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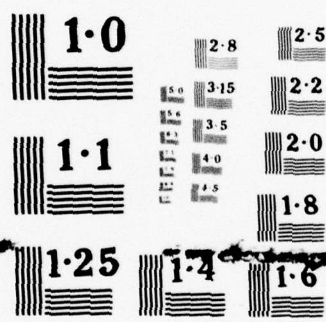
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WINDSHIELD QUALITY AND PILOT PERFORMANCE

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AEROSPACE MEDICAL RESEARCH LABORATORY
AEROSPACE MEDICAL DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

NOTICES

TECHNICAL REVIEW AND APPROVAL

AMRL-TR-77-39

This report has been reviewed by the Information Office (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

CHARLES BATES, JR.
Chief
Human Engineering Division
Aerospace Medical Research Laboratory

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Two experimental investigations were performed with C-141 pilots making aircraft landings with a 727-200 flight crew training simulator mounted on a three-degree-of-freedom motion base. The terrain image was computer-generated and the 1000 TV line, full color scene was displayed at optical infinity with a resolution of 2.9 arc minutes. All pilots were extensively tested for visual skills. Optical distortion panels between the pilot and the visual scene simulated a range of windscreen image qualities from excellent to poor. One study used 8 pilots, 4

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20. Abstract (Continued)

windscreen qualities, 2 times-of-day and 2 visibility conditions. A second study used 6 pilots, 3 windscreen qualities, 2 times-of-day, and 4 replications. In both studies, ten dependent measures were taken of pilots' performance.

Decreased windscreen optical quality increased centerline deviations at touchdown point. Windscreen quality and time-of-day significantly interacted. Night approaches with poor windscreens were significantly above glide slope, but on glide slope with better windscreens. Approaches were low for all windscreens in daytime landings. Poor optical quality windscreens caused apparently more cautious night landings: higher faster approaches, more rapid descents and touchdowns that were harder and further down the runway. Recommendations are made for measuring windscreen optical quality effects on flight performance.

SUMMARY

This experimental investigation of the relationship between windscreen quality and pilot performance utilizes the skill of eight Air Force C-141 pilots. These men were tested and found to have excellent vision. The windscreen quality was varied by three distortion acrylic panels, supplied and evaluated by the USAF, and placed between the pilot and the forward air-to-surface visual scene. The vehicle was a 727-200 flight crew training simulator complete as to flight instruments, controls and performance in replicating the aircraft. The simulator was mounted on a three-degrees-of-freedom motion platform, and all data was collected with motion on. The simulator was equipped with a General Electric Compuscene. This 1000 line, full color, computer-generated image system had the highest resolution available at the time of the data collection, 2.87 arc minutes.

The visual skills of the pilots were measured by refraction before data collection was initiated. Special tests of achromatic stereoscopic skill, perception of the frontal plane, an effect of differential magnification were included as separate complimentary investigations.

The main investigation had two phases. Phase I included four levels of windscreen optical quality, two times-of-day, two visibility conditions, and utilized eight USAF pilots. They made straight-in approaches from 4.7 miles out, starting on the glide slope (2.5°) and on localizer. During the experimental runs altitude, azimuth, glide slope, and vertical velocity information was taken away from the experimental pilot.

Phase II employed six of the eight pilots in making 2-mile approaches, with offset origins and limited visibility. Three windscreen qualities, two times-of-day and four replications were used as independent variables in Phase II. Ten dependent measures were recorded from the host computer. These data were submitted to analyses of variance at equal log distances from touchdown.

Decreasing windscreen quality, as a main effect, generally increased centerline deviations at touchdown and produced longer touchdown distances. During approaches, windscreen quality interacted with time-of-day to significantly alter the flight pattern. Night approaches with poor windscreens were significantly above glide slope, with better quality windscreens producing approaches on glide slope at night, and approaches below glide slope being made for all day scenes, regardless of windscreen image quality. The generalization is that poor windscreen quality and night conditions produce a flight response reflecting caution on the part of the pilot. Approaches were higher and a little faster, with more rapid descent rates later on, producing harder touchdowns and touchdowns further down the runway when the visual information was limited by the night scene and made less reliable by the distorting windscreens.

PREFACE

This study was initiated by the Crew Station Integration Branch, Human Engineering Division of the Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio under Project 7184: "Man-Machine Interface Design Technology," Task 718412: Human Engineering Applications to System Design, Test and Evaluations." This research was done in support of and was funded by the Improved Windshield Protection Development Program, Project 1926 of the Air Force Flight Dynamics Laboratory, Wright Patterson Air Force Base, Ohio. The research was conducted by the Crew Systems organization of the Logistics Equipment and Stimulators portion of the Logistics Support and Services Division of Boeing Aerospace Company, Seattle, Washington. This work was done under USAF contract F33615-76-C-0516 and the Technical Monitor was Dr. H. C. Self of the Aerospace Medical Research Laboratory.

The authors are most appreciative of Dr. Self's help and advice, as they are of the work of his associates. Special credit and appreciation is extended to the 8th MAS Group, McChord AFB and Lt. Col. Purdue for making possible the participation of eight pilots of his organization. They were: Lt. Col. Lawrence R. Downey, Major Richard Rohrer and Captains Lacy, George Wheeler, Ernest H. Jones, Jr., Carl Rinker, Orando Grey and Steven McConnell. Each gave excellent performances as pilots, cheerfully supported our work, and provided excellent comments and ratings.

We are also particularly appreciative of the support we had from the Flight Crew Training Directorate of Boeing Commercial Airplane Company. The engineering effort, the maintenance and scheduling of the simulators and the image generators made the data collection and recording possible. The work of Manord Rucker as Flight Instructor and Safety Pilot was very much appreciated by the USAF pilots and the authors.

We appreciate the editing, typing, and organizing assistance of Ms. Helen von Tobel in both the draft and final stages of this report.

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INTRODUCTION

GENERAL ASPECTS OF THE PROBLEM

The problem of providing good forward visibility for the pilot of any aircraft is a normal design requirement. Some individuals may say that in this era of electronics, the sensor capabilities in radar, infrared and elint have lowered the priority for excellent forward visual capabilities. The data from the Vietnam engagement contradicts this assertion. The U.S. Navy data indicate that visual sightings accounted for a much higher frequency of detection than these electronic systems. These data would indicate that excellent air-to-air visual capabilities remains a military combat requirement as well as a peacetime collision avoidance problem. The requirements for good forward vision for take-offs and landings remain, particularly as aircraft speeds and weights have risen.

Attainment of a windshield design, with a minimum of interference with the pilot's vision, has become increasingly difficult for the aircraft designer as flight speeds have increased. The aerodynamic and structural considerations have imposed the requirement that windscreens be thick, multi-layered, coated, curved and slanted backward at a very shallow angle. These characteristics, in turn, have increased the visual problem by adding windscreen inclination displacement, attenuation of illuminance, angular and curvilinear deviations, internal reflections, multiple images and haze. If the external-internal surfaces are not perfectly matched, the windscreen adds another distortion of magnifying some portions of the visual field.

SOME COMMERCIAL AIRCRAFT PARTIAL SOLUTIONS

These conflicting requirements have led to some expensive design considerations. The supersonic transport's hinged nose section permits good pilot visibility during take-offs and landings. But, during other regimes requiring the nose-up position, forward vision is considerably degraded (Larry, 1966). More than twenty years ago, flight research by Roscoe and his associates demonstrated that pilots could take off, fly and land an aircraft using only a periscope for forward vision. However, as a solution, the periscope never appeared to be acceptable. One of the factors may have been the relationship of size and distance as perceived on a display near the pilot (periscope) and at a distance (extra-aircraft scene), Vanderplas (1954). Roscoe (1950) had found the ratio to be a 1.25 enlargement of the near-display size to match the distant perception. Roscoe (1975), with the encouragement and support of ONR, reviewed his 1950 data in light of more recent data on visual accommodation (focusing). His hypothesis is that the pilot's visual system accommodates to the near visual field even though he is viewing an image at optical infinity. The increased curvature of the crystalline lens of the eye with near-field accommodation is associated with an image on the retina which is smaller than that associated with the relaxed accommodation when viewing directly the far scene. This hypothesis is consistent with the "instrument myopia" data and the very recent data of Johnson, C. (1974).

MILITARY AIRCRAFT WINDSCREENS

For military aircraft, subsonic and supersonic, no use has been made of the hinged nose, periscope, or other similar innovation as a means of achieving good forward visibility. The windscreens of military aircraft, therefore, have to varying degrees attenuated the pilot's forward vision. The F-111 windscreen represents an extreme departure from the prior convention of the use of forward flat panels and 60° maximum angle of incidence. Grether, 1973, reports the reaction of seven F-111 pilots from Nellis AFB, Nevada. Their review of windscreens' major deficiencies included objections: (1) Blind Areas, particularly over the side and to the rear, (2) Optical Distortions which interfered with estimations of height above the terrain, (3) Multiple Images, particularly at night, including duplication of the external scene (including the runway), (4) Compatibility with the gun sight, such that most did not use the visual sight, (5) Comparisons With Former Aircraft Windshields were in favor of older aircraft and the four complaint areas listed above were mentioned again in the comparisons.

