SUMMARY REPORT OF THE SIMULATION COMMITTEE

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The Simulation Committee consisted of the following:

Richard L. Kurkowski (Chairman), NASA/Ames Research Co.
Charles R. Chalk,'Calspan Corporation
Paul L. Jernigan, Douglas Aircraft Company
Jim Luers, University of Dayton Research Institute
Dwight R. Schaeffer, Boeing Aerospace Co.

As in the case of the other standing committees, this committee held a two hour session with each of the four rotating committees. The sessions were not highly structured so as to allow a free exchange to determine the status of aircraft/meteorology simulation technology, what the problem areas were, and what additional work was needed. Each of the four sessions was surprisingly fresh, non-repetitive, and with slightly different emphasis; however, the discussion relative to wind shear seemed to dominate these meetings, as well as the topic presentations.

The multitude of individual points of concern and information supplied in the four sessions have been summarized and organized using the following outline:

I. Simulators and Their Uses
II. Atmospheric Disturbance Modeling Requirements
III. Status of Simulator Capabilities for Modeling Disturbances
IV. Status of Atmospheric Disturbance Models

V. Specific Problem Areas

A. Definitions, Data Measurements Analysis, and Formats
B. Simulation Studies Criteria
C. Atmospheric Disturbance Models
D. Aircraft/Atmospheric Disturbance Response Modeling
E. Critical Case Studies
F. Atmospheric Disturbances and Meteorological Conditions
G. Pilot Learning Effects
H. Operations Related Discussions

I. Simulators and Their Uses

Simulators come in all shapes, sizes, complexities, and costs. A software model of a system without pilot or hardware involved can be considered a simulator in a loose sense, and this approach is used extensively for paper studies of aircraft and aircraft systems concepts. These studies include: aircraft performance, system performance, structural response, guidance navigation and control, failure mode analyses, etc. Increased complexity comes with adding hardware such as in "iron bird" control system simulators, or with the addition of a pilot station including controls and displays. A pilot simulator can be static base or moving base. In training, static cockpits are used for procedures training with moving base simulators used for critical flight phases and failures where motion affects the pilot's control and systems management tasks. Training as used here includes initial checkouts, type transitions, and recurrency or proficiency checks. Engineering and research simulators are generally more flexible devices wherein conditions and systems characteristics can be quickly varied so that a range of system parameters may be studied.

By their nature, Research Simulators tend to be the most flexible of any simulators and can be as complex as the task and size of the mission under study requires. Piloted simulator studies include: flight dynamics, handling qualities, control systems, guidance systems, navigation, ATC interface, certification criteria development, failure mode analyses, displays, and human factors. In addition, more and more use is being made of the piloted simulator to recreate the critical flight situation for aircraft accident investigations.

II. Atmospheric Disturbance Modeling Requirements

Atmospheric disturbance used in simulations include ground level mean wind, wind shear and turbulence. Wind shear models should include both horizontal and vertical shears with time or altitude change. Turbulence models normally include all three velocity components, oriented to the body axis of the aircraft, i.e., longitudinal, lateral, and vertical (u, v, w). The sophistication and fidelity of models for atmospheric disturbances vary as a function of: the type of simulator, the study objectives or task to be performed, and the resources (time, manpower, and money) available to the project.

For training simulators, representative disturbance models can be used with some variation in intensity to expose pilots to a range of situations. For instance, representative wind shears should be used to train pilots to recognize the shear situation and learn how to cope with shear conditions. Research simulators have varying requirements for disturbance modeling. For piloted simulators, again, representative models with varying intensity can be used. For autopilot studies, criteria development and structural design, accurate statistical and temporal models are required to assure accurate study results. For accident investigation simulations, exact duplication of weather (ceiling and visibility, ground winds, wind shear, and turbulence) existing at the time of the accident are required.

The common approach to simulating disturbances is to use filtered random noise generator signals to simulate turbulence and to superimpose this on top of wind shear profiles which are stored as table look ups. For some simulation tasks these models can be frozen (i.e., no altitude variation). Others such as landing approach require variation with altitude and horizontal space. Some complex models have been mechanized with 4-D (x, y, z, t) characteristics.

