Introduction

A real-time piloted flight simulator is under development in the Laboratory for Control and Automation at Princeton University. This facility will be used to study piloted flight through a simulated wind shear. It will also provide a testbed for real-time flight guidance laws. The hardware configuration and aerodynamic model used are discussed. The microburst model to be incorporated into the simulation is introduced, and some proposed cockpit display concepts are described.

Simulator Architecture

The simulator presently consists of two computer subsystems. An IBM PC-AT contains the aerodynamic model of the aircraft. This computer samples pilot inputs through a 12 bit A/D board, and integrates the aircraft equations of motion. Aircraft attitude and position variables are transmitted by the AT to a Silicon Graphics IRIS Workstation, which in turn generates an external visual scene and a primary flight instrument display. The present visual scene contains a representation of Teterboro Airport and a simplified depiction of the Manhattan skyline. The flight instruments are formatted to resemble a modern electronic flight instrumentation system (EFIS). The display is partitioned so that the top half of the screen contains the out-of-window display, while the bottom half displays the EFIS. A graphical representation of a Boeing 737 instrument panel has also been developed on the IRIS.

LCA Flight Simulator Hardware Architecture



Simulator Aerodynamic Model

The simulator is presently configured to represent the dynamics of a Boeing 737 Transport. The aerodynamic data for the aircraft are taken from the Sperry TCV Simulation developed for NASA Langley. A major portion of these data comes from wind tunnel testing, corrected for Reynold's number and aeroelastic effects. Much of it has been confirmed in flight testing of the 737, and adjusted if necessary to match actual 737 flight characteristics. As such, the Sperry simulation provides a faithful representation of 737 dynamics over a broad flight envelope. Nonlinearities such as stall behavior and control saturation are modeled in the simulation. These effects may be significant in a wind shear environment, where high angles of attack and full control capacity could be required to escape a hazardous situation.

- Nonlinear model of aircraft dynamics developed by Sperry Systems for NASA Langley
- Simulation based on the 6 DOF force and moment equations of the airplane
- Solution of these equations yields the flight path and angular orientation of the airplane at each instant in time
- Aerodynamic loads on aircraft are functions of
    - Mach number
    - Altitude
    - Incidence angles
    - Rotation rates
    - Control deflections
    - Geometry changes (flap, gear, & spoiler deflection)
    - Ground proximity

Analytic Downburst Model

A microburst model has not yet been interfaced with the aircraft equations of motion. The present plans are to use an analytic model developed by Rosa Oseguera and Rowland Bowles at NASA Langley. This simple time-invariant model permits the simulation of different shears through the specification of four parameters. Wind components and spatial derivatives are easily obtained in cartesian coordinates from the velocity equations. This downburst model will be integrated with the equations of motion of the aircraft, and used to study conceptual wind shear hazard and flight guidance displays.

- Developed at NASA Langley by Oseguera and Bowles

- Represents an axisymmetric stagnation point flow, based on velocity profiles from the Terminal Area Simulation System model

- Time-invariant model

- Altitude dependence includes boundary layer effects near the ground, and closely matches real-world measurements

- Permits simulation of different shears through specification of four parameters:

  1) radius of the downdraft column
  2) maximum wind velocity (horizontal or vertical)
  3) altitude of maximum outflow
  4) depth of outflow

- Wind components in x,y, and z directions are easily obtained from velocity equations for a given aircraft position relative to downburst core

Display of Wind Shear Information

Once the microburst has been incorporated into the simulation, it will be necessary to augment the flight displays in some manner to provide the pilot with some indication of the potential hazard due to the wind shear. The type of display that will be considered assumes some sort of forward-look wind shear information. The hazard to the aircraft will be characterized by the "F-Factor", a concept developed at NASA Langley. This parameter completely describes the effect of a wind shear on the performance of an aircraft, in terms of its constant speed climb gradient capability. A persistent value of F greater than about 0.15 will exceed the climb capability of most transport aircraft.

The display concept under consideration will graphically present the anticipated F-Factor ahead of the aircraft, possibly in a head-up format. A display concept has been developed at NASA Langley that uses anticipated F-Factor to predict the aircraft flight path. Such a display may be developed for the simulator at Princeton, but initially the F-Factor will be used to characterize the wind shear hazard.

