N88-17630

SIMULATOR INVESTIGATION OF WIND SHEAR RECOVERY TECHNIQUES

DAVID A. HINTON

NASA - LaRC

OCTOBER 22, 1987

THIS RESEARCH REPRESENTS A PORTION OF THE WORK BEING PERFORMED FOR THE MASTER OF SCIENCE DEGREE WITH THE GEORGE WASHINGTON UNIVERSITY

OBJECTIVE

- DEVELOPMENT OF PRACTICAL FLIGHT PROCEDURES AND GUIDANCE FOR NEAR-OPTIMAL TRAJECTORIES DURING INADVERTENT WIND SHEAR ENCOUNTERS FOLLOWING TAKEOFF

APPROACH

- CONDUCT PRELIMINARY DEVELOPMENT OF CANDIDATE STRATEGIES USING BATCH SIMULATION OF POINT MASS AIRPLANE

- EVALUATE CANDIDATE GUIDANCE STRATEGIES IN PILOTED, REAL TIME, 6 D.O.F. SIMULATION

BATCH SIMULATION

- POINT-MASS B737-100 PERFORMANCE MODEL

- FLIGHT IN VERTICAL PLANE

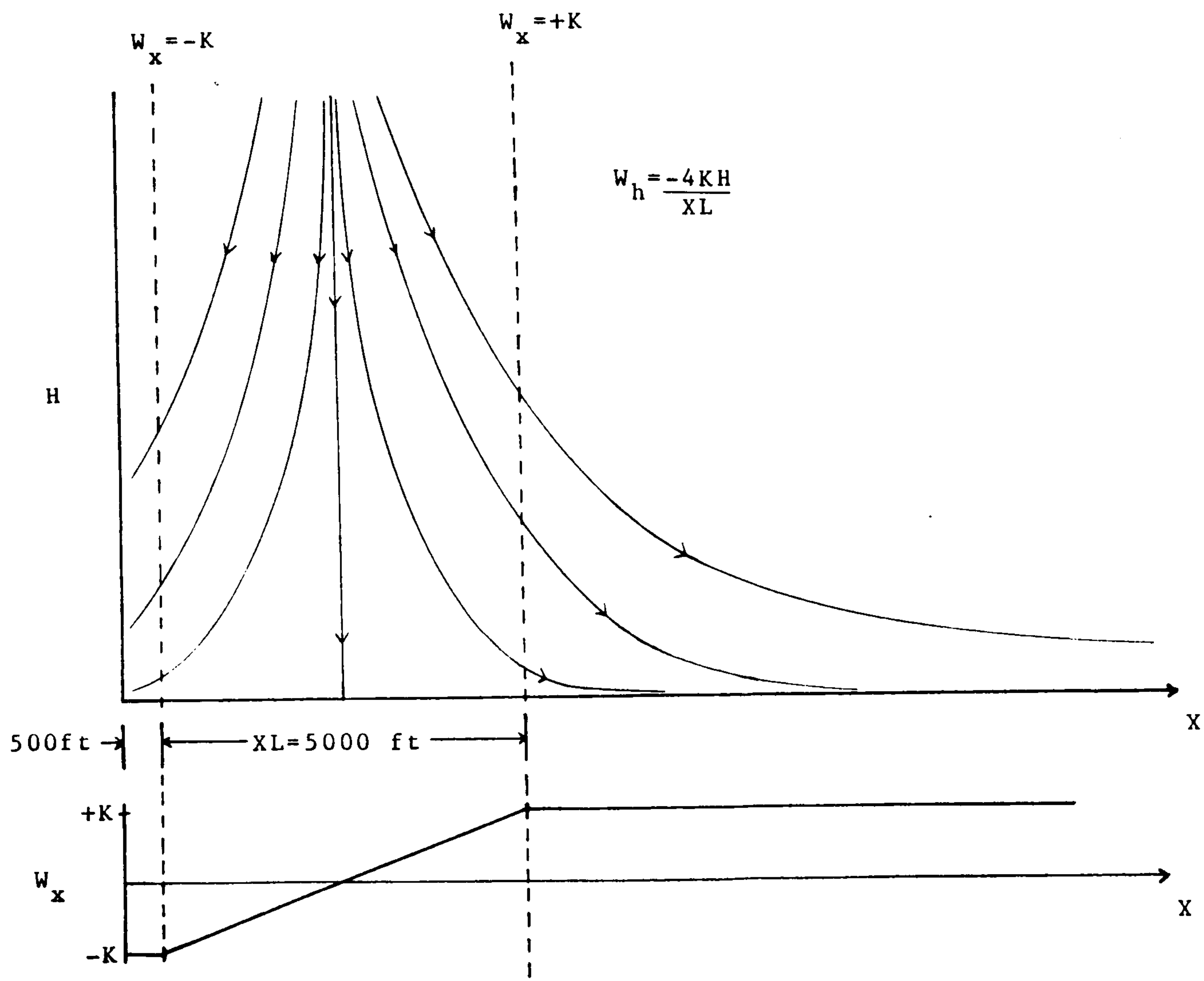
- POSITION-BASED ANALYTICAL WIND MODEL

- 3 GUIDANCE STRATEGIES DEVELOPED FOR REAL-TIME PHASE
  - o PITCH HOLD - FOR NONRETROFIT
  - o ACCELERATION - FOR RETROFIT TO NON-IRU AIRCRAFT
  - o FLIGHT PATH ANGLE - FOR RETROFIT TO IRU-EQUIPPED AIRCRAFT

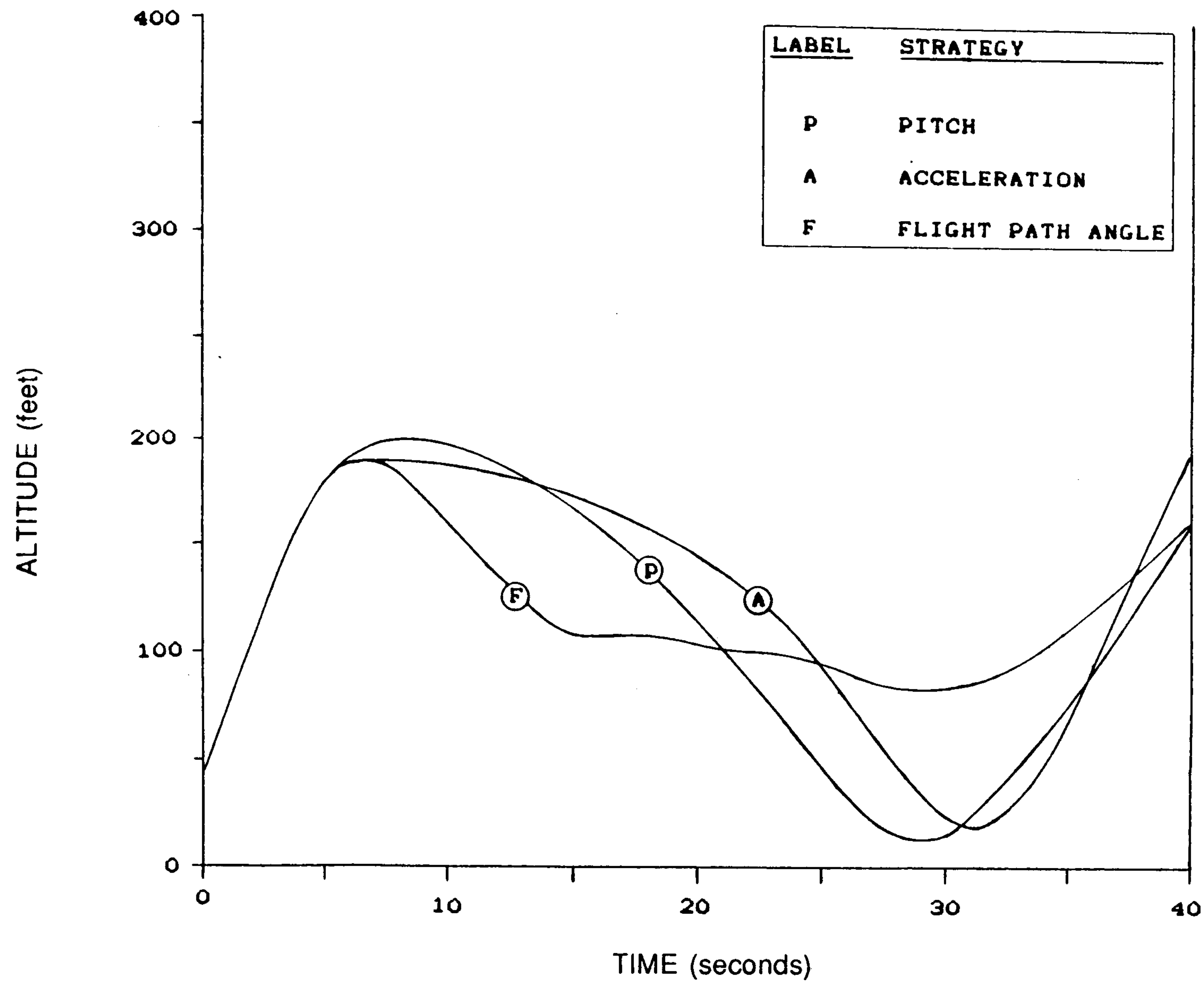
- BEST OVERALL RESULTS WITH FLIGHT PATH ANGLE STRATEGY

- LESSONS:
  - QUICKLY ARREST CLIMB IN TAKEOFF WIND SHEAR ENCOUNTER
  - USE MINIMUM FPA AND MAXIMUM KINETIC ENERGY THROUGH SHEAR
  - REACH LIMIT ANGLE OF ATTACK AT END OF SHEAR