111. Status of Simulator Capabilities for Modeling Disturbances

The question was raised as to the capacity and capabilities of simulators to handle atmospheric disturbance data and models. This is a function of the specific simulator. With most simulators using large memory capacity, there has been no problem in simulating local disturbances acting upon simulated aircraft. Most training simulators have the capacity to implement the turbulence and shear models. The point was made that even though the models are adequate, the implementation of the turbulence and wind models in training simulators may be improperly mechanized.

The ability of the simulator to duplicate motion cues is highly variable depending upon the specific simulator and its degrees of freedom and "wash out" program. Very few simulators can duplicate the very high acceleration associated with severe turbulence environments, especially when you consider the low frequency, large amplitude, portion of the response spectrum. Visual displays also start to limit and exhibit lags if driven outside their nominal amplitude-frequency envelope.

IV. Status of Atmospheric Disturbance Models

Atmospheric disturbances may be divided into categories such as ground level mean winds, low level wind shears, terminal area wind shears, low altitude turbulence and high altitude turbulence. Using these categories a table was prepared by the group chairman to indicate the approximate status of disturbance model data as reflected by the committee meetings. This status is shown in Table I.

Table I

Status of Atmospheric Disturbances Models

	Data for Models		
	Adequate	Needs Assimilation Dissemination	More Needed
Ground Level Mean Wind	J	?	?
Wind Shear			
Low Level			
Localized Effects (buildings, terrain, carriers, non-aviation ships)		J	√
Terminal Area			
Stable Atmosphere			
Inversion		√	√
Warm Front		√	√
Unstable Atmosphere			
Thunderstorm		√	√
Atmospheric Turbulence			
Low Altitude		J	√
High Altitude		√	√

Ground level mean wind data and models are generally adequate, although specific unique sites may require assimilation of existing data or additional data. Models of low level wind shear with unique site characteristics such as buildings, terrain features, aircraft carrier, and "non-aviation" ships, are not readily available although work is progressing in this area. Assimilation of existing data and additional data is needed to model shears in warm front and inversion conditions. This is also true of gust. front wind shears associated with thunderstorms like the JFK accident conditions. More accurate data on this type of wind shear is needed to scope the magnitudes and characteristics which can be expected in aircraft operations.

Atmospheric turbulence models are in fair shape although additional data and analysis of existing data is desirable. One of the problems in this area is that there are too many models and some sort of standardization is required. Additionally, the models may not be implemented properly in the simulation. Patchy qualities and intermittency of atmospheric turbulence needs to be specified. Some studies have shown that for piloted simulations, small variations in spectral models are not significant to pilot ratings of aircraft handling qualities. Additional data is needed for VTOL aircraft operations and to answer spatial distribution effects questions.

V. Specific Problem Areas

This section points out specific problem areas which were discussed in various categories and indicates in some instances, potential research to solve the problems.

A. Definitions, Data Measurement, Analysis, and Format

There is a need for standardized definition of terms, e.g., what is the difference between turbulence and wind shear? Basically it's a matter of frequency content but the cutoff between the two can vary depending upon type of aircraft and approach speeds. Further definition is required. Terminology for wind shear should be standardized.

Considerable meteorological data has been gathered over the years. Most of this data is not aircraft control-related and is more aimed at synoptic modeling with very low frequency characteristics. Data suitable for aircraft application has been and is being generated, however. But these data need to be analyzed and translated into models which are in a format that the aeronautics user can apply. The models should not be so complicated that whole computers are used up. Leadership and direction are needed in this area. Models should not be so complicated that they permit duplication of all possible atmospheric cases. The models need to be "simplified" and generalized for simulation purposes. Cooperation between meteorologists and engineers is required.