ACCEPTANCE OF STANDARDS FOR OPTICAL WINDSCREEN PARAMETERS

"In actual practice, the standards which exist are rather arbitrary, and are based, to a considerable extent, on what the industrial production technology can provide" (Grether, 1973). Currently, data on pilot visual performance and pilot ratings verify the need for vision to be as good as possible. These data do not provide a suitable basis for setting optical standards for aircraft windscreens. As an example, Glover (1955) gives "suitable" values for transmission and haze values for windscreens without the data or analysis from which the values are derived. Grether (1973) points out the U.S. Military aircraft standards position the windscreen normal to the line of sight, and Great Britain uses the installed angle of inclination.

Several variations of the basic techniques of photographing through the windscreen have been proposed and used. Some have proved unreliable, some expensive in data reduction, none with an acceptance level that is based on pilot performance. Rubin (1968) introduced three parameters, cost (c), light transmission (t), and drag (D) in a single figure of merit in an attempt to standardize windscreen angle for high speed aircraft. His general logic is defensible although his curves for drag and cost were arbitrary. Cost and aircraft performance data are very important and deserve to be in the formula.

Grether (1973) estimated the upper price of a single F-111 windshield panel to be $20,000. From January 1968 to February 1969, 193 left and 123 right panels were manufactured. The estimated cost of $5,240,000 is undoubtedly high, due in part to the 84 (32%) rejected panels. The standards contained in FZM-12-10952 (Thompson, 1970), may be too critical in one dimension (i.e., deviation), too lenient in another (i.e., differential magnification), and incomplete in another (i.e., chromatic deviation). Since deviation is relatively easy to measure, it may have occurred that these standards are too restrictive, raising the cost of manufacture without altering pilot performance significantly. However, it may be the interaction among distortion, magnification and windshield inclination that will alter pilot performance more than any single class of optical variation.

There is an illustration in the literature: in 1945, Pittsburg Plate Glass Company's Glass Division Research Laboratories scaled five 8" x 18" panels for the AAF Aero Medical Laboratory. These were used by Schachter and Chapanis (1945) to study the effect of optical deviation and distortion in glass on depth perception as measured by the Howard-Dolman apparatus. These panels ranged in optical deviation from less than 3 to greater than 7, but less than 10 arc minutes. However, in a separate study, these authors showed that their five "pilots" had an average deviation in setting the distance of the two rods of 7 arc. sec.; through a one diopter prism (deviation = 34 arc. min.) this value was 8.4 arc. sec.; and through a filter of 17% transmission (83% decrease in intensity) an 8.1 arc. sec. deviation, and with a prism plus the brightness attenuation a 10.5 arc. sec. deviation. These are excellent stereoscopic performances when compared with the USAF threshold of 32 seconds of arc for acceptance into flight training. However, the attenuation that inclining these test panels produced was very different, as will be seen in figure 1. The combined effect of inclination, deviation, and lower transmittance of these glass panels sharply reduces these individuals' ability to discriminate relative range line-of-sight on a straight-in approach. One finds that these observers could use depth perception to aid their judgment of height and distance from 2100 yards out if they had a "perfect" windscreen. However, the poorest quality windscreen inclined to 70°, would limit this group's use of stereopsis to 124 yards.

In figure 1, we have added the range of inclination of the F-111 windscreen. The implication is that only with a windscreen of a few deviations, all being less than 3 arc minutes, could an F-111 pilot use his depth perception from stereopsis to his advantage, even within 500 yards.

THE AIR FORCE PROGRAM

The overall problem is a research study designed to determine the degradation of pilot visual performance as it relates to mission task accomplishment as influenced by aircraft windscreens. This will be accomplished by using transparent panels of graded distortion.

Scope of the AMD/AFFDL Visual Effects of Windscreens (VIEW) Program

The approach of the VIEW program began with the goal of measuring the effects of distortion characteristics with existing methods and measures applicable to visual landing performance. Pilot performance was to be assessed inflight and in a flight simulator. Planned was a concurrent program aimed at developing new measures of optical assessment and relating these to dynamic visual performance. These efforts provide the basis for writing windscreen distortion specifications.

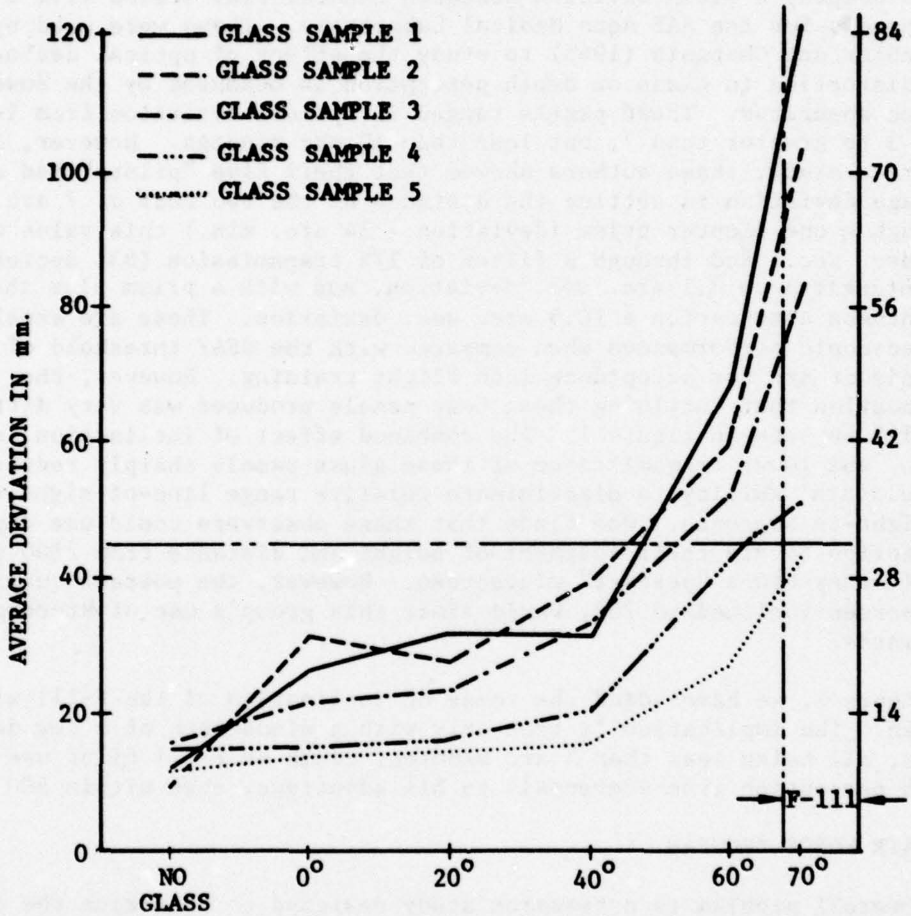


Figure 1. Stereoscopic Performance as a Function of Distortion and Angle of Incidence. (Windshield Slope). Average Deviations in Millimeters and Arc Seconds for Five Subjects on the Howard - Dolman Apparatus. Revised from Schachter and Chapanis, 1945.

The Air Force had contracted for the development and production of ten optically distorted windscreen panels of quantitatively known properties. The scaling of image qualities is a joint effort of the School of Aviation medicine and the Aerospace Medical Research Laboratory. The Aerospace Medical Division supported by te Air Force Flight Dynamics Laboratory is continuing with their effort to establish and verify acceptable optical specifications for B-1 type windscreens. A second step was to evaluate pilot performance in the left seat of the simulator Advanced Manned Strategic Aircraft (AMSA) cockpit with the acrylic transparent panels, fabricated by Pittsburgh Plat Glass Company, installed as interchangeable inserts immediately behind the permanent left windscreen. These panels were 2-1/2 x 4 feet and approximately flat. The angle of installation was 40^{o} from horizontal as measured from the beam line.

Scaling of Windscreen Quality

AMRL personnel photographed through the optical panels a grid board of white lines against a black field. This procedure was similar to the method described in General Dynamics Report FZM-12-10952 A, pp. 22-30. Dr. Self at AMRL conducted three psychophysical ratings of the apparent distortions in these photographs. Twenty observers were asked to mark eleven 8 x 10 prints from that showing the least distortion (no. 1 position) to the greatest distortion (no. 11 position). His instructions may be described as "laissez faire," or allowing each observer to use his personal criteria for distortion. The ratings resulted in two sets of distorting windscreens between which there was a slight, medium and large distortion of about equal magnitude. One pair was used in the flight test program and the second pair in the simulation test program. The pilot's eye point and distance from the optical panel were duplicated in the two independent investigations. The angle of inclination of the distortion panel to the line of site could not be duplicated and was greater (40^{o}) for the flight test than the 28^{o} in the simulation study.

The CALSPAN-AFFDL Flight Test

The flight test investigation was undertaken at CALSPAN in Buffalo, N.Y. USAF pilots made night approaches to a selected runway while flying the instrumented and computer-augmented C-131 aircraft. Mr. William Welde's design included the four levels of windscreen distortion, four pilots and four replications. Selected dependent measures were recorded on tape and are being statistically analyzed.