SHEAR MODEL A



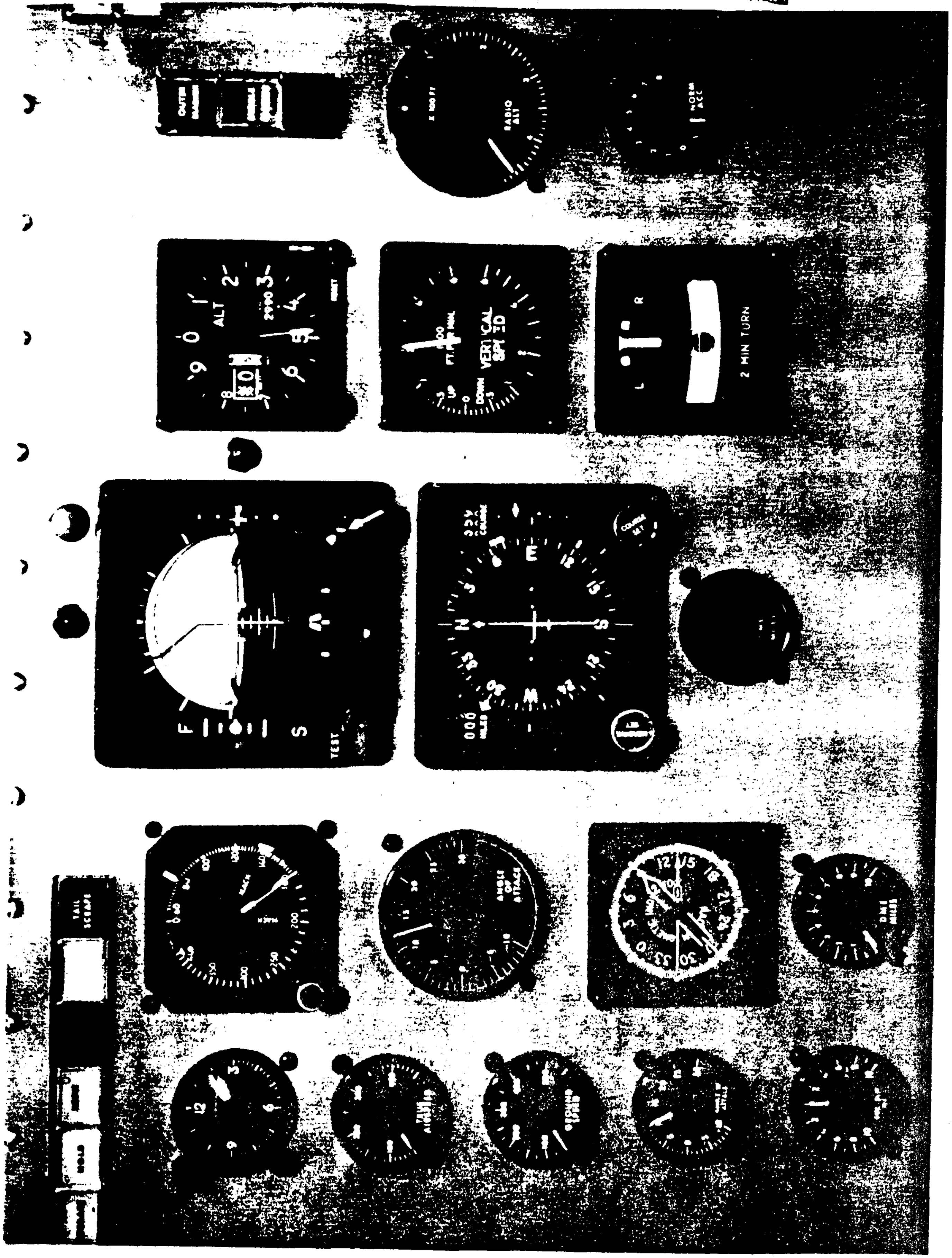
THREE GUIDANCE STRATEGIES



ORIGINAL PAGE IS OF POOR QUALITY

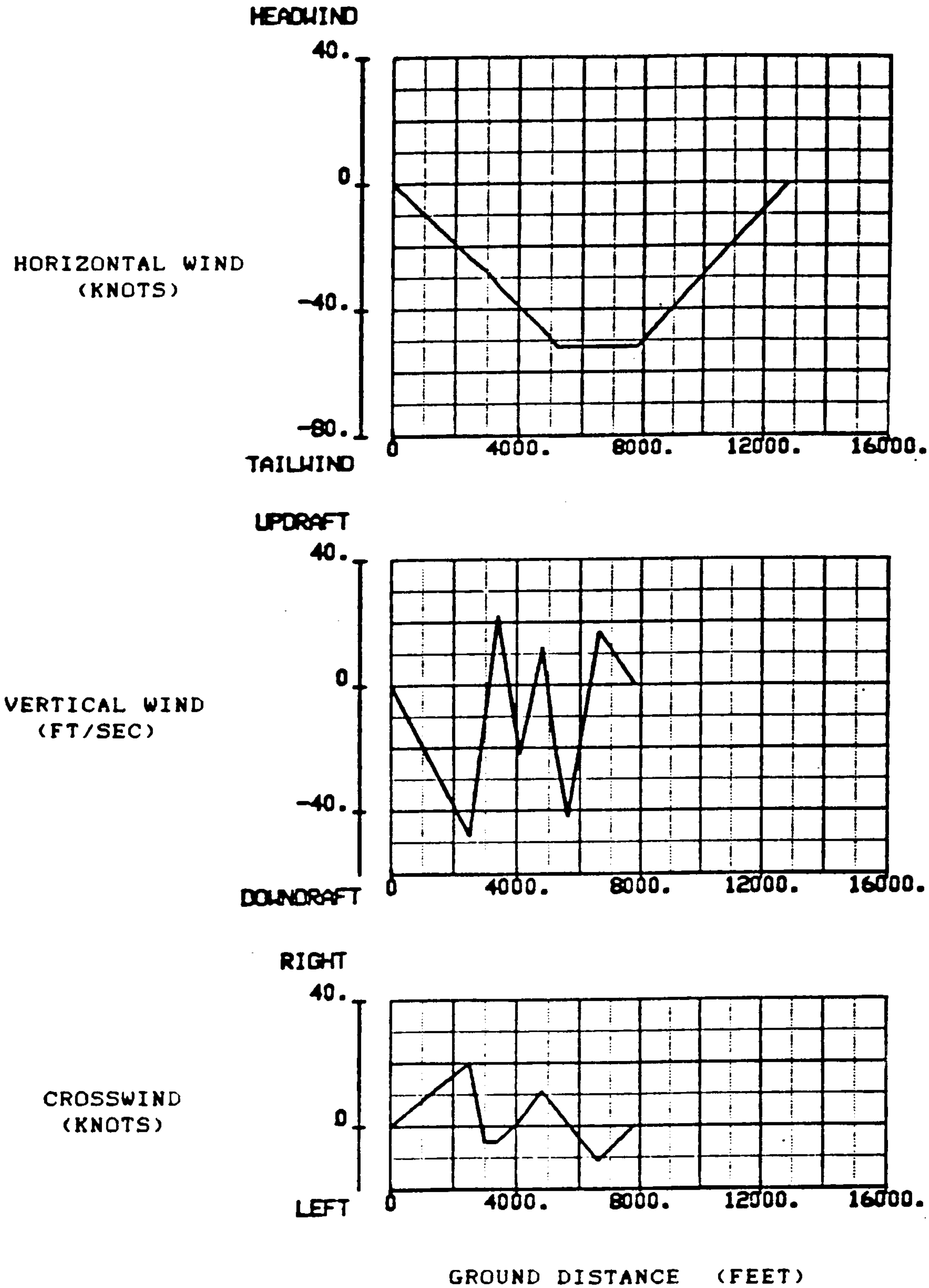
REAL-TIME SIMULATION

- B737-100, 6 D.O.F. MOTION, OUTSIDE VISUAL SCENE
- CONVENTIONAL FLIGHT DECK
- THREE GUIDANCE OPTIONS, FROM BATCH SIMULATION
- TWO WIND SHEAR MODELS
    - SHEAR A, FROM BATCH STUDY, NONTURBULENT
    - SHEAR B, DFW-BASED TRAINING SHEAR, VORTEX TURBULENCE
- SHEAR ENCOUNTERED AT PRESET ALTITUDE FOLLOWING NORMAL TAKEOFF
- PERFECT INSITU SENSING ASSUMED, IMMEDIATE ALERT AND GUIDANCE AT SHEAR ENTRY



