

SUMMARY REPORT OF THE
AIRCRAFT DESIGN COMMITTEE

Robert J. Woodcock
Principal Scientist
Control Criteria Branch
Flight Control Division
Air Force Flight Dynamics Laboratory

Members of the Aircraft Design Committee and their principal background in aircraft design were:

Robert J. Woodcock (Chairman), Air Force
Flight Dynamics Laboratory, flying qualities
Arthur E. Kressly, Douglas Aircraft Company,
stability and control

John C. Houbolt, NASA/Langley Research Center,
atmospheric models and structural analysis

Jack Hinkleman, FAA, Systems Research & Development Service

Douglas E. Guilbert, Aeronautical
Systems Division, Staff Meteorologist

Meetings were held with the four "rotating committees" for interchanges based on a list of suggested questions provided to stimulate discussion.

Considerable interest was also shown in aircraft operations. First, design must be based on operational methods and problems. Aircraft design for the worst atmospheric disturbances is an impossibility. Instead, the most extreme cases must be predicted and avoided. In particular, there are limits on the magnitude of wind shear and (at least for transports and such low-load-factor aircraft) thunderstorm turbulence that can be designed for. A recent

example was the C-141 lost at Mildenhall in an encounter with a very severe thunderstorm cell. Also cited was the reluctance or inability of air traffic controllers or tower operators to take the responsibility of directing aircraft around storms or telling pilots not to land, particularly during heavy traffic and bad weather conditions when such a responsibility would interfere with their primary responsibility of separating aircraft. Communication problems, including language differences, have been noted among engineers, meteorologists and operators--and even among engineers of various disciplines.

Discussions generally were lively. There was some consensus, but also much domination by a few who were most familiar with a particular subject.

I. Structures

The first two questions concerned structural design for turbulence: adequacy of engineering procedures, their form, and the data base. The concern expressed was for methods that could be applied to new concepts for which past rules of thumb might not apply, but keeping the requirements flexible enough to allow different design approaches as warranted. It still has not been completely determined that present criteria are adequate for all composite structures, with larger deflections, different frequencies and modes possible.

One problem is the age of the old standards, some over forty years old. New criteria can't be retrofit to aircraft designs already certificated. And because the basis is accumulated experience, old requirements, such as the 75 ft/sec design gust, cannot be applied with confidence to radically new designs. Even the von Karman and Dryden gust spectra go back to the 1930's. At least the numbers should be self-consistent. Some dispute remains on the exact shape of the power spectra at low frequency. Houbolt, in

particular, prefers the power spectral approach over use of discrete gusts. For linear systems, the former can get the same results as easily, and do more too--for example, uncover the high-response modes. He would use a design envelope for strength, mission analysis for fatigue.

Away from the ground, available design methods are generally adequate for consideration of atmospheric disturbances; any question would be about their application. Exceptions are a poor understanding of turbulence nonstationarity, patchiness or intermittency, and the spatial distribution. Houbolt noted that rolling often has accompanied vertical gusts he has experienced, and that in a number of accidents turbulence has caused one wing to break off but not the other. He suggested using an airplane fitted with angle of attack and sideslip probes at each wing tip and the tail to measure correlations.

For structural design, wind shear does not appear to be a problem (Question 5). But more data are needed on patchiness.

A tremendous amount of meteorological data exists which has not been analyzed. But some digging would be required to determine the suitability of specific data for a given purpose.

Light aircraft too, the Piper Navajo and Beech 35 were mentioned, have had structural failures in turbulence. Of the Part 23 airplanes the larger, heavier ones are thought to be more susceptible.

Helicopter and VTOL problems were recognized to be completely different, and received little attention in the discussions.

II. Flight Control

Under Question 3, concerning turbulence simulation, were discussed flying qualities and flight control system design. Related to this is Question 6, on the importance of wind shear to aircraft flight control systems. In the last 100 to 200 feet of altitude, wind shear can cause a hard landing. At 300 to 400 feet it can cause an airplane to land short. Knowledge of shear corresponds to our knowledge of gusts 25 to 50 years ago.