Requirements for Additional Alternative Studies

The flight test program faced some of the traditional hazards in developing quantitative data. The Air Force Scientific and Operational Personnel recognized these hazards and the need for additional back-up data.

Aircraft are both expensive and are subject to uncontrolled variance. In flight test experimental studies the greatest source of variance is the weather. To obtain proper quantitative data, which generalizes to a larger population of pilots, a representative sample of pilots must fly with each optical panel. Ideally, the order effect should be controlled by counterbalancing so that practice does not impose a bias. The ideal flight plan should let each pilot do all the same tasks with each quality of windscreen under the same weather conditions. Ideally, the dependent measure should be objective and quantitative in the same way as a good laboratory study. The complexity of these requirements to obtain a statistically treatable and definable performance is generally curtailed by weather or economics in most tests.

Pilot opinion is a very valuable source of information for getting ideas and direction for research and improved operations. However, to ask pilots to verbalize the "hows" and "whys" of everything they do and treat their responses as scientific data is not only improper but unfair to the pilot.

Ask yourself, for example, how you know, as an automobile driver, at what speed to turn a right angle climbing corner on wet macadam and with what acceleration so that you don't break traction with the inside power wheel. Good auto drivers do this regularly, but verbalize it very rarely, and few, if any, have tried to recognize the reliable cues they use in the discrimination. Pilot opinion is also very perishable, as conversations among pilots begin to make these opinions regress toward the opinion of the outspoken and dominant pilot. Flying is the occupation that draws them together, and conversations will include the experimental studies. Pilot opinion, as is true of any opinion data, is debatable unless the number of people giving their opinion is very large (N = 500 - 1000) and the methodological controls have been pretested. In most studies where engineering variables are the independent variables, the numbers of participants is small (N = 10 - 16). These considerations lead toward the expectancy that the CALSPAN investigation would provide very insightful data, comments and suggestions for future research. However, it might have fallen short of providing the quantitative data needed to relate pilots visual performance with the transparent panel quality.

The Simulation Aspects of the VIEW Program

The VIEW program therefore included a simulation program to run concurrently with the CALSPAN flight test and extend to the end of fiscal year 1977. The simulation program could provide backup data by nearly duplicating some portions of the flight test program. It could extend the investigations in areas where independent variables such as weather could be manipulated and controlled. Duplication of let-downs to day conditions could also be made with matching weather, wind, and not be concerned about changes of contrast and shadows changing the visual information. This is the report on the simulation portion of the VIEW program.

THE PROBLEM

THE GENERAL PROBLEM

Recent experience in the design and use of windscreens for high-speed aircraft has led to a need for practical minimal optical specifications that will assure safety. Safety has two aspects; safe from penetration by birds and hail while proving safe visual performance by pilots. Previously acceptable optical standards are difficult to meet when provision for very high aerodynamic forces, high impact forces and low radar reflectivity coatings are included. Therefore the cost effectiveness as well as physical characteristics must be traded off against degradation of pilot performance. Traditionally, the secondary criteria of "good" optical properties, "good" pilot performance and pilot acceptance are highly correlated. Pilot complaints about the F-111 and B-1 windscreens have been frequent, the number of optical rejects have been high, and costs have escalated.

What is needed is a pilot performance measure that allows quantitative assessment and a proper "clout" in the trade-off battle of physical requirements vs. visual requirements. Safety and combat performance are reduced if the proper balance is not achieved.

THE SPECIFIC PROBLEM OF THE SIMULATOR RESEARCH

The specific task of this Boeing study was to measure the performance of aircraft pilots in simulated approach and landing tasks.

- To determine the relationship among some dependent measures and windscreen optical qualities.

- To determine the interactive effect of time of day and atmospheric changes in visibility conditions with windscreen optical qualities.

- To provide the USAF with information on dependent variables which are sensitive to windshield qualities in the dynamic flight situation.

- To assure the USAF that the results obtained are valid and would apply to pilots with exceptionally good vision.

- To simulate magnification effects, over and beyond those supplied in the optical attenuators, and determine threshold changes in stereoscopic visual performance associated with each level.

- If feasible, to recommend cutoff points of optical qualities beyond which pilot performance in approach and landing is attenuated.

THE METHOD - PHASE I

PURPOSE OF STUDY AND APPROACH

This test was conducted as part of an evaluation program for the specification of aircraft windscreen quality. The overall program consists of (1) physical measures of the optical properties of the windscreens, e.g., transmissivity, modulation transfer characteristics, spatial and chromatic distortions, (2) testing in a flight simulator, and (3) testing in an experimental aircraft. The second part, simulation testing, was assigned to Boeing to be conducted in their Flight Crew Training facility.

The standards of the optical industry, developed to specify the characteristics of a variety of optical devices, are inadequate for application to aircraft windscreen quality, in some cases because they are too stringent, in others because they fail to relate to some critical aspects of visually-mediated flight. In an optical instrument using spherical lenses, certain tradeoffs can be considered, e.g., on-axis vs. off-axis resolution, which do not apply to windscreens.

At the other extreme of the theoretical-applied continuum there is the demonstration of windscreen quality by installation of test windscreens in operational aircraft. This kind of test (1) is quite expensive, (2) may be fraught with unacceptable levels of danger to the pilot, and (3) cannot be conducted under the desired conditions of test control. While the first two impediments are obvious, the third is no less critical if the test is to be vigorous enough to permit clear recommendations. To expect a group of pilots to make repeated flights with a selected set of conditions, such as visibility and time of day, in a set of aircraft fitted with a graded set of windscreens for a controlled comparison would assume more than credible cooperation from nature.

The goals of the Phase 1 effort were (1) to establish the feasibility of the use of flight simulators for this kind of investigation, (2) to obtain information relevant to the selection of sensitive measures of pilot performance in approaches and landings, (3) to determine the effectiveness of pilot opinion as a predictor of pilot performance in the evaluation of visual characteristics of windscreens, and (4) to ascertain the degree of relationship between selected measures of visual ability and performance data obtained from the same pilots in the simulator. It is noteworthy that we are not specifically concerned with the acceptability of these particular windscreens for installation in operational aircraft, but rather with the development of valid techniques for the establishment of windscreen quality specifications. The generality of the findings are also limited, naturally, by the magnitude of the study.

THE APPARATUS

The investigations of pilot performance as a function of windscreen quality used a dynamic presentation of the external world and all the flight instruments and controls of a 727-200 aircraft.

The Full Color, CGI, Scene Generator

The external visual scene was provided by the General Electric Compuscene, the first full-color, day, dawn-dusk and night CGI system. At the time of the collection of data (September, 1976 and December, 1976) it was the only such scene in existence. It remains unique in its resolution capability as the system is a 1000 raster line system using 25 inch RCA, shadow mask, 3 gun color CRT. The active T.V. raster lines number 735 and the number of elements per line are 880. This provides a minimum resolution of 2.47 arc minutes vertically and 2.78 arc minutes horizontally.

For the narrow-body simulators, one of which is the 727, the CGI system has four displays, all of 30° vertically and 40° horizontally. The forward scenes are common for both pilots and these are fed from a common channel and image generator. Two additional channels are associated with the same image generator. One provides the Captain's left side window, the other the first officer's right side window. These are centered on the pilot's head rotation point and 60° from the centerline of the forward scene. The side displays have 20° up and 10° downward view, while the forward displays have a 15° up and 15° downward view. The display's luminosity measured at the pilot's eye position is 6.05 ft.L. in the center with a 15% drop off at the extreme edge of the CRT. The distortion limits allowed were 2% within ± 15° of the center of the image. Distortions beyond 15° to the corners on the 045, 215, 225 and 315 meridians did not exceed 3%. All displays met these standards and the Captain's forward display, the critical one in this investigation, had the least distortion of the four.

The CRTs are viewed through an optical window in which all rays are collimated to beyond 10 meters. The virtual image is perceived as being at "infinity," and there is no magnification of the CRT by the optics. The optical plan of the infinity window is given in figure 2.

The absolute size error of objects averages 0.11% as a function of altitude up to 20,000 feet. Pattern, location and movement of objects are of similar specification. There are no shadows, but dawn and dusk luminances and color shifts are realistic.

The visual system lags and changes in velocity have a lag of 50 milliseconds and therefore are below the visual threshold for the human eye.

The update of the visual system is designed to have a frame and refresh rate of 60 times per second. The inputs from the 727 simulator's computer to the visual are, however 15 per second.