NASA
L-87-5712

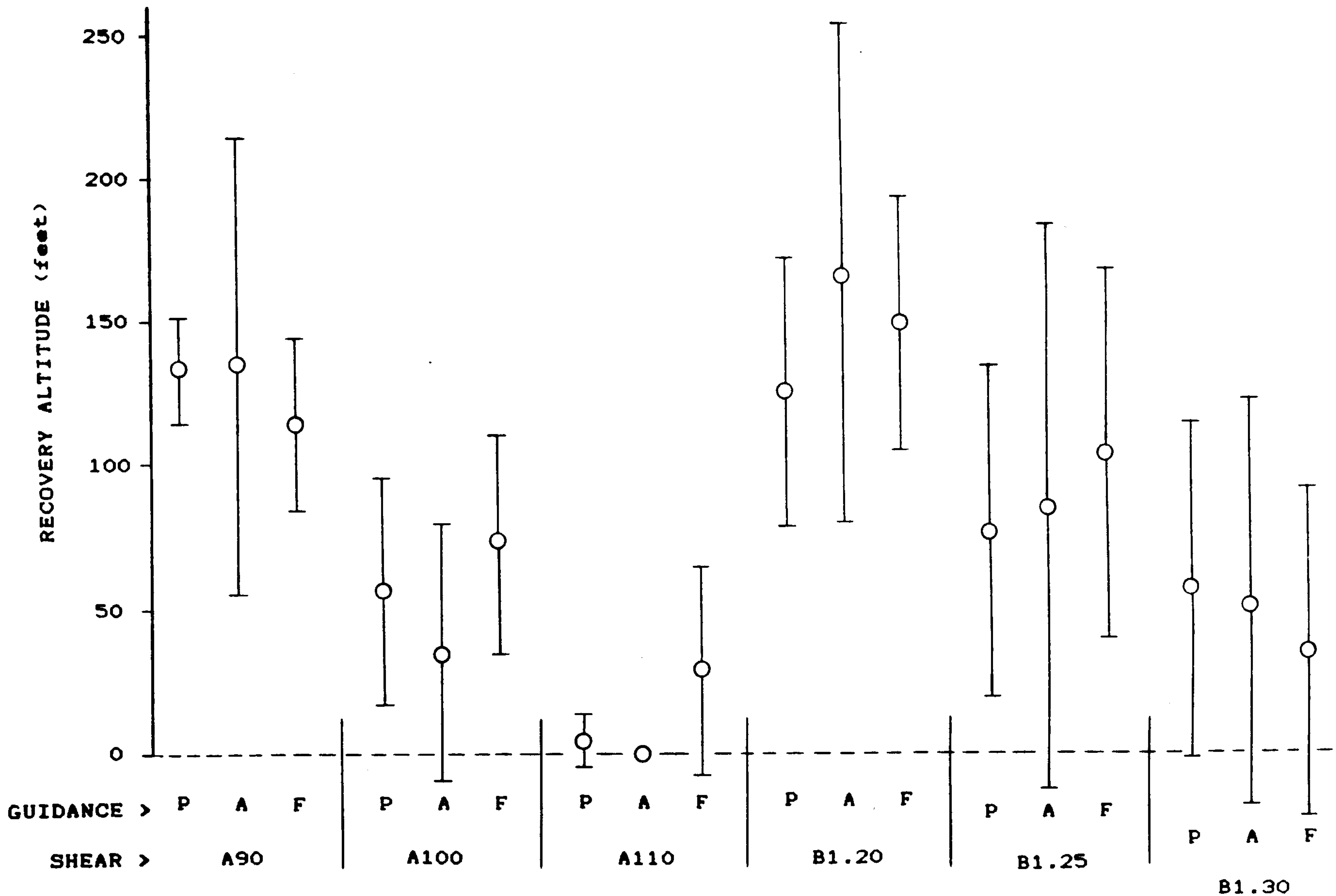
SHEAR MODEL B



REAL TIME MATRIX

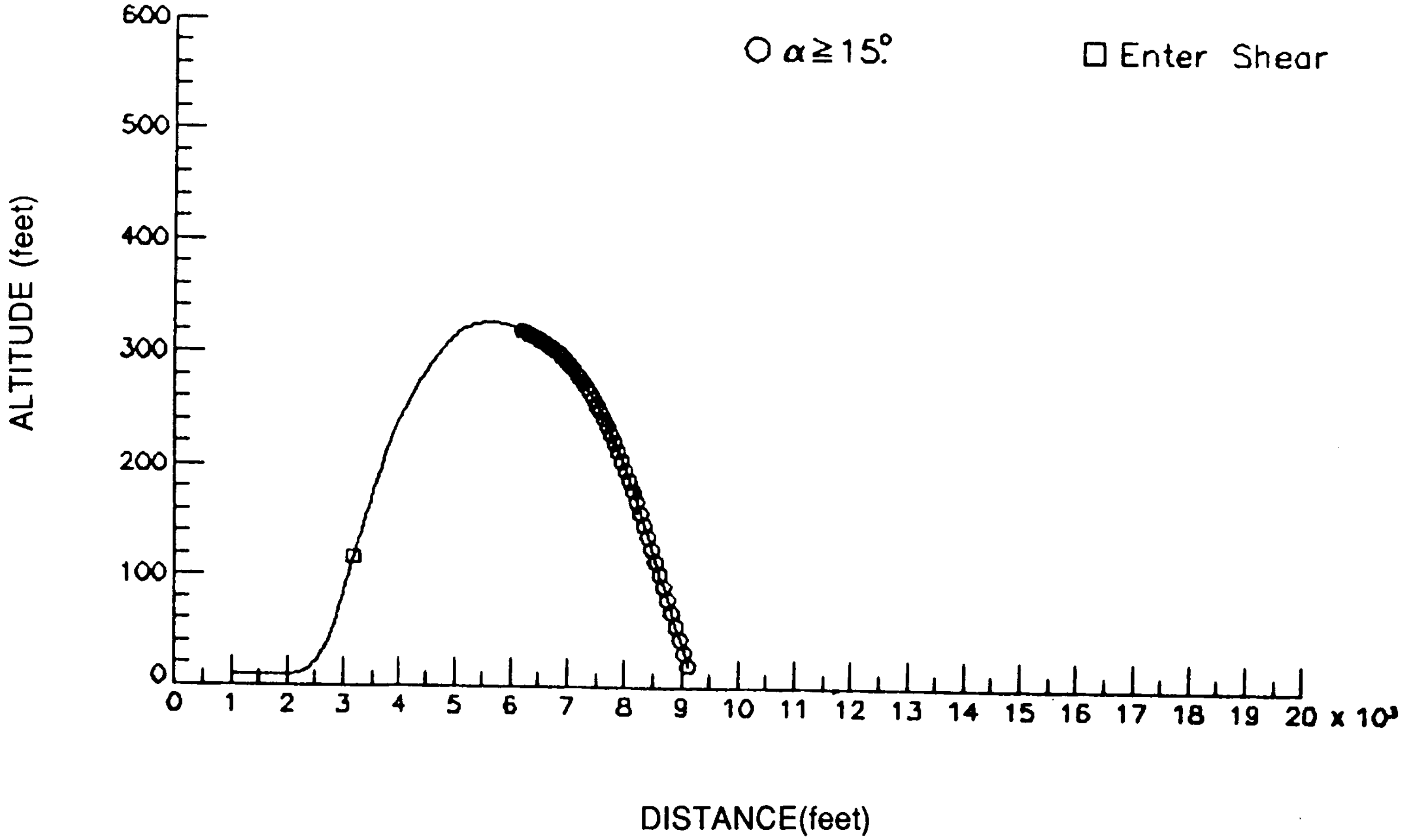
- 3 PILOTS
- 3 GUIDANCE STRATEGIES
- 7 SHEAR VARIATIONS
  - 3 LEVELS OF SHEAR A, ENTERED AT 100 FOOT ALTITUDE
  - 3 LEVELS OF SHEAR B, ENTERED AT 100 FOOT ALTITUDE
  - 1 LEVEL OF SHEAR A, ENTERED AT 20 FOOT ALTITUDE
- 21 CELLS, 4 REPETITIONS IN EACH CELL PER PILOT
- GUIDANCE OPTION CHANGED EVERY 6 RUNS, SHEAR WAS RANDOMLY VARIED