On approach, a tail-to-headwind shear is particularly troublesome and a common frontal encounter. In order to maintain glideslope, less throttle will be used anyway with a constant tailwind. Then upon entering a decreasing tailwind shear, airspeed tends to increase because of aircraft inertia. To avoid overshooting, a pilot is inclined (even instructed) to throttle back more. The resulting deceleration can match the wind shear's effect, thus making airspeed fairly constant as long as the wind continues to shear. But below the altitude at which the shear stops, the aircraft will continue to decelerate, now losing airspeed rapidly. With limited maximum thrust and engine lag too, the pilot will be hard put to maintain the flight path. A DC-10 at Buffalo gained 25 kt airspeed but then ended up 25 kt slow. Confronted with this wind shear, a pilot must limit use of throttle. Shear rate then, not just the instantaneous change, is important. In the same altitude range the pilot may be switching from instrument to visual flight, an adjustment that may take several seconds to make.

The opinion was expressed that unaided, a pilot can handle a shear gradient no greater than 4kt/100 ft. For automatic landing certification, FAA requires simulations with an 8kt/100 ft wind shear gradient. Even higher values have been encountered. Associated downdrafts can compound

the problem. Autoland systems are more sensitive than a pilot, have more data, and so may do better.

Capt. John Bliss, after a close call on approach, has devised and is patenting a system for onboard use that monitors the changing difference between ground speed and true airspeed to warn pilots of shear and tailwinds. Some commercial jumbo jets have inertial navigation systems from which ground speed is available. Doppler radar could be used. DME is thought to have too much lag for speed measurement useful in shears. With no help, present procedures definitely lead to trouble. Pilots need warning from the west side of the airfield when to keep away because of eastward-moving fronts.

Good design criteria are needed for performance margins to counter wind shear. Some aircraft have a large pitot-static error in airspeed indication, which doesn't help. Up to 9 or 10 m/sec downdrafts have been found near the surface. A representative sample of wind shears which encompass expected variations would be a very useful design help. The need to sample extremes which should be avoided gives problems of several sorts. Work is in progress and some data are available, but adequacy could not be assessed. Trying to forecast wind shear from synoptic data at seven East-Coast airports is just about impossible. The East Coast has large wind shears. In five or six cases warm fronts were found to be much worse than cold fronts, an apparent anomaly, since it is not common to associate severe weather with warm fronts. There are T arrays at Elizabeth and White Sands and towers at Brookhaven and elsewhere for measurements. There is work by Aeronautical Research Associates of Princeton and University of Oklahoma for NASA, and at UTSI, Frost is measuring flow around and in the wakes of actual buildings, etc., and mapping the flow field throughout the

vertical plane. NOAA at Boulder is looking at major fronts that way. Aircraft in service would make excellent wind shear and gust probes. But operators fear use of the data in violation proceedings; legislation might be needed.

For some aircraft a change in approach flap setting might be helpful to alleviate wind shear effects, but this is limited to settings for which certification was obtained (stopping distance being critical). The DC-9 originally had only 60° and 25° settings usable, but a 40° setting now has been approved.

For the take-off, cargo operations have a problem dragging out at maximum gross weight. Pulling power back for noise abatement at 1500 ft, before drag reduction, the airplane just sits there with no acceleration. This is a problem even with no wind shear, though noise abatement is forgotten if a critical performance problem develops. The current 3.2% climb gradient on a hot day with all engines is marginal for wind shear. A related concern is that knowledgeable airport managers may be pressed to emphasize noise abatement at the expense of safety.

Wake vortices from aircraft were not much discussed. Severe upsets have been experienced, leading to much effort at analysis and prediction. Apparently these efforts are thought to be sufficient as far as meteorological aspects are concerned.

Another operational problem, noted by Green of American Airlines, has been engine compressor stall in crosswinds on the ground. The cause seems to be insufficient design consideration rather than limited design capability.

For flying qualities and flight control design, the same instantaneous spatial distributions of horizontal and vertical gusts are needed that are needed for structural design, and also the characterization of patchiness and

intermittency, mentioned earlier, at all altitudes. Near the ground more data are needed on eddy size, spanwise gradients, lateral gusts, correlation with wind, etc. These are important for both analysis and simulation. For example, recent work at **NASA** Langley has shown deteriorating pilot ratings of aircraft flying qualities as the turbulence 'simulation becomes more sophisticated.

Thunderstorms, downdrafts, etc., combine both design and operational problems in finding suitable aircraft limits and ways to avoid exceeding them. The data appear to be available and avoidance work is in progress. This committee wants to emphasize the need. **A** coordinating panel was suggested to guide the work.

Extreme gusts can be avoided by staying clear of storms with 40 db or greater radar reflectivity, although the most intense gusts may be ten to fifteen miles from the point at which reflectivity is highest. Faced with a 200 mile squall line, then, a private pilot had better wait or go completely around it. Doppler, however, can do better for large aircraft.