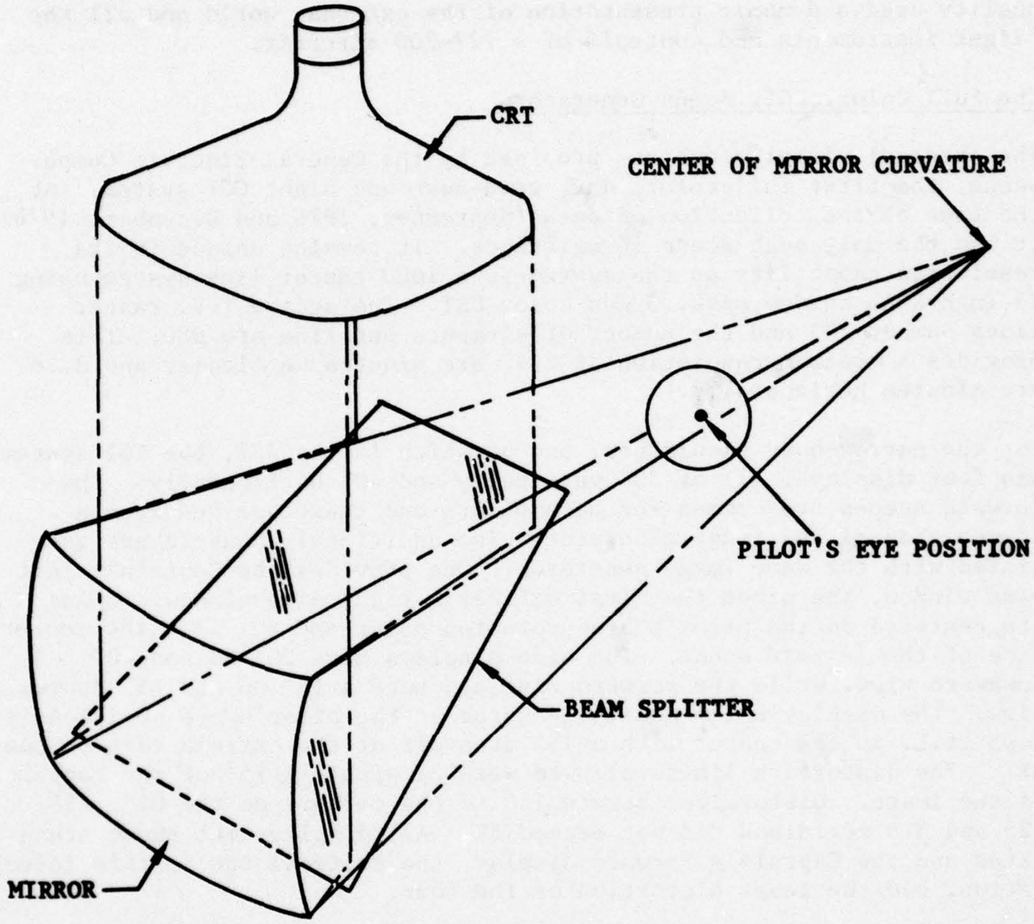


Figure 2. Optical Plan of the Infinity Window in the Simulator

The image generator provides landscape and environmental details by storing 4096 edges in the data base and displaying 1024 of these at any one time as distributed between the forward scene and two side scenes. At night, 2000 lights may be displayed. These have full color and represent a two dimensional world of 100 miles on a side centered around an airport. Mountains and hills are available as are CAT II and ICAO markings. The runway details include texturing, threshold, and 1000, 2000 and 3000 foot touchdown designations.

The night scene includes taxiway, VASI, CAT II, beacons, strobes, approach, runway centerline, REILS, highways, cities, towns and individual lights. The runway edge and approach lights may be controlled in intensity through five steps. The strobes can be called up or cancelled by the pilot's direction. Touchdown, taxiway and landing lights may be included on demand. There is a dawn-dusk environment which combines all the subgroups of the day and night listings above.

Special effects include haze, fog, clouds, cloud tops, cloud bottoms, visibility and RVR. Scud can be introduced and its effect is a random lowering of visibility for intervals of random duration. Although the data base world is planar, there are three dimensional objects such as hangars, control towers, etc. in the scene.

Three data bases with different runway configurations are available. The Grant County Airport at Moses Lake, Washington, (MWH) was used in this investigation. The image of this base is generated from a computer program that contains selected details of the real world scene complemented by some specific additions to assist in the perception of relative motion. The runways used in training were two, 14-32, a former B-52 runway of 13,500 feet and 300 feet wide and Boardman Field, a 4000' x 140' shoft takeoff and landing practice strip. A sketch of the Moses Lake data base is included as figure 3. The experimental letdowns were all made to runway 321.

The night scene used some portion of the 2000 light capability. Runway edge lights, approach lights, threshold lights and air field rotating beacon were displayed. The luminance of the lights were relatively constant for all distances except as atmosphere attenuated the more distant lights. The point source size was above that for the real world for distances greater than 1000 feet, 1.25 arc minutes. The size of lights were distributed as 11% falling in the 2.47 x 2.78 arc minute category; 45% at 5.6 x 2.78 arc min. and 44% at 9.6 arc minutes.

The "texture" on the runway, i.e., the gray cement surface, the threshold markings, centerline 1000, 2000, 3000, 4000 and 5000 foot marking were set to appear at 2500' (or farther) from the visual touchdown point.

The combined effect of "texture" appearance and "equal" luminosity of lights would have nominal effect on height over threshold of about 4 feet low or 40 feet above the ground. This is based on instructor pilot flights with visual approaches to runway 321 at night under good visibility conditions. (Kraft, Anderson and Elworth, 1977).

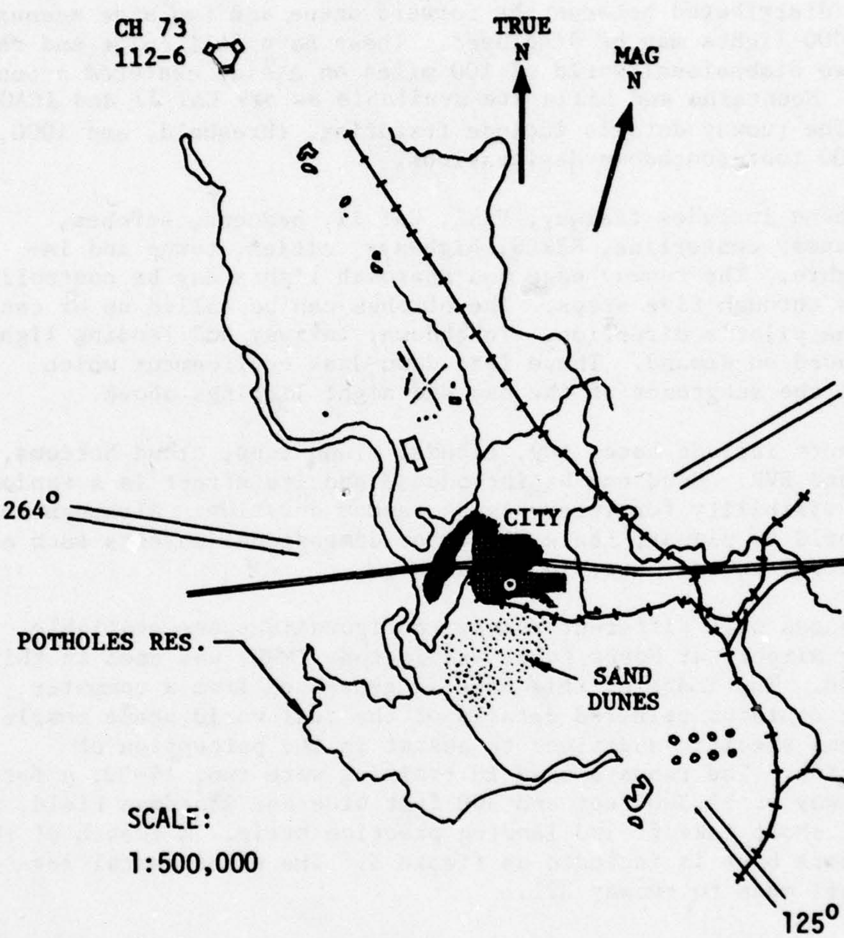


Figure 3. Grant County Data Base Map

THE 727-200 FLIGHT CREW TRAINING SIMULATOR

The 727-100 Conductron-designed and built simulator was chosen as the "research aircraft." This simulator was first purchased in November, 1968 and received FAA certification in December, 1969. Since that date it has been updated and modeled after the 727-200 with JT8D-15 Pratt and Whitney engines. The host computer is a Honeywell DDP-124. The instrumentation is complete for the 200 series aircraft and the flight director in both investigations was a Collins F.D. 108, although the command aspect was not activated in these studies.

The cab is complete as to all displays and controls, radios, annunciators, etc. The forward section is a duplicate of the aircraft and the Flight Crew Training Division of Boeing Commercial Airplane Company uses this simulator in transition and recurrent training of airline pilots and flight engineers. The aft portion of the cab includes an instructor's station with control of aircraft position in space, relocation relative to radio beacon and ranges, freeze control and multitudes of failure modes. It is at this station that remote control of the visual scene parameters is possible.

The luminance level within the cockpit was controlled by the pilots. The red and white flood lights were off during operations and instrument back lighting was adjustable by rheostat. Independent controls existed for the forward, overhead, center, pedestal, engineer's and instructor's panels.

The cab was mounted on a three degree of freedom motion platform. The motion system was on during all experimental and training trials.

Assurances that the simulator operated in a manner similar to the 727-200 aircraft was obtained by the write-up or "squawk" system wherein all variances were written up by the instructor pilots and changed by maintenance personnel on a daily basis.