MEAN AND STANDARD DEVIATION OF RECOVERY ALTITUDE FOR GUIDANCE/SHEAR COMBINATIONS



EXAMPLE OF ACCELERATION GUIDANCE OPTION

SHEAR A100

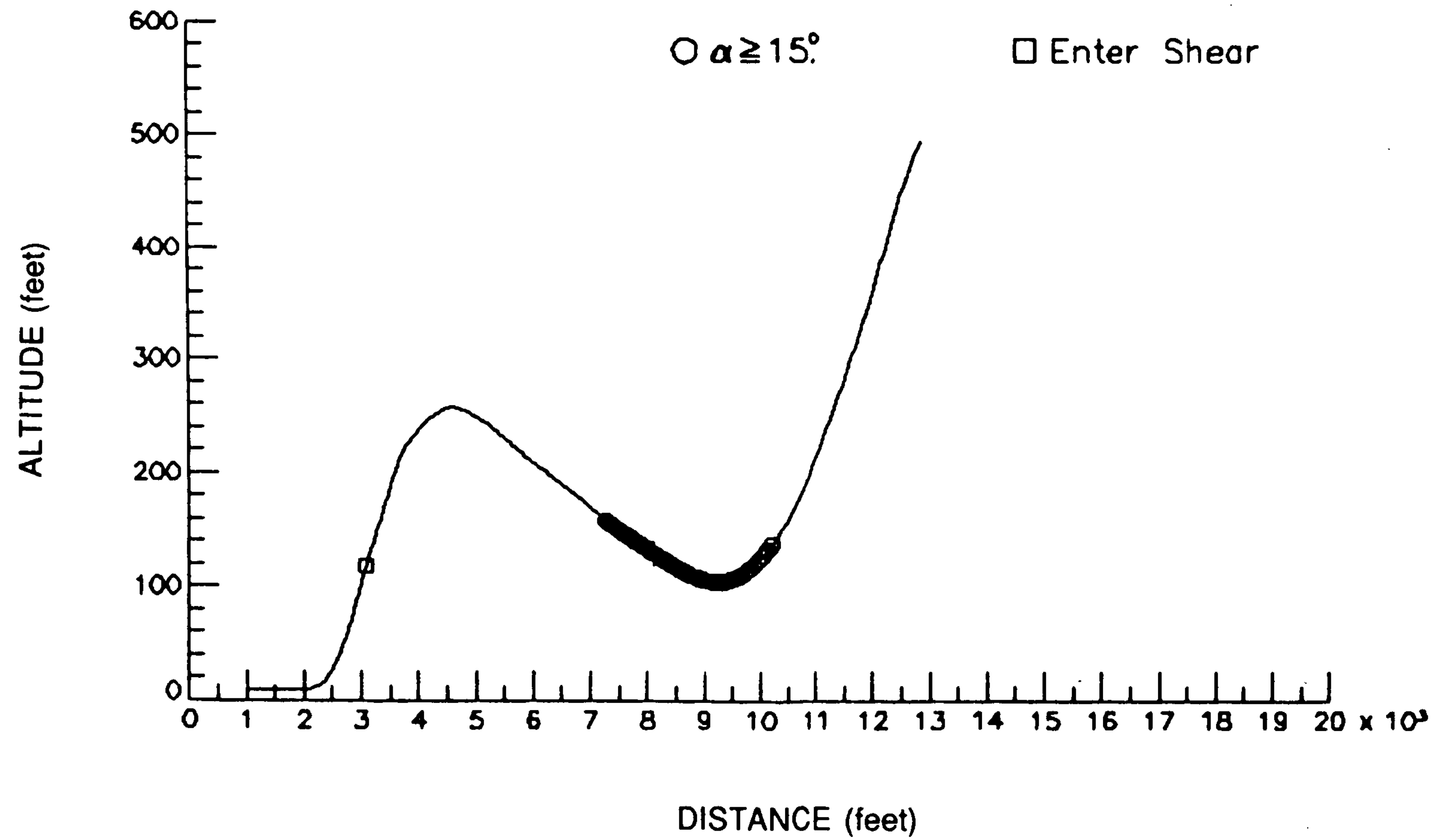


PRECEDING PAGE BLANK NOT FILMED

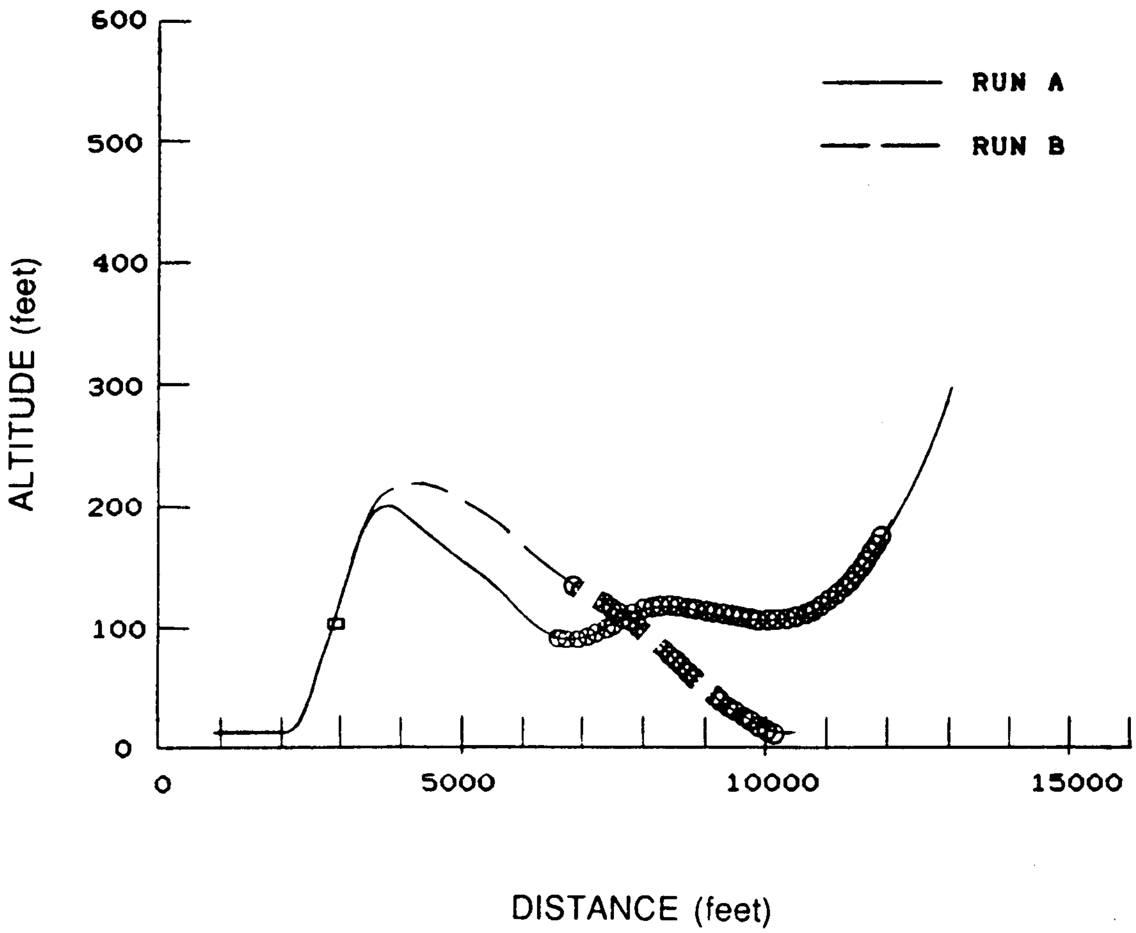
345, 346

EXAMPLE OF FLIGHT PATH ANGLE GUIDANCE

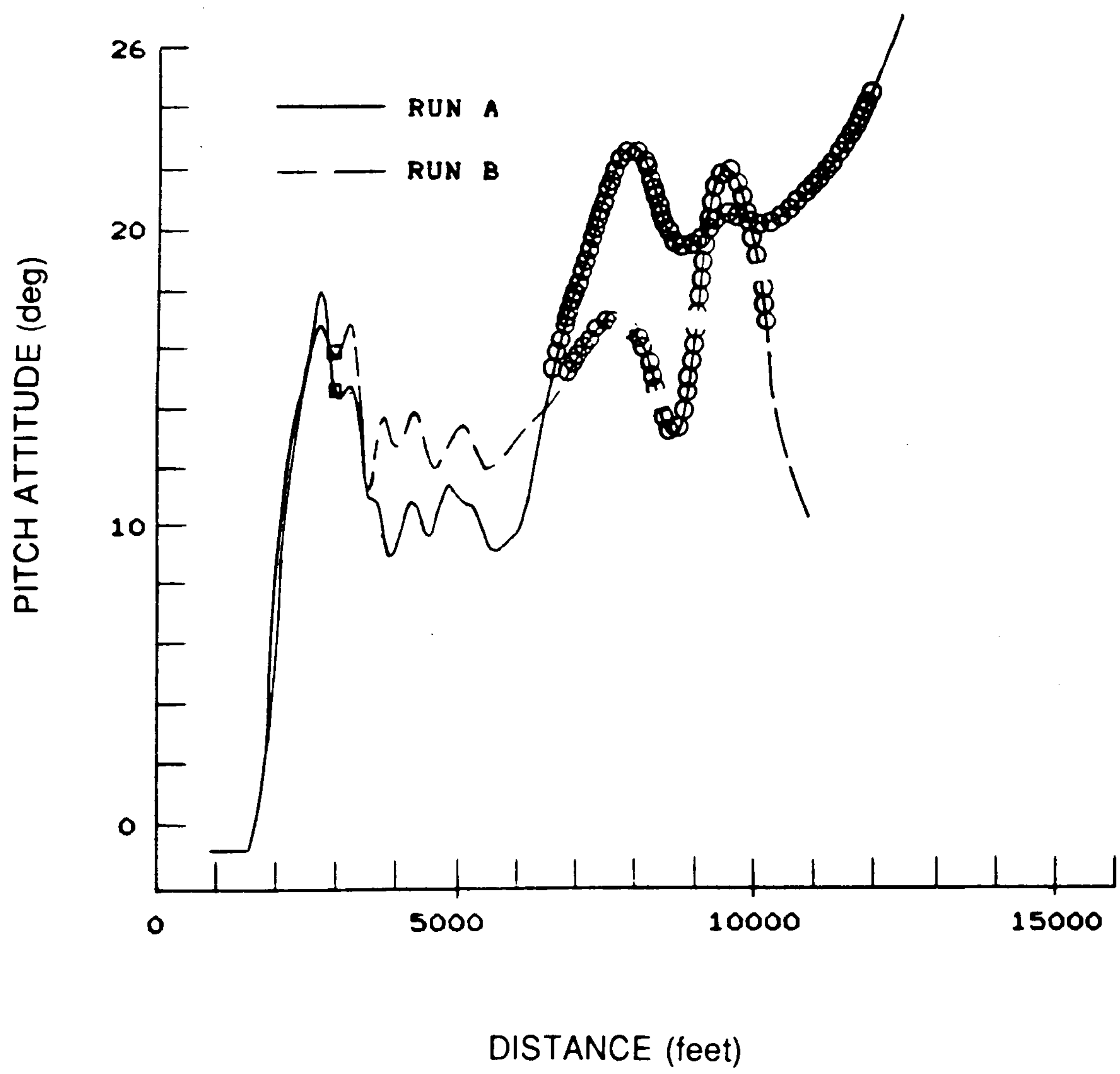
SHEAR A100



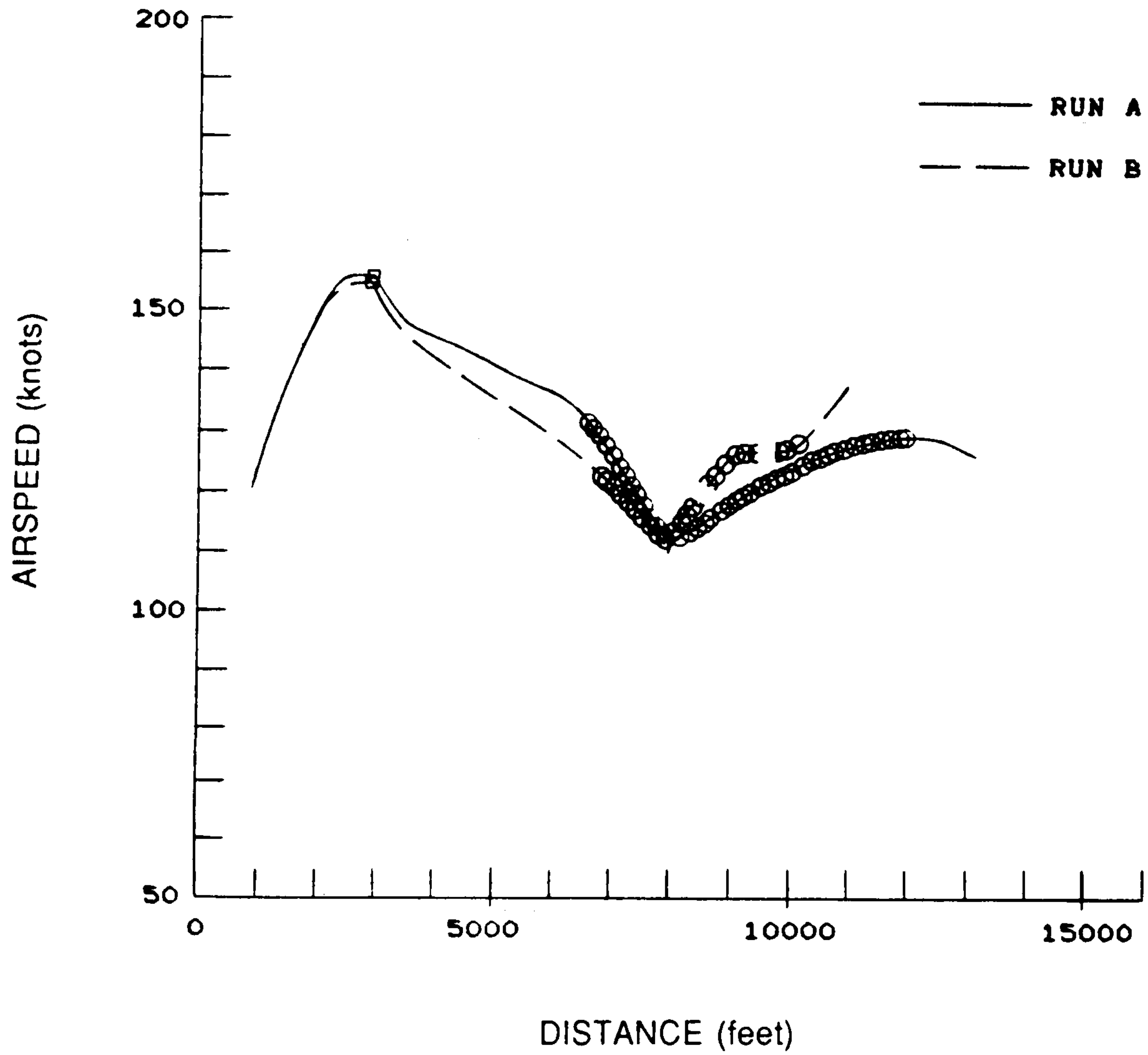
COMPARISON OF ALTITUDE PLOTS IN TWO RUNS WITH SHEAR A110 AND FLIGHT PATH ANGLE GUIDANCE



COMPARISON OF PITCH ATTITUDE IN TWO RUNS WITH SHEAR A110 AND FLIGHT PATH ANGLE GUIDANCE



COMPARISON OF AIRSPEED IN TWO RUNS WITH SHEAR A110 AND FLIGHT PATH ANGLE GUIDANCE



FACTORS INTRODUCED BY SHEAR B

- CONTROL PROBLEMS ASSOCIATED WITH VERTICAL WIND CHANGE

- AVERAGE RMS PITCH ERROR INCREASED FROM 2.45 DEG TO 3.87 DEG (SHEAR A TO B)