Turbulence models need to be standardized. Boeing, for instance, has some fifteen or more models in use in the company. Some Government organization should be involved to cause this standardization to come about. The turbulence model in MIL-F-8785B provided a start in this direction. However, users of the turbulence section of MIL-F-8785B document should be cautioned to consult AFFDL-TR-72-41, titled "Revisions to MIL-F-8785 (ASG), Proposed by Cornell Aeronautical Laboratory." TR-72-41 contains proposed revisions to section 3.7, Atmospheric Disturbances, including:

1) New definition of the values for σ_u, σ_w, σ_v
2) Interpretation of rotary gust disturbances
3) Development of a wind shear model

B. Simulation Studies Criteria

Many simulation studies and analyses are made for the purpose of determining a system's characteristics relative to a set of accepted criteria. In military aircraft handling qualities, for instance, MIL Spec. F-8785B has been the guide for acceptability. Such criteria must be carefully determined so as to not lead to meaningless tests. Work on autoland systems was sighted as an area for better criteria. Present requirements state a goal of one fatal accident on 10^{-9} landings. Companies are interpreting this criteria literally and devising simplified analog simulation which is run at fast time for many, many trials. Complex digital simulations which run at real time or slower can become very expensive and time-consuming. More guidance is required in this area. It was felt that narrower error dispersions should be required. New approaches were suggested such as used by Foster and Neuman (NASA-Ames) wherein turbulence and wind shear disturbance cases for autoland were limited to those which could cause large dispersions and hard landings.

C. Atmospheric Disturbance Models

With regard to wind shear, a need was expressed for more information on local effects of terrain, buildings, etc., on flow in the local environs of airports, STOL ports, or VTOL pads. Specific concern was expressed over the St. Thomas, Virgin Islands, situation. The FAA would like a model of the flow for this airport which they could use as a guide on wind sensor locations for providing landing aircraft pilots with better information than is presently available. One technique for flow visualization of such situation was suggested. This would entail photographs of snow showers and the flow patterns. This would not work, of course, for warm climates but maybe smoke pots could be used for this approach.

Models are needed to define the shear environment in the vicinity of thunderstorms where the most severe cases occur. NSSL severe thunderstorm data bank is extensive and additional spring storms data is in the process of being gathered. Analysis and modeling of this data will be used to try to forecast storm severity and turbulence especially for gust fronts, and to predict turbulence and shear magnitudes to be expected.

For training simulators, representative wind shear models are needed, including severe conditions, in order to expose pilots to wind shear situations, especially those which exceed the performance capabilities of transport aircraft.

With regard to atmospheric turbulence modeling for simulation, there was no unanimous agreement on any one of the many turbulence models now in the literature and under development. It was felt that the MIL spec F-8785B turbulence model was a very good start but more work is required. Additional analysis is required on the variation of scale length and rms intensity with altitude. Indications are that the scale length for low altitude should be smaller than specified in the MIL spec model. Considerable work has been done on non-Gaussian models which exhibit more patchy and more intermittent characteristics similar to those observed in measured data. Some controversy developed over this point. It was suggested that the present Gaussian models would also appear patchy if the proper axis reference system was used. Most turbulence model mechanizations are oriented to the aircraft body axis system. It was argued that the turbulence should be modeled in an earth reference wind axis system and then transferred to the aircraft body axis as a function of aircraft heading, etc. Additional information was provided which showed a strong coherence of turbulence data at various altitudes. The question was also raised as to the coherence of the u,v,w components of turbulence. When they are highly correlated, high structural loads can be induced such as on a T-tail aircraft. Also, high pilot workload results when multiple axes upsets occur.

Thunderstorm turbulence model in MIL-F-8785B was questioned. Was it meaningful? Are different modeling methods required? Some data has been collected in Project Rough Rider wherein various aircraft (T-33, F-100, F-105, B-57B, F4) were used to collect thunderstorm data in the U.S. and southeast Asia. Most of the collection is at high altitude (45-60 thousand feet). Thunderstorm turbulence spectra appear to be similar to clear air with the 5/3 roll off. The knee of the curve may be different or be a function of storm size. The location of the knee of the curve may be important for very fast aircraft:.

The distribution of spatial effects of turbulence velocities over the span and length of an airplane was discussed. It was not clear how important this effect is for piloted simulations. For structural loads it may be quite important and required. Further work and testing is required. Battelle, (PNL) Pacific Northwest Laboratory, has data from towers which were spaced close enough to show spatial distribution for aircraft. This FAA funded program does not include this type of analysis. It was suggested that the government should fund such an analysis and publication. Tower data has been shown to correlate with flight measurements from instrumented airplane "fly by." The University of Washington has done some work in this area for NASA-Ames and a report will be out shortly on the results of low altitude flight measurements with dual wing tip gust probes. A question was raised with regard to Taylor's Hypothesis, i.e., how low can aircraft speed become before the hypothesis tends to be violated?