THE WINDSCREENS

There were four "windscreen" conditions used as an independent variable. The first "windscreen" was no transparent surface between the pilot's eyes and the beamsplitter of the Compuscene. In figure 4, the top photograph represents this condition. In this figure it also gives the reader an estimate of the resolution of these pictures, which is relatively low as these were taken at a camera-to-windscreen distance of nearly 30 feet to exaggerate the areas of distortion so that they would make visible the area and type of distortion involved. The three photographs below the "Good" windscreen represent those furnished by the government for this investigation. They were made under contract by Pittsburgh Plate Glass as part of the VIEW program. These were selected as: near the beginning (#2), middle (#3), and the end (#4) of the range of rankings by subjective distortion. Dr. Self of AMRL conducted the selection of these from a set of eleven based on their ranking by 20 observers. The grid-line photographs for these three windscreens, as used in the ranking, are reproduced in Appendix VIII, page 106.

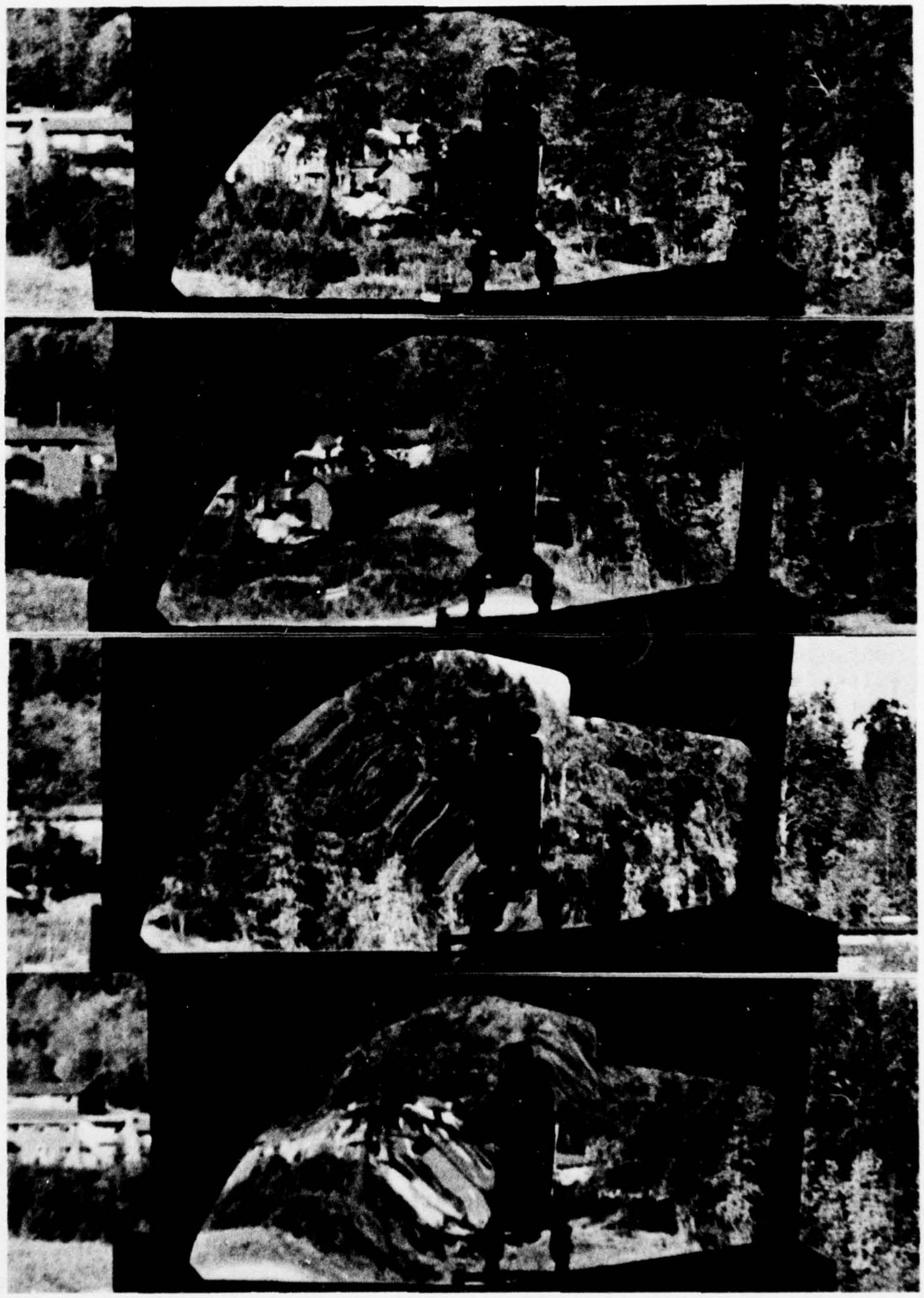


Figure 4. Depiction of Windscreen Distortion Areas and Direction (Photography has been designed to distort the magnitude of the aberrations so that the area and direction could be observed.)

Although there are very different qualities of distortion in the three scenes, (figure 4), it will be noted that the area and extent of the distortion is consistent with the AMRL rankings of the grids.

The windscreens were cut and notched so they could be placed in the left forward window frame of the 727-200 simulator. The locating mechanism provided centering of the eye reference point on the windscreen with a Cyclopean eye position of the pilot, an inclination of 28° and perpendicular left-right axis relative to the line of sight. An empirical study of the repositioning accuracy with the simple mounting system is contained in Appendix 1.

SUBJECTS

To maximize the validity of this study's findings, currently operational Air Force pilots were selected to provide the performance data and the subjective quality judgments. A group of eight C-141 pilots were supplied by the 8th MAS Group, with headquarters at McChord Air Force Base. They were assigned for one day of temporary duty to serve in this windscreen study.

Optometric Refractive Analysis

The visual performance of the eight pilots was measured to determine their pre-performance test skill. The tests conducted included a complete optometric examination, which in many determinations replicated their flight physical in those aspects that pertained to vision. This procedure assured temporal proximity of this refractive examination to the performance of the simulated flight task, and gave a refractive assessment of the accommodative range (range of distances that the pilot can focus objects clearly).

Achromatic Stereoscopic Acuity

The pilots were also tested for their achromatic stereoscopic acuity. This was accomplished with the eight stereo-transparencies of the Critical Limen Stereo Test. This particular test has been evaluated under USAF contracts F33615-72-C-1259 and F33615-73-C-4034 and reported in AMRL-TR-73-36 and AMRL-TR-73-104. It is a unique test in that it uses two confusion dimensions, size and contrast, at four levels for each dimension.

The purpose of using this test was two-fold. First, the basic test gave a measure of the balance of the visual attributes of the individual pilots. Then, secondly, three replications of this test image (right or left eye) were enlarged by approximately 2, 4 and 8% and the attenuation of stereoscopic performance was obtained by comparison with the basic test. The increased size of one image was very similar to the "lensing" effect reported in the F-111 windscreen evaluations. If the left eye is seeing the external scene through greater differential curvature (inside vs. outside surfaces) than the right eye, the retinal images will be of different sizes and the result is headaches, burning sensations in the eyes and, above 2% size difference, an expected loss in stereoscopic performance. We studied up to 8%, believing that marked changes in stereopsis would be manifested before this limit is reached. This level is within the 21% difference reported using the General Dynamics metric of lensing on poor windshields for the F-111.

The Instructor Pilot

The right forward seat in the 727-200 was occupied in each investigation by Mr. Manord Rucker. This Boeing Flight Crew Training Instructor pilot trained each of the C-141 pilots in transitioning to the 727-200. For the first hour in the Phase I sessions, Mr. Rucker served in his familiar role as an instructor. With the beginning of each experimental run he assumed the role of an experimental safety pilot. Mr. Rucker has been a 727 instructor pilot for 8 years and has accumulated 2500 hours in this aircraft.

EXPERIMENTAL DESIGN (PHASE I)

Independent Variables

Three government-furnished windshields were used in the test. These were selected from a set of eleven in a brief study by AF AMRL personnel in which the examples in the set were ordered by 20 observers according to the amounts of subjective distortion they produced. The ones selected were those which (a) showed the greatest stability in their ranking by the group of observers and (b) represented roughly the beginning, the middle, and the end of the range. These three windshields plus the condition in which no windshield was used comprised the four windshield conditions of the study.

Each of the four windshield quality conditions were used for four approaches for each pilot. These were: 1) a daylight approach with 30 n. miles visibility and runway visual range of 200,000 ft., the "Day/Clear" condition; 2) a night approach with the same visibility condition (Night/Clear); 3) a daylight approach with 20 n. miles visibility and 36,000 ft. runway visual range, the "Day/Hazy" condition; and 4) a night approach with the same limited visibility condition.

The experimental design for Phase I is shown in figure 5. In this complete factorial, each of the eight pilots flew an approach under each combination of the 4 windscreen qualities, 2 times-of-day, and 2 visibilities.