- LOWER ΔW_x VALUES CAN BE PENETRATED IN SHEAR B

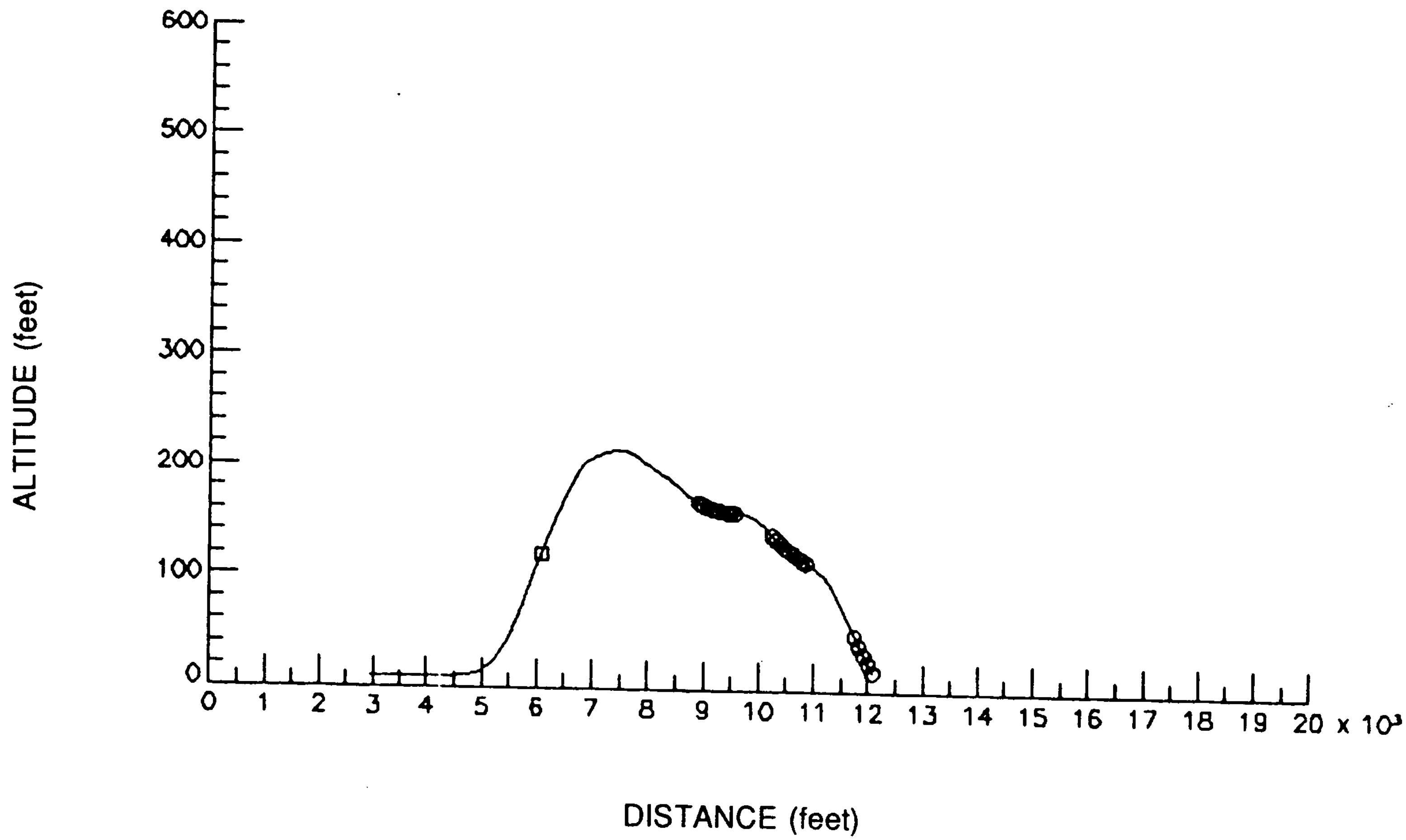
- FREQUENCY OF W_h REVERSALS EXCITES PITCH OSCILLATION

- FINAL DOWNDRAFT OF SHEAR USUALLY CAUSED LARGE REDUCTION IN AOA AND FLIGHT PATH ANGLE

- POSSIBLE CHANGE IN OPTIMAL TRAJECTORY

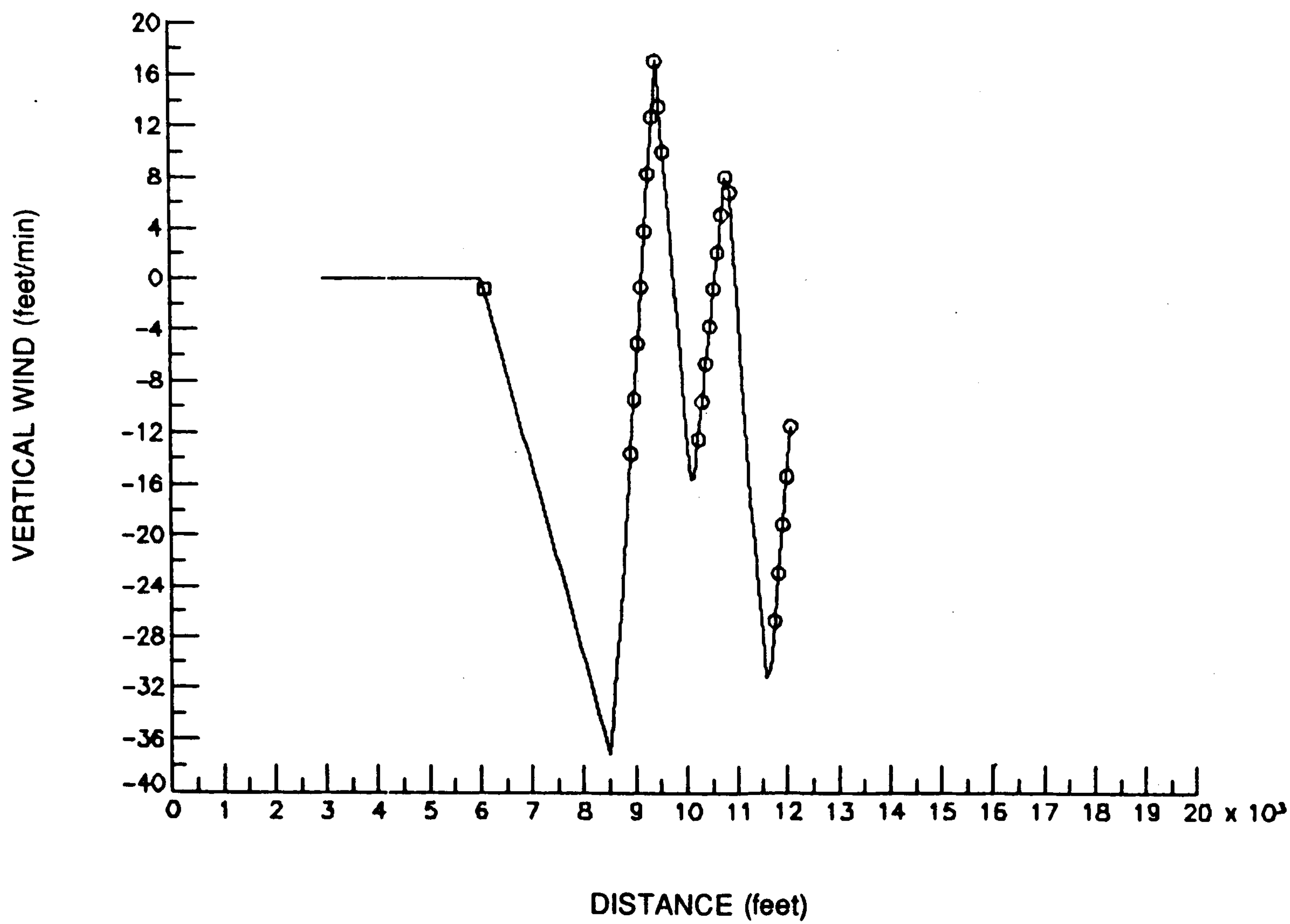
EXAMPLE OF FLIGHT THROUGH SHEAR B1.3

ALTITUDE



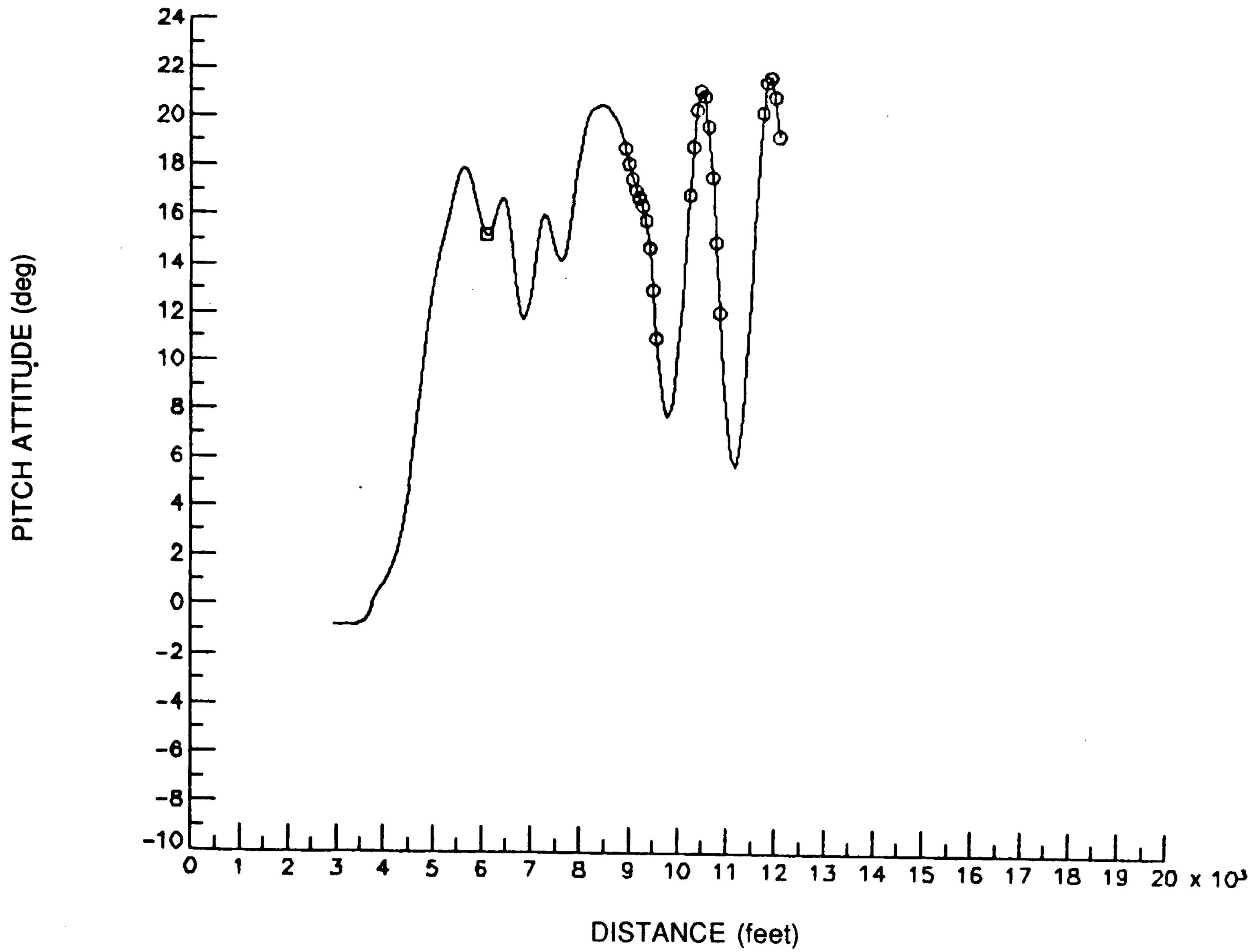
EXAMPLE OF FLIGHT THROUGH SHEAR B1.3

VERTICAL WIND



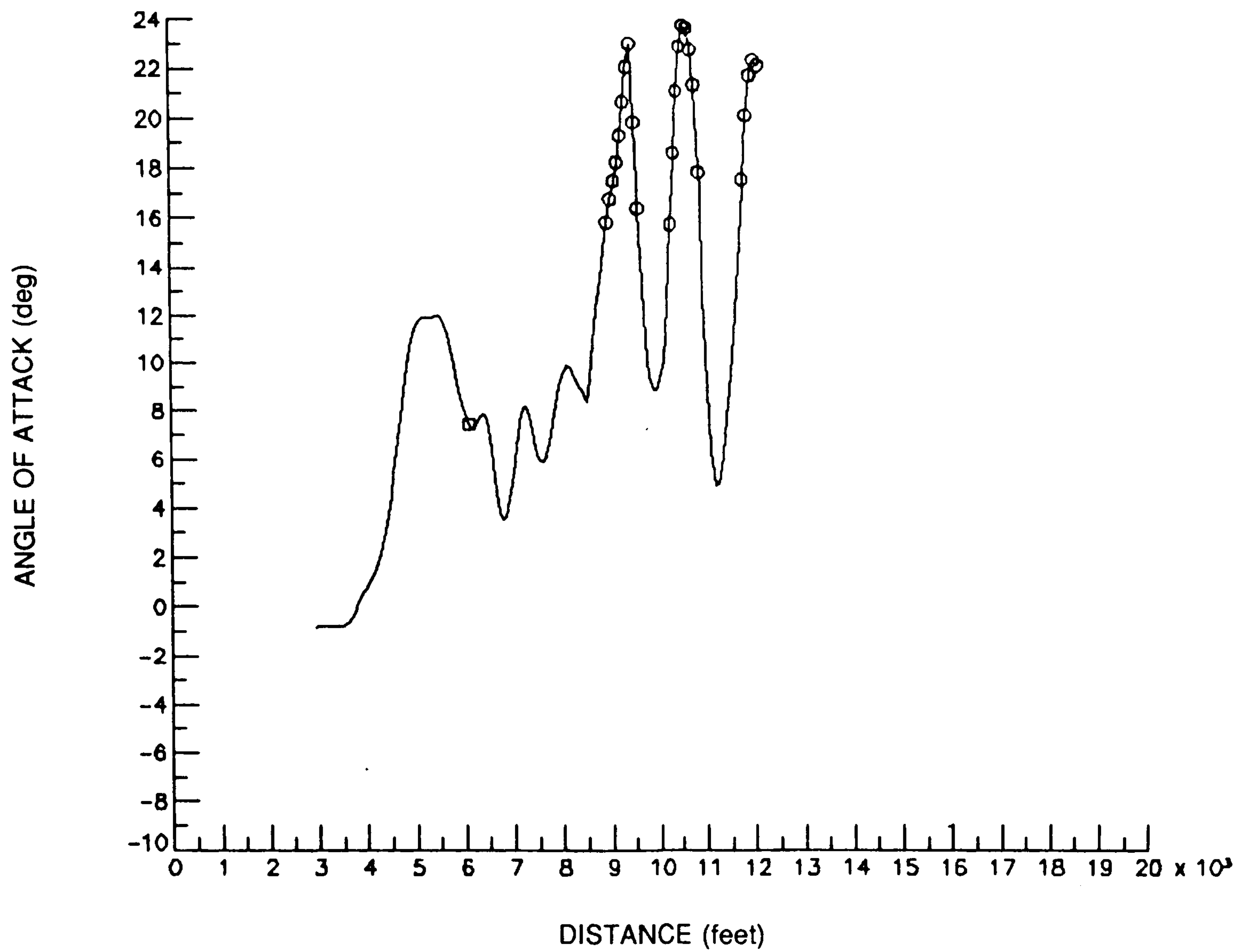
EXAMPLE OF FLIGHT THROUGH SHEAR B1.3

PITCH ATTITUDE



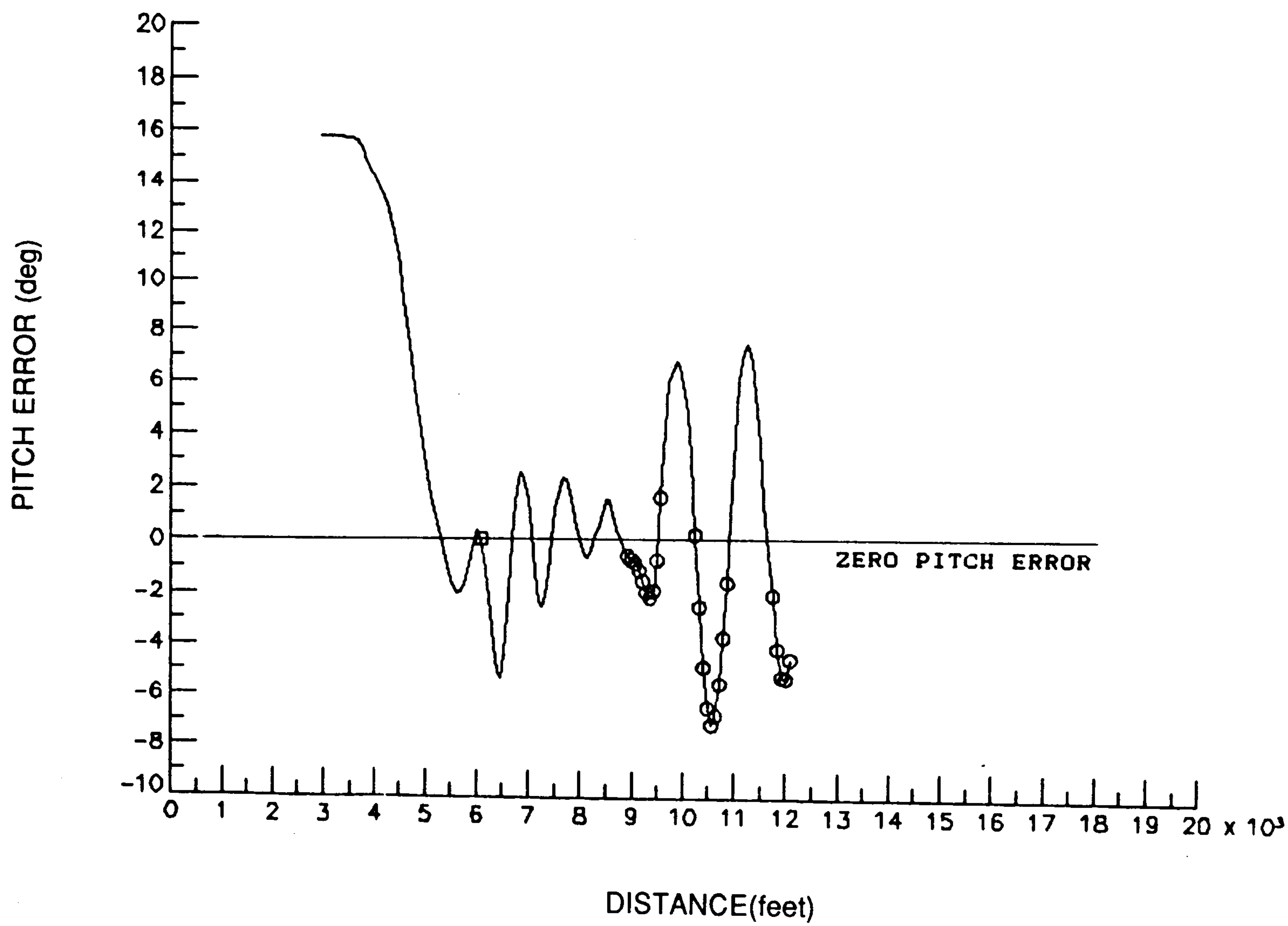
EXAMPLE OF FLIGHT THROUGH SHEAR B1.3

ANGLE OF ATTACK



EXAMPLE OF FLIGHT THROUGH SHEAR B1.3

PITCH ERROR



PILOT COMMENTS

- INITIALLY RELUCTANT TO REDUCE PITCH WHEN ENTERING SHEAR

- ACCELERATION GUIDANCE INITIALLY SEEMED MORE "NATURAL", LATER THE FLIGHT PATH ANGLE WAS PREFERRED

- ALERT AND AUTOMATIC FLIGHT DIRECTOR SWITCHING WAS ACCEPTABLE, LATERAL STEERING AND AOA GAGE WERE NOT USEFUL

- INTENTIONAL DESCENT BY "ALTITUDE-SMART" GUIDANCE WAS ACCEPTABLE

- PILOTS DEVIATED FROM GUIDANCE WHEN IT APPEARED TO BE LEADING THEM TO VERY LOW ALTITUDES

CONCLUSIONS

- MOST PROMISING GUIDANCE IS FLIGHT PATH ANGLE
- AIRSPEED DISTRIBUTION WAS IMPORTANT; BEST PERFORMANCE ACHIEVED BY INITIAL REDUCTION IN PITCH TO CONSERVE AIRSPEED, THEN TRADING OFF AIRSPEED AT END OF SHEAR
- ADDITIONAL FACTORS INTRODUCED BY VORTEX PENETRATION, MAY ALTER CHARACTERISTICS OF OPTIMAL RECOVERY
- AIRPLANE HAD LESS ΔW_x CAPABILITY IN VORTEX FLOW SHEAR MODEL THAN IN CLASSIC MICROBURST MODEL
- DIFFERENCE IN RECOVERY CAPABILITY BETWEEN GUIDANCE OPTIONS WAS SMALL COMPARED TO EXPERIMENTAL VARIATION BETWEEN RUNS
- ADDITIONAL RESEARCH NEEDED ON PRECISE HAZARD DEFINITION AND OPTIMAL TRAJECTORIES IN VORTEX ENCOUNTERS

SIMULATOR INVESTIGATION OF WIND SHEAR RECOVERY TECHNIQUES

An effort was conducted to develop techniques for flying "near optimal" trajectories, during inadvertent microburst encounters, when the microburst flow field ahead of the airplane is not known. Only the takeoff wind shear encounter case was considered. The research was done in two phases. In the first phase, a batch simulation, consisting of a simple point-mass performance model of a transport category airplane, was used to develop candidate wind shear escape strategies. A simple analytical wind shear model was used in the development. In the second phase, the strategies were evaluated in a real-time, piloted simulation. Both the simple analytical wind shear model and a second model, based on the vortex circulation encountered in the Dallas-Fort Worth accident, were used in the piloted simulation. The three guidance options tested were: pitch attitude hold, which commanded a constant recovery pitch; acceleration, which decelerated the airplane as a function of the instantaneous shear strength; and flight path angle, which produced a minimum altitude trajectory. All guidance options were presented to the pilot on an electromechanical flight director for manual tracking.

The results showed that the most promising guidance option is the flight path angle guidance, but that the experimental variation in recovery performance between runs was greater than the differences between guidance options. The distribution of airspeed loss across a wind shear was important. In a severe shear, a steady reduction in airspeed was less efficient than initially conserving kinetic energy, and trading it off near the end of the shear. The vortex circulation shear introduced additional factors into the recovery. There is evidence that the optimal recovery strategy may be slightly different in the vortex encounter than in a classic downburst model. The maximum horizontal wind change capability of the airplane was much less in the vortex shear model than in the simple analytical model. The pilots were initially reluctant to reduce pitch attitude close to the ground, upon entering the shear, but later observed and commented on the benefits of an initial pitch reduction.

