Meteorological Inputs to Flight Simulators

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Introduction

FLIGHT simulators are devices to help train pilots. Originally only procedural trainers, flight simulators have become very sophisticated, emulating almost all of the tasks and sensations a pilot would experience in the cockpit. As the modeling of the aerodynamics and flight characteristics has improved, the hazardous flight environment outside the cockpit has begun to receive attention. This Note presents a brief survey of meteorological inputs to flight simulators from simple wind shear and turbulence models, through the latest FAA simulator requirements to possible future requirements for all-weather flight simulator training.

Flight simulators run large computer programs in real time to model the systems of an aircraft. For example, most of the equations of motion are being run at 10-30 iterations/s. This rate imposes limitations upon the sophistication of the models used and the amount of data which can be retrieved and manipulated. A turbulence model which might be used for aircraft design might not be appropriate for real-time flight simulation.

The variability of the weather presents some unique problems for simulation and the use of the simulator for training.[1] Simulations must be variable to the extent that they truly represent weather phenomena and not be completely predictable and learnable by the flight crew being trained. The recent FAA Rule 14 CFR, Pts. 61 and 121, will allow the simulator to be used for certification checks, and hence a realistic environmental simulation must be provided.

FAA Advanced Simulation Program

The FAA Final Rule 14 CFR, Pts. 61 and 121, the Advanced Simulation Program,[2] allows the use of an approved simulator for almost all airline pilot flight training and certification checks. For FAA simulator approval, this rule requires a large number of meteorological inputs to the simulator aerodynamic, visual, sound, and radar systems. Advanced simulation is a three-phase program providing for progressive simulator upgrade.

Phase I is the current landing approval program and requires a crosswind near the ground and a ground effect on roundout, flare, and touchdown.

Phase II deals with improving the ground and flight environment and requires three-dimensional wind shear dynamics, wet or icy runway contaminants, and the sounds of precipitation. Phase II visual requirements include for the approach and landing phase of flight (at and below an altitude of 2000 ft height within 10 miles of the airport) weather representations including the following: variable cloud density; partial obscuration of ground scenes, that is, the effect of a scattered to broken cloud deck; gradual breakout, patchy fog, the effect of fog on airport lighting, and category II and III weather conditions.

Phase III requirements include atmospheric disturbances such as rough air and cobblestone turbulence. The sounds of precipitation static shall be coordinated with special weather representations which include the sound, visual and motion effects of entering light, medium, and heavy precipitation near a thunderstorm on takeoff, approach, and landings. Weather radar presentations may be required.

Turbulence Simulation

Turbulence simulation was initially designed to give a "feeling of realism" and increase the pilot's workload as "rough air" was encountered. The simplest approach to turbulence simulation is to input random pulses into the simulation, including the motion system to provide essential cockpit cues. Even this simple approach provides a level of realistic simulation of certain phenomena, e.g., a high-speed encounter with "cobblestone turbulence."

Gaussian turbulence models using the Dryden power spectra have been in use for many years. However, true atmospheric turbulence is non-Gaussian with great intermittency and patchiness.[3] Non-Gaussian turbulence models produce greater realism but with increased computational time. Natural turbulence can be recorded and played back with amplitude and time scaling to simulate the aircraft's changing speed and changing turbulence characteristics. This technique was used with success in the Space Shuttle simulation. However this simulation approach is "canned" and therefore limited to the situation that was recorded.

The majority of current models provide only symmetric turbulence inputs, that is, longitudinal, lateral, and vertical gust components that act on the center of gravity of the aircraft. Much work is still needed in asymmetric inputs due to gust penetration effects especially at low speed. Gust effects include variations of the angle of attack across the span as well as along the flight path, and gust penetration delay and unsteady flow characteristics at the tail. The cross correlation of gusts and the importance of such correlations to aircraft need further attention from the meteorological community.[4] Etkin's four-point representation of the quasisteady linear-field model presents one useful method of implementing the pitching, rolling, and yawing moments which an aircraft experiences in atmospheric turbulence.[5]

At present turbulence simulation is acceptable to pilots if the simulation closely resembles a turbulent situation which they have experienced in the past. Atmospheric turbulence has a wide variety of characteristics depending upon the cause and nature of the particular situation. Determining suitable scale lengths and rms values is a difficult task. Atmospheric turbulence modelers use mean wind coordinates and modelers of turbulence for aircraft design use aircraft coordinates. Turbulence modelers for flight simulation must consider both coordinate systems and consider the scale lengths and rms values chosen to model the particular storm.

Wind and Wind Shear Simulation

In most simulators the instructor may directly input a horizontal wind speed and direction. This steady wind provides only inputs to the navigational systems for course corrections in flight or crosswind takeoff and landings. The recent trend has been to simulate extremely hazardous conditions for aircraft in the form of heavy wind shear conditions. Wind shear has been defined as a time variation of vector winds along the flight path causing a change in lift and/or a lateral drift. It is most hazardous close to the ground where the aircraft is in the landing configuration and is flying very close to stall speed.