Performance Measures (Dependent Variables)

Good quantitative indices of pilot performance in the approach and landing segment of flight in commercial jetliners are not easily found. The reason for this may be that acceptable performance is not difficult for pilots to achieve in the test situation, thus making it extremely difficult to find meaningful variation among pilots. The task was to follow a visual equivalent of 2.5° glide path angle and touch down at an indicated point (1000 ft. beyond runway threshold). Normally, deviations from glide slope (up or down) and from localizer (right or left) are visible as part of the flight direction display, and the pilot can refer to barometric and radar altimeters as well as to a vertical speed indicator. In the present

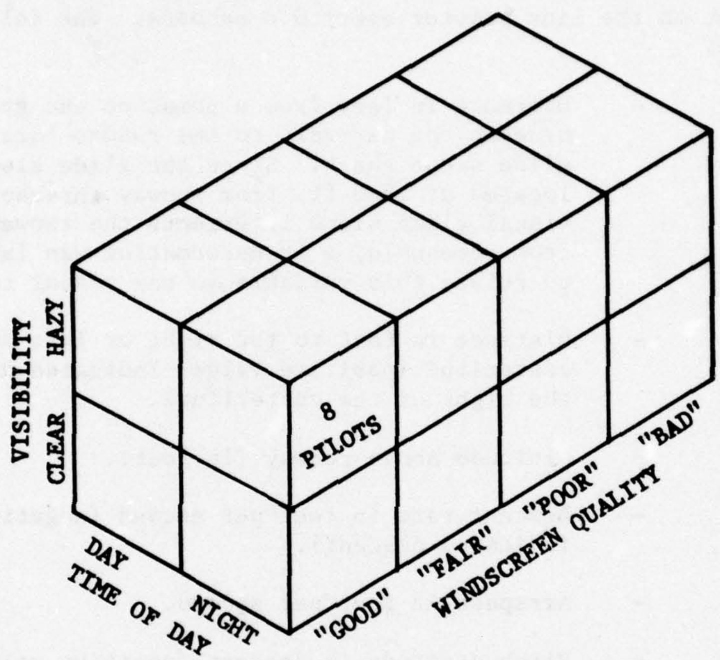


Figure 5. Experimental Design for Phase I Study

test situation these indicators of aircraft position and motion were made unavailable to the pilot, though they were present in the right-hand instructor pilot's display. We wanted the performance data to reflect the influence of the windshields on the visual quality of the outside scene rather than on the pilot's ability to ignore this scene when instrument indications were available.

Since one of the purposes of the study was to search for sensitive pilot performance indicators, a number of measures were recorded. They were printed out on the line printer every 0.8 seconds. The following measures were taken:

XR	-	Distance in feet from a point on the ground directly beneath the aircraft to the runway location of the glide slope shack. Since the glide slope shack was located at 1840 ft. from runway threshold and the visual glide slope intercepts the runway at 1000 ft. from threshold, a transformation was later required to relate this variable to the visual touchdown marker.
YR	-	Distance in feet to the right or left of the runway centerline (positive values indicated deviations to the right of the centerline).
HMHS	-	Altitude above runway (in feet).
Z	-	Descent rate in feet per second (negative values indicated descent).
VTRU	-	Airspeed in feet per second.
PCHD	-	Pitch attitude in degrees (positive values indicated nose up pitch).
ZPBS	-	Distance in feet above or below electronic glide slope.
TIME	-	Seconds after initiation of approach.

Appendix 2 depicts a portion of the printout of these dependent variables from the line printer.

Calculation of Touchdown Data

The dependent variable data from the line printer were organized into two sets, one describing touchdown parameters, and another encompassing the approach phase.

Since the values of the dependent variables were printed out at .8 second intervals, the amount of touchdown generally fell between two consecutive printouts. Therefore, an algorithm was developed to calculate the value of XR_{TD}, the distance from the visual touchdown marker to the touchdown point, based upon the values in the printout just before touchdown (XR_{-1}). The "first printout before touchdown" was determined by examination of the values for altitude and descent rate.

XR_{TD} (with short touchdowns being negative) was then calculated by the following equation:

$$XR_{TD} = XR_{-1} + (HMHS_{-1}/\dot{Z}_{-1}) \times (VTRU_{-1})$$

where: $HMHS_{-1}$ = altitude above runway (ft.)

$\dot{Z}_{-1}$ = descent rate (ft./sec.)

$VTRU_{-1}$ = airspeed (ft./sec.)

Touchdown values for elapsed time and glide slope deviation were similarly calculated.

In addition to these values, the Touchdown Data Set included the values of all the dependent variables on the last printout before touchdown occurred, plus the three previous printout interval values for pitch and descent rate. It was anticipated that the four consecutive readouts of these latter two variables would provide information on flare. Appendix 3 shows a portion of the computer printout of the selected/calculated values for these variables.

Sampling and Calculation of Approach Data

It seemed appropriate, in gathering approach data, to sample the printout more frequently as the pilot got closer to touching down, so a log scale was set up to define 16 points in the data, based upon distance out from the visual touchdown point. The following is a list of these 16 equal log-distance intervals, and their corresponding values based upon this reference. Appendix 4 shows the determination of the equal log-distance steps.

Data Point Before TD	Distance in Feet From Visual TD Marker (XRV)	Distance in Feet From G.S. Shack (XR)
1	125	965
2	175	1015
3	250	1090
4	350	1190
5	500	1340
6	710	1550
7	1010 (threshold)	1850
8	1430	2270
9	2030	2870
10	2880	3720
11	4080 (middle marker)	4920
12	5790	6630
13	8220	9060
14	11670	12510
15	16560	17400
16	23500	24340
Outer Marker (start of approach but not sampled)	29560	30400

As with touchdown data, rarely would the .8 second printout interval result in a set of data corresponding to any of these selected sampling points. Therefore, an algorithm was used to calculate the values for the dependent variables at each of these points. A linear interpolation between the data sets on either side of each of the selected points was chosen as the most reasonable method for determining these values, so data transcription began with recording a pair of bracketing data sets for each of the 16 XR values determined from the log scaling of approach distance. Then, for each XR point, a ratio was calculated for its location between the bracketing values, and this ratio applied in the interpolation of each of the other dependent variables. Appendix 5 depicts a portion of the computer printout with the calculated values for the dependent variables at each XRV point. These calculations were done with the IBM 360/65E computer and punched on cards to be used in the data analyses to follow.

PROCEDURE

Each McChord AFB pilot who served in the study devoted one day to it. The morning was spent in visual testing of various types including clinical refraction by an optometrist and measurement of perpendicularity of the perceptual frontal parallel plane and stereoscopic skills by an experimental psychologist. In the afternoon the pilot flew the simulator and answered questions about the three windshields and the visual simulation.

The pilots were introduced to the simulated 727 flight deck by an instructor pilot (IP) of the Boeing Flight Crew Training organization (the same IP served for all eight C-141 pilots). After a brief presentation by the IP of information on the Boeing 727 trijet with opportunities for questions and comparisons with the C-141, several practice approaches were made. During these approaches all instruments were available and the IP was using his background of experience in the teaching role to aid the experimental pilot to understand the airplane and how to handle it. (It was explained to the experimental pilot that during the data trials the IP would not serve as co-pilot or read airspeed, altitude etc.)

After the initial orientation by the IP, the AF pilot was given an opportunity to practice several approaches to a short airstrip (4000 ft. long x 140 ft. wide) and to a larger runway (13,500 ft. x 300 ft.). The landing was touch-and-go at the short runway. The long runway used for practice was runway 14 of the Moses Lake (MWH) simulation, the opposite direction of the same runway (runway 32) used for data trials. These practice approaches could be made with the aid of VASI if it was requested. After touchdown on runway 14, the AF pilot taxied to the other end before taking off on a heading of 321 degrees. After a second touchdown on runway 14, he was instructed to climb to 2500 ft. and turn to a 320 degree heading.

Before the data trials the vertical speed indicator and the barometric and radar altimeters were covered on the experimental pilot's side. To prevent the experimental pilot (EP) from glimpsing the instruments on the first officer's side where the IP was seated, a cardboard occluder was placed to the left of these instruments. No ILS glide slope or localizer information was available to the EP during data trials.

DME was not operating. The pilot had to rely on an attitude indicator, compass, and airspeed indicator in addition to the outside scene.

Each approach started 4.7 miles out at an altitude of 1334 ft. above ground level. The IP brought the airplane up to an altitude several hundred feet above starting altitude after the simulator operator had positioned the airplane over the outer marker and frozen it at that distance. He set up the airspeed and trimmed the craft before turning over the controls to the EP who then allowed it to descend until the starting altitude was reached, at which point the operator started the line printer and released the simulator to let the EP begin the approach.

The experimental runs were begun generally between 1315 and 1330 hrs. and were all complete by 1500 and 1600. Each pilot saw all windscreen conditions and flew four letdowns with each. Two were day approaches and two were night approaches. One of each of the time of day condition was combined with clear weather, the other with limited visibility. All pilots had a different order of working with each windscreen quality to minimize learning and fatigue effects. After four flights done with any one quality of windscreen the pilot verbalized his comments to a tape recorder. The windscreen changed and the next set of four flights begun. Eye reference height, windscreen position, and running order were strictly monitored by two experimenters.