Durrett noted one operational problem with thunderstorms for the space shuttle. **A** 1½-hour lead is needed for de-orbit and return to Kennedy Space Center, but there a thunderstorm can build from a clear sky in that time.

111. Data Needs

On meteorological data (Question 4), one additional need is for an inventory of atmospheric data for aircraft design. 130 or so data accumulation programs have been run. It was beyond the ability of this recorder to keep track of the data sources mentioned, and some of the references weren't all that clear anyway. Ramsdell had just surveyed micro-meteorological data, and FAA is correcting low-level data as

well as generating new data. Someone should correlate existing thunderstorm data. The Aircraft Design Committee strongly endorsed undertaking a survey of what is available, its format and limitations. A consensus was that aircraft are the best data probes.

Operationally, improvement is needed in forecasting and reporting atmospheric conditions. Especially in the terminal area, the occurrence of shear and turbulence needs to be related to the existence of "bad weather," although shear has been observed also in smooth air. Enroute, systematic reporting of atmospheric conditions is needed to improve forecasting capability. A start is to be made by collecting wind, temperature, etc., data continuously via satellite from a few commercial airliners. Most airlines are reluctant to volunteer to carry around the extra 75 pounds needed to do that, but this will be a vast improvement over radiosonde data.

IV. Lightning

None of the Aircraft Design Committee members was knowledgeable on lightning protection, Question 7. We listened with interest, at some length, to Plumer at one session and to Durrett at a later one.

From Plumer we learned something of the mechanism of lightning on aircraft. It is the return stroke from the ground that is the big jolt. Discharge takes about half a second, skipping down the length of the aircraft from nose to tail and holding onto the trailing edge. The charge is most intense initially, dropping off as the strike progresses aft. Damage may occur either directly or from currents induced in aircraft systems. There is a theory that lightning strikes ringing back and forth from nose to tail at the speed of light induce extremely high voltage. A nose pitot

boom makes a good lightning rod. So does the 747's wing tip probe. Lightning follows the pitot heater power cord. Static discharges will quiet noise but are ineffective against lightning.

A major problem with design criteria is uncertainty about the maximum voltages to be expected at altitude. Small-scale zaps give scary transients when scaled up to the 200,000 amperes measured at ground level.

Two design trends increase the severity of the lightning problem. One is sophisticated electronics in applications critical for flight safety, as in the basic flight control system. Digital operation and the low voltage level in current electronics applications cause special concern for the effects of electrical transients. The second trend is to composite structures. Not only do composites lack the shielding and grounding properties of metal structures, they also may be more susceptible to damage by lightning strikes. Lightning has also been observed to cause engine compressor stall. The integrity of composites can probably be assured by adding another layer of laminate, changing the resin composition, or some such procedure.

Successful protection is thought possible, and not too costly, through good design practice. On NASA's Orbiter this includes two-wire systems, short ground lines, shielding of analytically-determined strike and maximum-field-intensity points, and nose diverter strips (insulation underneath is affected by a strike). It is important to consider lightning early in the design phase. Testing is expensive, but at least one sample of each component should be tested. The first one generally fails in test, requiring some redesign. The expense and risk preclude lightning tests on the complete assembled Orbiter. There is concern about re-entry if a lightning strike is sustained on the way up, which might

cause spalling of the heat shield, for example. For aircraft, a lightning hole in a radome can be enlarged by rain.

There continue to be enough fires and explosions related to aircraft fuel systems to generate uncertainty that we know enough about sources of ignition by lightning. Kerosene is better than JP-4 fuel, which is more volatile and flammable at altitudes for lightning strikes. There is a thought that rather than lightning causing an accident, possibly the aircraft breakup and fuel spill might induce lightning.

Plumer would very much like to get reports of "interesting" lightning strikes--that is, ones affecting aircraft structure or equipment which have been experienced in aircraft operation. It was noted that NASA will be flying a Lear Jet with Air Force Flight Dynamics Laboratory instrumentation at Kennedy to find out if the induced current really is less at altitude or not.

V. Other Factors

Questions 8 and 9 concern temperature, rain, hail, icing, pressure, density, corrosives, abrasives, etc. While operational problems are recognized, it is felt that sufficient data are available for design. How to apply the data isn't always as clear. Mention of icing brought out some scary stories of quick, large buildups; pilot awareness is needed.