KIOUMARS NAJMABADI (BOEING) - Earlier you showed the altitude profile of the three strategies when subjected to your analytical wind model where the horizontal wind is the same for all the strategies. But, any strategy which tries to climb will be penalized because your vertical wind is a function of altitude. Now did you compare, or do you have the same comparison for your B model?

DAVE HINTON (NASA LaRC) - Not directly. The reason is the B model is not implemented in the batch simulation. You're refering to this first chart, this one?

KIOUMARS NAJMABADI (BOEING) - That is right.

DAVE HINTON (NASA LaRC) - Okay. That particular simulation batch model does not have the vortex shear in there. The reason is, it is a very simple point airplane model and I can't hope to really duplicate all the effects. That is, the stability effects and control problems associated with shear B. Therefore, I didn't put that one in.

KIOUMARS NAJMABADI (BOEING) - The fact is that if you climb higher--I agree with you that the intensity of the down draft and all will increase--but at the same time I think that also the shear in the horizontal will decrease. If you look at the existing model.

DAVE HINTON (NASA LaRC) - I did run these same cases with no vertical wind present. The effect was not as large. But I saw that it was bad to climb there also. It was not just the effect of having the vertical wind stronger at altitude. Just giving up the airspeed is also bad.

PAUL CAMUS (Airbus Industrie) - I have two comments related to one of your viewgraphs. The comparison of altitude plots in two runs with flight path angle guidance, I notice that there is a large experimental variation in performance recovery between two runs with the same guidance. If you consider run A, a large pitch change demand is required to stop the altitude loss. And it seems to me that in the case of run B the pilot did not respond to the flight director commands.

DAVE HINTON (NASA LaRC) - He did not respond as quickly or as aggressively?

PAUL CAMUS (Airbus Industrie) - Yes.

DAVE HINTON (NASA LaRC) - That is correct. The pilots all temper the flight director somewhat with what they expect to do. And if there is a very large say--from 16 degrees to 10 degree pitch change--pilots may follow it very aggressively or not so aggressively.

PAUL CAMUS (Airbus Industrie) - Which means that it might be a problem of training, and the constant pitch might be the best anyhow.

DAVE HINTON (NASA LaRC) - There are a lot of issues that I didn't have time to get into. A lot of training issues were raised during the simulation study.

PAUL CAMUS (Airbus Industrie) - I have a second point. It seems that you accept a large flight path declination before you accept the deceleration of the plane. Therefore, during the initial phase you have to pitch down to track the air speed--Also a down draft at this moment.

DAVE HINTON (NASA LaRC) - In shear B that is precisely what happened. In shear B you'll notice we are climbing and then we change that over to a descent. At that same time the airplane has been hit with the first down draft, which was the strongest one, and because the down draft is helping the pilot to accomplish his objectives (in arresting the rate of climb) it wasn't even really noticed. The last down draft, which was not quite as strong, is usually the one that really hurt the aircraft.