Eight approach/landing trials were run before a rest period of about fifteen minutes was taken after which the remaining eight trials were completed. In a smoothly running session approximately five minutes separated the start of two successive trials. Actual flight time averaged just a few seconds in excess of two minutes for an approach and landing. From the time the EP first entered the simulator until the last landing was completed three to three and one-half hours passed.

Experimenter protocols were made as written accounts of each trial by an experimenter present in the simulator cab. These notes include all variations in procedure, partial or transient instrument vagaries, pilot and instructor comments. Notes on performances were included as cross checks on digital readouts.

On the completion of the experimental sessions a review was conducted between experimenters and the pilot. The simulation runs were all made with the same personnel operating at the same experimental station.

RESULTS - PHASE I

SELECTION OF ANALYSES

The data gathered from Phase I were subjected to the following main analyses in an effort to get as complete a picture as possible of the effects on performance:

(A) Touchdown Data

1. Order Effect ANOVAs (2 sets)
2. Main Effect ANOVAs ("Flare" and "Touchdown" sets)
3. Correlation Matrix (Independent and Dependent Variables)

(B) Approach Data

1. Main Effect ANOVAs

   a) Data from runway threshold out
   b) Data from threshold into 125 ft. before visual touchdown marker (1000 ft. from threshold)
   c) ANOVAs at every other (equal log distances) approach point (125, 250, 500, 1010, 2030, 4080, and 8220 feet from the visual touchdown marker)

2. Correlation matrix (across approach points)

In addition to these analyses, approximately 200 plots were generated to assist in visualizing the effects and iterations of the independent and dependent variables. In the ANOVA sets, a separate ANOVA was run for each dependent variable, resulting in a total of almost 100 ANOVAs. Even with this seemingly excessive number, only half of the 16 selected log-distance data points were analyzed by individual ANOVAs.

ANALYSES OF TOUCHDOWN DATA

Two ANOVA's were run on the touchdown data to evaluate any effects due to the order of presentation of the independent variables (windscreens, time-of-day and visibility). The first was a factorial, testing Condition (windscreen x time x visibility) Order and Pilots while the second sub-divided Condition Order into Windscreen Order x Time/Visibility Sequence-within-Order. These ANOVAs were run on each dependent variable. No significant differences were found between the means for Order nor for Sequence-within-Order for any of the dependent variables, but large significant differences were found for Pilots, as was expected. Appendix 6 depicts a page from the computer printout for the ANOVA on XR_{-1}.

The windscreens influenced the performance of the pilots at touchdown to a significant degree for the main effects, as shown in table 1.

Deviation From Runway Centerline

In the order of "Fair," "Good," "Bad," and "Poor" windscreens, the average touchdown deviation from runway centerline increased: 1.4 ft. (R); 1.9 ft. (R); 7.1 ft. (L) and 8.0 ft. (L).

Table 1. Areas of Statistical Significance in the ANOVAs of Touchdown Data (Phase I)

Dependent Variables*

	1	2	3	4	5	6	7	8	9	10	11	12	13	df
	YR	VTRU	$\dot{z}$				PCHD				XR	GSD	TIME	
	-1	-1	-4	-3	-2	-1	-4	-3	-2	-1	TD	TD	TD	
WINDSHIELDS	4.42										3.84	3.85	7.53	3-21
TIME OF DAY			6.42	6.76	8.02	9.02					15.30	15.19	11.69	1-7
VISIBILITY														
(PILOTS)														
WxT					3.24	7.57	8.77	8.98	6.69					3-21
WxV		3.19												3-21
TxV														
WxP														
TxP														
VxP														
WxTxV		3.30												3-21
WxTxP														
WxVxP														
TxVxP														
WxTxVxP														

*Third line indicates which readout (before touchdown) data are from.

NOTE 1: Of 91 tests, 18 met statistical significance requirements.

NOTE 2: Crossed out squares represent tests considered not legitimate comparisons for this statistical design.

Touchdown Distance Along Runway

The average touchdown distance for the "Fair" window was 92 ft. short, the "Good" 87 ft. long The "Poor" and "Bad" windows were, on the average, long by 315 and 407 ft. Combining the data for the four windscreens and plotting them as a frequency distribution gives the skewed distribution found in figure 6.

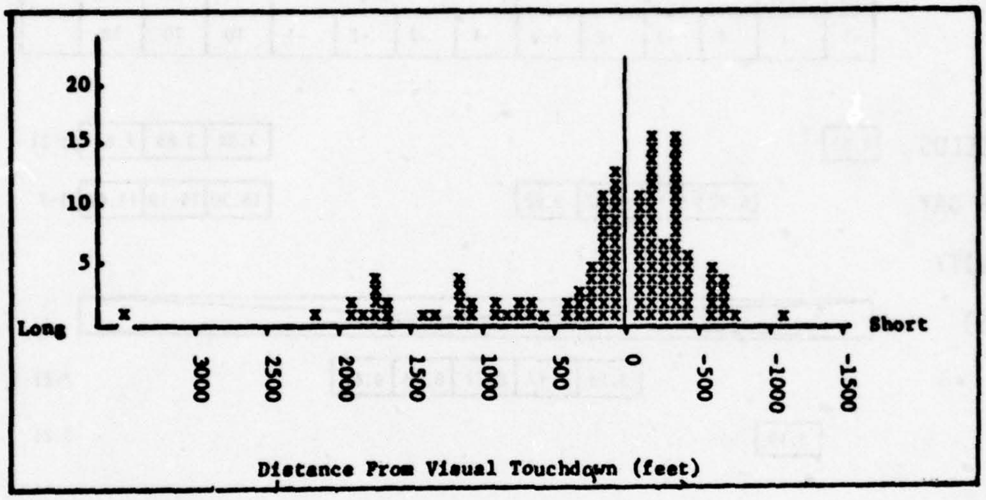


Figure 6. Touchdown Distribution (Phase I Investigation)

The average touchdown distance for all four conditions is 179 ft. beyond the front edge of the 1000 ft. mark. This is somewhat better than the average touchdown distances of 560 ft. long for 189 landings of 707-120s in 1960, and 300 ft. long for 103 landings in 1959 (Stickle, 1961). The "Good" and "Fair" windscreens were associated with closer average touchdown distances (table 2), while the "Poor" and "Bad" windscreens were associated with longer touchdown distances. These relationships can be seen in figure 7. Utilizing a rectangular area equivalent to $\pm 1\sigma$ of distance along the runway combined with $\pm 1\sigma$ of the deviation from the centerline as a touchdown footprint, gives us a reference to the probable area that would include 68% of the touchdowns. These areas are, for the attenuating windows, in the same order as the subjective rankings of image quality done by AMRL. The poorer the judged image quality, the larger the touchdown area required by the pilots in making landings. However, the clear windscreen condition had a $\pm 1\sigma$ "footprint" similar to that for the "Poor" windscreen. The least variance therefore was found with the "Fair" windscreen. The difference between the "Good" and "Fair" windscreens may reflect greater pilot caution when a minimum attenuating windscreen was evident compared with no attenuator, the "Good" condition.

TABLE 2

MEANS FOR SIGNIFICANT EFFECTS OF WINDSCREEN VARIABLE
IN THE TOUCHDOWN ANOVA
(PHASE I)