The major emphasis in wind shear simulations has been in modeling the conditions at the time of aircraft accidents. Flight recorder information from accident reconstructions has provided wind profiles along the glide slope. In these reconstructions of wind profiles care must be taken to separate the motions of the aircraft from the wind effects. Wind tower data have also been transformed into glide slope

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winds through a time-space conversion. The glide slope wind profiles provide three components of wind as a function of altitude (or position along glide slope). The Stanford Research Institute performed work for the FAA to develop wind fields consisting of a set of wind profiles located along the vertical plane containing the glide slope. These two-dimensional wind fields provide three components of wind as a function of altitude and distance to touchdown. The wind field data sources include accident reconstructions, wind tower data, and meteorological models.[6]

Hazardous meteorological situations tend to be localized and quite time variable. Three-dimensional wind data with time variation are required for adequate training in storm avoidance and storm penetration training in conjunction with weather radar presentations. Only the recent development of multiple Doppler radar analyses has made the acquisition of three-dimensional wind data possible. Unfortunately, such analyses have been limited to studying the most severe thunderstorms, the type a pilot would avoid at all costs. The innocuous little thunderstorm with a hidden downburst has in the past received little attention from meteorological researchers. Such storms are short-lived and very localized, requiring a large commitment of equipment and manpower. The National Severe Storm Laboratory in Norman, Okla., has recorded many such storms but more research is required.

The Joint Airport Weather Studies (JAWS) Project to be supported by NASA, NSF, and FAA is designed to study thunderstorms down to the Earth's surface with a resolution previously unobtainable in convective storms. Field data has been collected during the spring and summer of 1982 in the vicinity of the Stapleton Airport in Denver, Colo. The JAWS Project has the stated specific objective to collect vastly improved two- and three-dimensional thunderstorm wind shear data for utilization in manned flight simulators for training airline pilots.[7]

Speculations and Future Requirements

In addition to the stated requirements of the FAA Advanced Simulation Program, both military and commercial simulator customers are desiring better training for hazardous flight and ground conditions due to weather. The FAA requirements specify weather representations for the approach and landing phase of flight at and below 2000 ft altitude and within 10 miles of the airport. Mesoscale storms and downbursts, gust fronts, and heavy precipitation will need to be modeled along with the runway contamination resulting from the snow, ice, or rain present. Precipitation rates are needed in cloud and below cloud for the simulation of the aerodynamic effects of heavy precipitation resulting in drag and lift effects due to airfoil roughening.[8]

Radar information is becoming increasingly important as more training is required in pilot routing of aircraft and hazardous weather avoidance procedures. Weather radar simulation will probably require greater vertical resolution in radar data than is presently given by meteorological radars.

Simulators may begin to be used as a test bed for meteorological models of thunderstorms which have caused aircraft incidents. The meteorological conditions have been well modeled if simulator pilots fly a flight path similar to that taken by the original aircraft. Simulators may also be used to test wind shear detection systems in the cockpit.

Conclusions

Meteorological inputs for flight simulators have become more complex as more realistic and varied simulations are required. The sophistication of the weather modeling is limited by real-time computational requirements. The use of approved simulators for FAA certification checks requires a degree of weather variability to be modeled. Turbulence models for simulation need to include the pitching, rolling, and yawing moments experienced while flying through atmospheric turbulence. Turbulence scale lengths, rms values, and gust cross correlations need to be chosen to closely match the atmospheric conditions being modeled. Three-dimensional wind data with time variation are required to adequately simulate wind shear conditions around thunderstorms for training in storm avoidance and penetration. Weather radar information is becoming more important to simulation as more training is required in pilot routing and hazardous weather avoidance. An integrated simulation is required to be consistent with real world situations. As weather simulations become more complex, more emphasis must be placed upon internal meteorological logic than burdening the instructor. In short, the importance of meteorological simulation for purposes of flight crew training has now gained wide recognition, but much work needs to be done before this field of simulation gains the sophistication already achieved in other areas of simulation.

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Aerodynamic Characteristics of a Slotted vs Smooth-Skin Supercritical Wing Model

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Background

FOR more than 20 years, engineers have considered high-speed flutter model testing to be necessary for final verification that an aircraft is free from flutter. The complex effects of transonic aerodynamics on flutter appear to be even more important with the advent of the supercritical airfoil designs. Recent model tests indicate conflicting results concerning the severity of the compressibility effects of supercritical airfoils on flutter speed.[1,2]

Even though high-speed models have been tested for many years using sectionalized model construction, concern has increased over the possibility that the unevenness and gaps between the sections created interference with the formation of shock waves and other aerodynamic characteristics.

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