- Characterize the intensity of the wind shear using the "F-Factor":

$$F = \frac{\dot{W}_x}{g} + \frac{W_h}{V}$$

where

$$\dot{W}_x = \frac{\partial W_x}{\partial x}\dot{x} + \frac{\partial W_x}{\partial h}\dot{h} + \frac{\partial W_x}{\partial t}$$

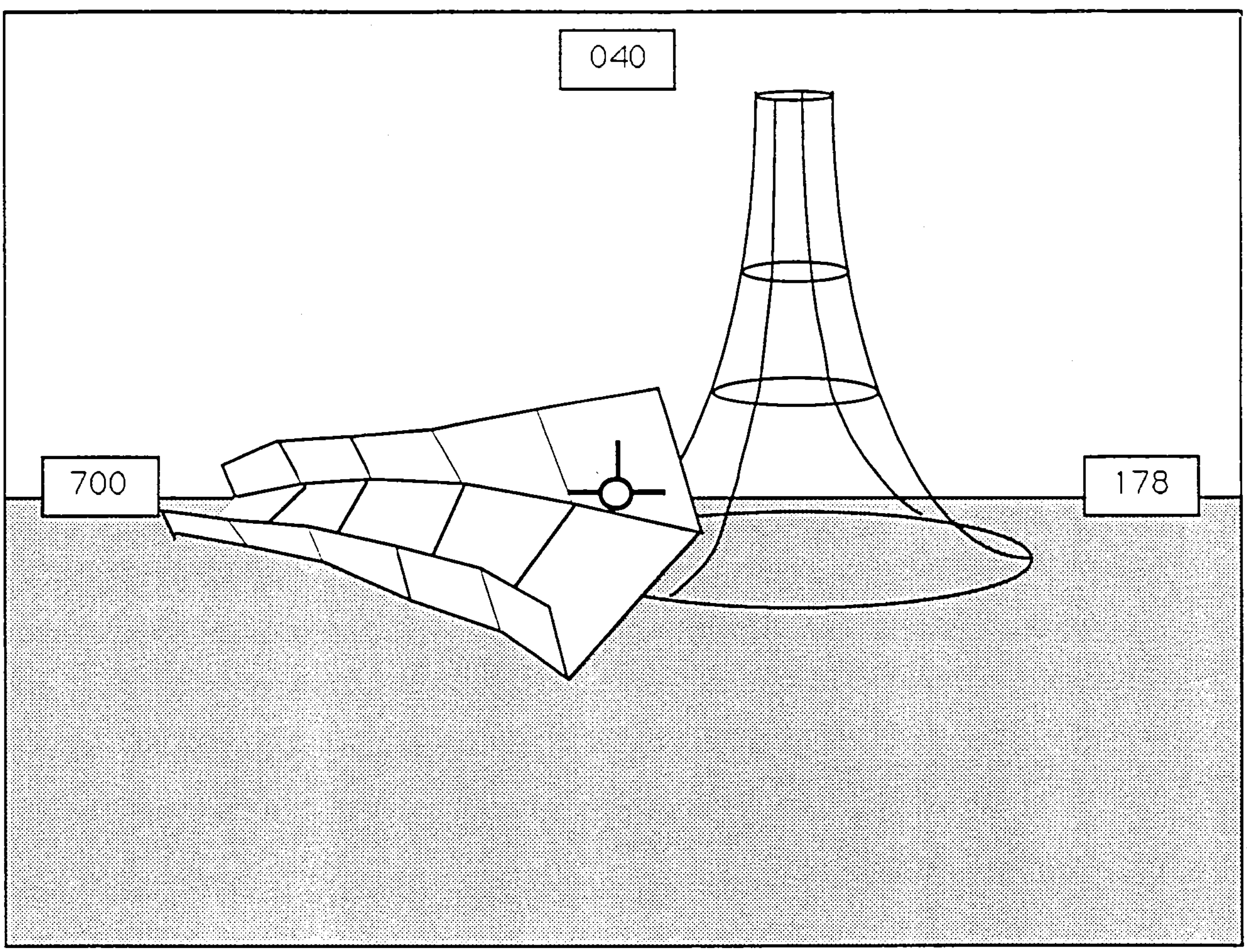
- F is a function of the aircraft's trajectory, and relates directly to its constant airspeed climb gradient capability

- Objective is to visually represent the F-Factor ahead of the airplane, to characterize the anticipated hazard due to the wind shear

- Flight guidance commands must also be presented to the pilot

"Highway in the Sky" Display Concept

In addition to a hazard display, it would be useful to have some sort of flight guidance command display. Typically, this takes the form of a set of command bars on the artificial horizon. A possible alternative to this conventional format is the so called "Highway in the Sky". Developed at the Flight Dynamics Laboratory at Wright Patterson Air Force Base, this display predicts the future aircraft trajectory based on the current state and the guidance strategy generated by the flight management computers. Rather than predicting future aircraft states, it would be interesting to use such a display to plot an escape profile out of a microburst. This would require the existence of an escape strategy, which could include lateral maneuvers. The "highway in the sky" would then display the flight path the pilot should take to avoid the wind shear hazard.



Future Work

- Implement the Oseguera-Bowles wind shear model in the aircraft's equations of motion

- Develop displays to characterize wind shear hazard, and investigate alternatives to "command bars"

- Continue development of simulator hardware