PAUL CAMUS (Airbus Industrie) - Do you believe that a pilot would be prepared to accept a negative vertical speed in the initial phase when he has high kenetic energy?

DAVE HINTON (NASA LaRC) - Our pilots did seem to believe that it was acceptable to have smart guidance decending them towards the ground. The rate of decent in each of these cases was limited to about the same value you would see in the glide slope, about 600 feet per minute, so it was a very gentle decent. Again, it goes back to training, because initially the pilots did not like it. After flying about 30, 40 50 runs they began to see the advantages of doing that, and were more aggressive in pitching over. Obviously, you can not have every airline crew flying a hundred runs. So there is a definite training issue.

PAUL CAMUS (Airbus Industrie) - Thank you.

DICK BRAY (NASA Ames) - Dave, I want to sort of put this to you as a question. On your flight path control law going into shear B, the perfect following of that shear law would still require very rapid pitch of the aircraft at about that 6 second period wouldn't it?--Just to maintain? In other words that was a very demanding, very active pitch task produced by that law.

DAVE HINTON (NASA LaRC) - The pilots varied. They tried various gains, of course. Three pilots used for our research were test pilots here at NASA, not line pilots. They varied their gains and I did not see anything beyond the realm of what you could do in an operational environment. They did not feel it was beyond the realm. The guidance was presented to them in the form of--if I wanted them to go to 10 degrees of pitch--that is where I put the needle on the flight director. It is entirely up to the pilot to close the loop and get the airplane to that pitch attitude.

DICK BRAY (NASA Ames) - Okay. But just flying through that would, if he followed it perfectly, be a very, very active pitch.

DAVE HINTON (NASA LaRC) - Actually, the needle movement was limited to three degrees per second, so that is not beyond the realm. That was the limit on the pitch needle movement rate.

DICK BRAY (NASA Ames) - You wave a sort of nasty dynamic problem with that particular shear. I was wondering whether you ever considered flying to an air mass flight path instead of an inertial flight path.

DAVE HINTON (NASA LaRC) - We could do it either way, it would be a similar task.

DICK BRAY (NASA Ames) - Yeah, well there should be an awful lot less activity if you were deriving flight path, with angle of attack with the proper amount of lag on it. It should really stabilize the pitch command. You'll get an oscillation in the flight path but (paused)

RALPH COKELEY (Lockheed) - Dave, I've got some concerns, and I don't question the validity of what you have shown us, but I want to point out to the rest of us that have not been in the piloting picture (and perhaps associated with some of the other studies), that at this moment we don't have a means of recognizing the shear instantaneously. And, for the next four years we are going to be doing it differently and training some 25000 pilots to do it differently. Up to that time our accident picture has been letting the nose drop too far and too late. So, the emphasis for the next four years is going to be not to let that happen inadvertently when you don't recognize it. So even assuming that this is valid, we've got some road-crossing, down the road, to change paths and change guidance strategies to make something like this work.

DAVE HINTON (NASA Ames) - That is true. That is very true.