There is need for turbulence models for VTOL aircraft when airspeed goes to zero. There is no standard model for this case. The MIL Spec model can be tricked into working for this case by including very small mean velocities in the model. In addition, there is a need for turbulence and wind shear models for VTOL aircraft landing on small ships, in some cases on a notched step on the stern of the ship. The wake of the ship could cause considerable control problems.

D. Aircraft/Atmospheric Disturbance Response Modeling

More attention must be given to mechanization of atmospheric disturbances and related modeling of aircraft responses to these disturbances. Many simulation reports come out without any documentation of the algorithms used in the mechanization. It was suggested that future reports should include this information or at least give reference to such documentation. One such undocumented variation is the axes system used. As stated earlier, most mechanizations orient mean wind to earth reference and turbulence to body axes. Yet considerable statistical and tower turbulence data is referenced to the mean direction of the wind. As stated, simulations should be done with turbulence and mean wind referenced to earth and transformed to aircraft body axes. It was noted that airline training simulators are not generally programmed properly to simulate wind shear. They do have approximations of shear which can scare pilots a bit but most need to be reprogrammed to more properly simulate representative shear profiles. Further work is needed in methods to model disturbances as distributed lift rather than the common single point model. Information is needed on VTOL airplane response to large sideslip situations. This is the critical area for most high performance VTOL aircraft. Wind tunnel data is required.

E. Critical Case Studies

Further information is needed to determine what the critical wind shear profiles and magnitudes are which would induce hard landings for various types of aircraft. Different aircraft types will have different response to the same wind shear. For a given aircraft, variations should include configuration and weight variations and engine out cases. For training simulators, only a limited number of wind shear models need be defined (maybe four). Magnitudes should be varied to include limit situations and less severe cases. For research and engineering simulators, a limited number of profiles need to be defined. These should include variable shear and variable direction. For structural design only extreme cases need to be defined. One method of analysis was suggested based on Boeing SST studies wherein joint probabilities of turbulence and failure states were determined for various criticality levels. Possibly a wind shear analysis could be made in an analogous manner.

F. Atmospheric Disturbances and Meteorological Conditions

Some discussion was held on the relationship of disturbances and meteorological condition (i.e., ceilings, visibilities). For instance, there are some areas of the world where high wind and fog exist simultaneously, but this is not the general case. Generally, speeds are low and turbulence is low when fog exists. Correlation between visual observations of thunderstorms or rain showers and severity of disturbances cannot be reliably made. For instance, John Bliss, the Flying Tiger captain who preceded the fatal EAL 727 flight in approach to JFK in June '75, stated that he had flown through lots of rain showers that looked worse than this one at Kennedy.

G. Pilot Learning Effects

Some discussion centered on the learning effects in piloted simulations. There is a risk that if only a few models are used, pilots can learn the wind shear profile and "outsmart" the simulator; however, the problem may not be significant for "production" training programs where there generally is not very much time to take a long look at special situations. For research and engineering simulations where case after case is run, project engineers need to guard against the learning effect for valid results.

H. Operations Related Discussions

It was suggested that aircraft equipped with inertial navigation systems be used to measure wind conditions and be used as real time probes on a routine basis. This information could be automatically transmitted to approach control for use in advising subsequent aircraft during their landing approach. It may even be possible to use the transponder to transmit wind info directly back up to other aircraft.

The question of autoland vs. pilot role was raised. Specifically, it was suggested that much of the problem with wind shear during approach disappears if the autoland is left engaged. This was countered with the fact that most aircraft do not have autoland systems. Even if they did, a CAT III beam must be used to touchdown and not many airports have CAT III qualified ILS systems. So autoland is not the total answer to the problem. It was suggested that a potential research program should examine further the pilot's role during autoland approaches especially in the event of strong wind shears. If the pilot dislikes the autoland approach and disengages at low altitude, large transients due to the disengage could be more than the pilot can handle.