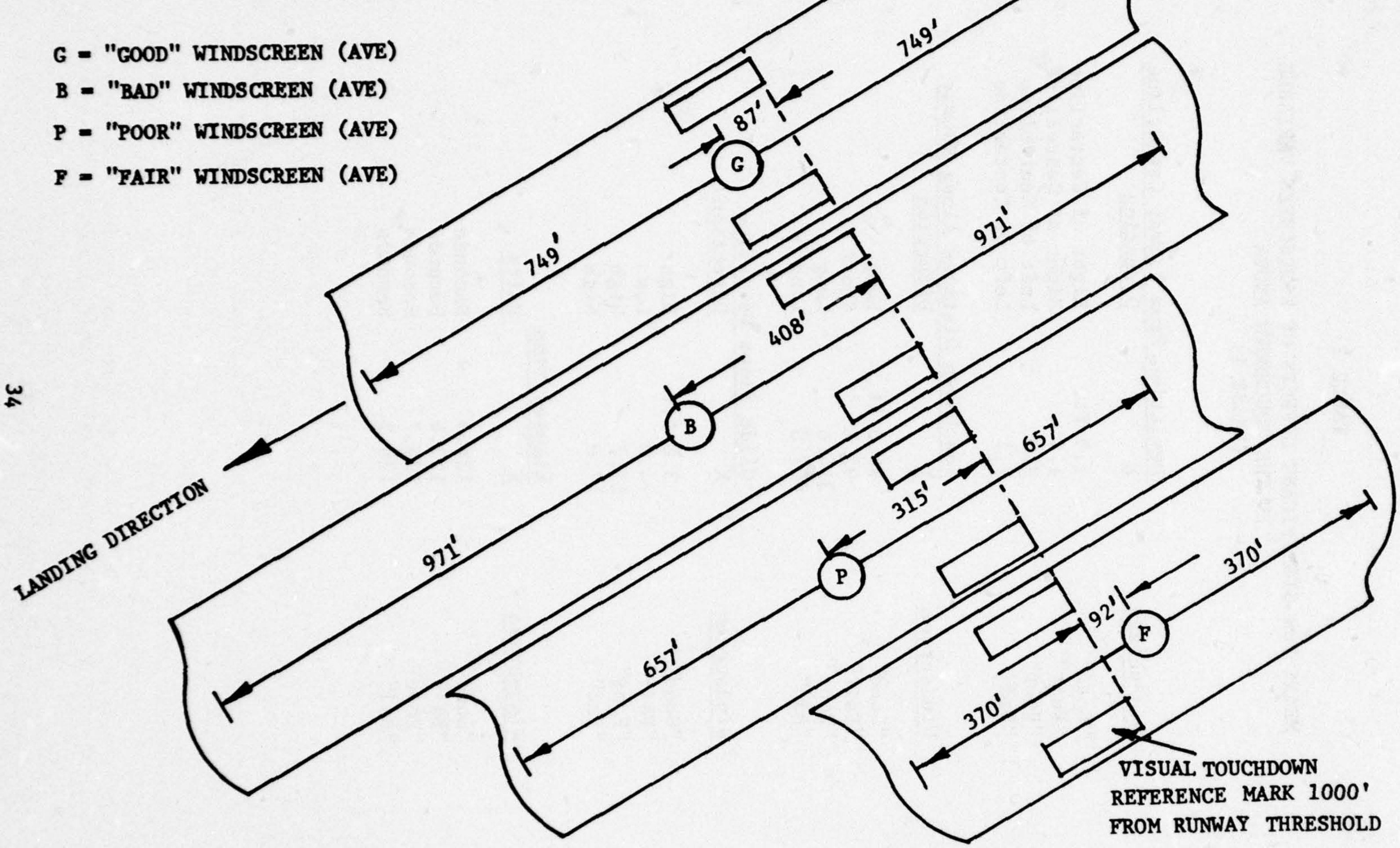
Windscreen	Deviation From Runway Centerline X	Direction
"Good"	1.9 ft.	Right of Centerline
"Fair"	1.4	Right of Centerline
"Poor"	8.0	Left of Centerline
"Bad"	7.1	Left of Centerline

Windscreen	Touchdown Distance Along Runway X	Direction
"Good"	86.8 ft.	Long
"Fair"	92.1	Short
"Poor"	314.6	Long
"Bad"	407.0	Long

Windscreen	Glide Slope Deviation X	Direction
"Good"	3.8 ft.	High
"Fair"	4.0	Low
"Poor"	13.7	High
"Bad"	17.8	High

Windscreen	Elapsed Time X	Units
"Good"	124.9	Seconds
"Fair"	123.6	Seconds
"Poor"	125.7	Seconds
"Bad"	126.3	Seconds

Figure 7. Effect of Windscreen Quality on Longitudinal Touchdown Footprint ($\pm 1\sigma$) (Phase I)



It will be noted that figure 8 shows that the approach altitude from the middle marker in and the touchdown position along the runway also correlate perfectly. The "Fair" windscreen produced the lowest average altitude at each log distance in from 4080 ft., and the shortest touchdown point. The "Good," "Poor," and "Bad" windscreens, in that order, resulted in higher flight paths and longer touchdown distances. This is reflected in the glide slope deviations and in the elapsed times of the descent-approach.

Time-of-Day

Time-of-Day as an independent variable is significant as a main effect for rate of descent at the four sampling times just before touchdown. In addition, there is a major effect upon touchdown distance (XRTD), glide slope deviation and elapsed time. The sampling times before touchdown were at .8 second intervals from the last readout before touchdown. In figure 9, the night and day rates of descent are seen to be almost constant for these four sampling points before touchdown.

The statistically significantly greater rate of descent (more than 2 ft. per second) for the night scene is of considerable practical concern. In the first instance, how does the day or night rate of descent compare with that measured for real aircraft and for other simulators? One caution, before undertaking any comparison: this study and the point light study with the Compuscene in table 3 have been collected without altimetery, glide slope display or vertical speed indication. The aircraft and other simulator studies used complete instrumentation. This investigation shows rates of descent that are higher than those obtained in other investigations, with the exception of Crane's (1962) study of a simulator identified as "B". Both the absence of altimetry, glide slope and vertical speed indicators and the poor quality windows would be positive contributors of these higher rates of descent. All the simulator investigations included in table 3 are significantly different from the rates of descent on touchdown as measured by Stickle, Silsby and others. We have yet to establish whether the new CGI visual systems will result in descent rates that are comparable to real aircraft touchdowns.

Comparisons among these data, such as the night vs. day data within this study, are warranted. The night descent rate of > 10 feet/second is great enough to deserve consideration of its cause. Such a vertical velocity at touchdown would exceed the design limits for the gear on a real 727 aircraft. The reason for the greater descent rate at night this close to touchdown is probably related to earlier aspects of the approach. The approach data show that, at all measured distances, the average altitude maintained with the night scene is higher than that flown to the day scene. It may be that the absence of ground "texture" beyond that provided by the "point sources" of light is insufficient visual information for the pilot to make precise judgments. Without verbalizing it, he therefore makes a more cautious approach, maintaining a higher altitude and a little greater speed in the absence of the greater amount of information available from the day scene.

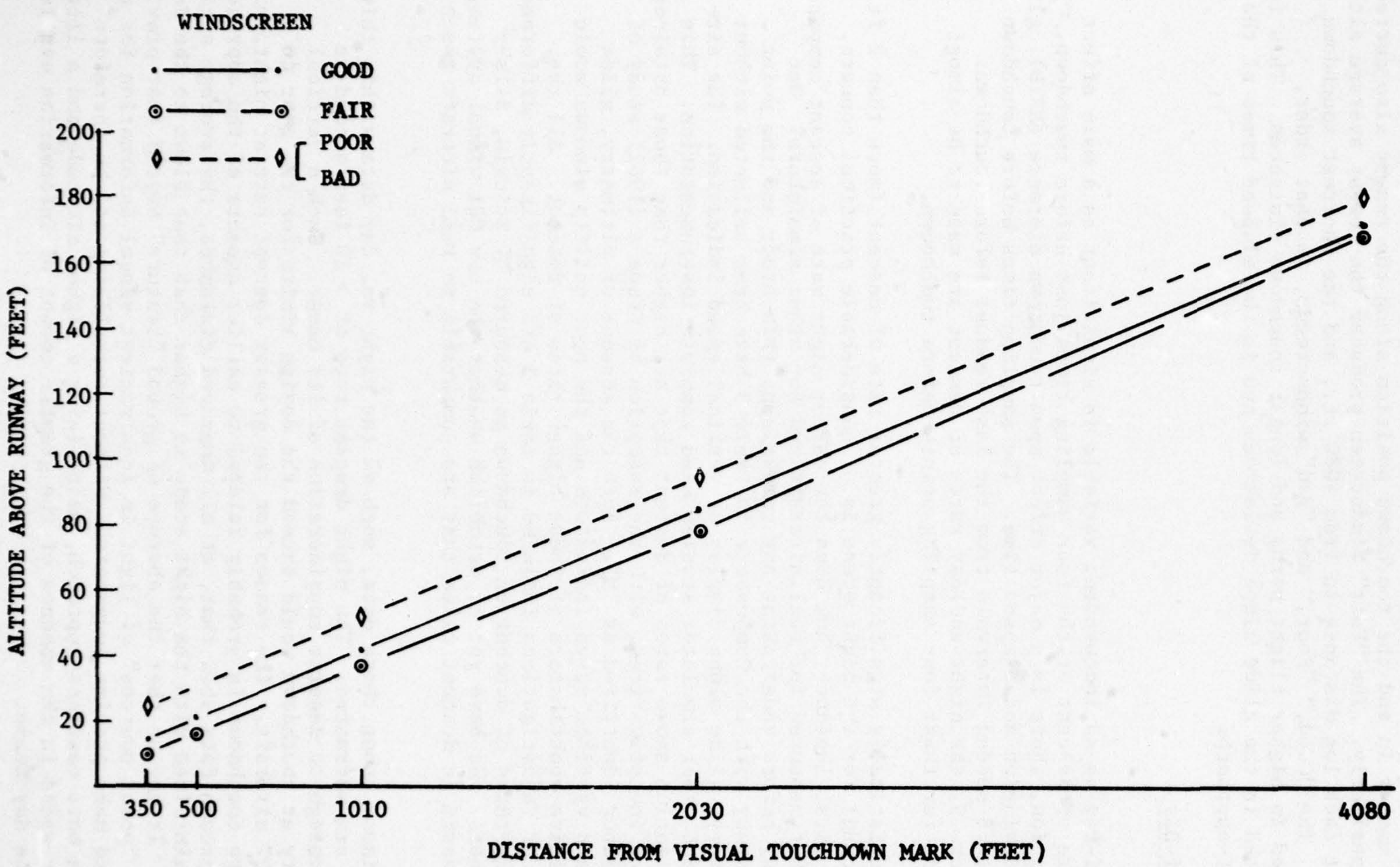


Figure 8. Effect of Windscreen Quality on Average Altitude (All Conditions Combined)(Phase I)

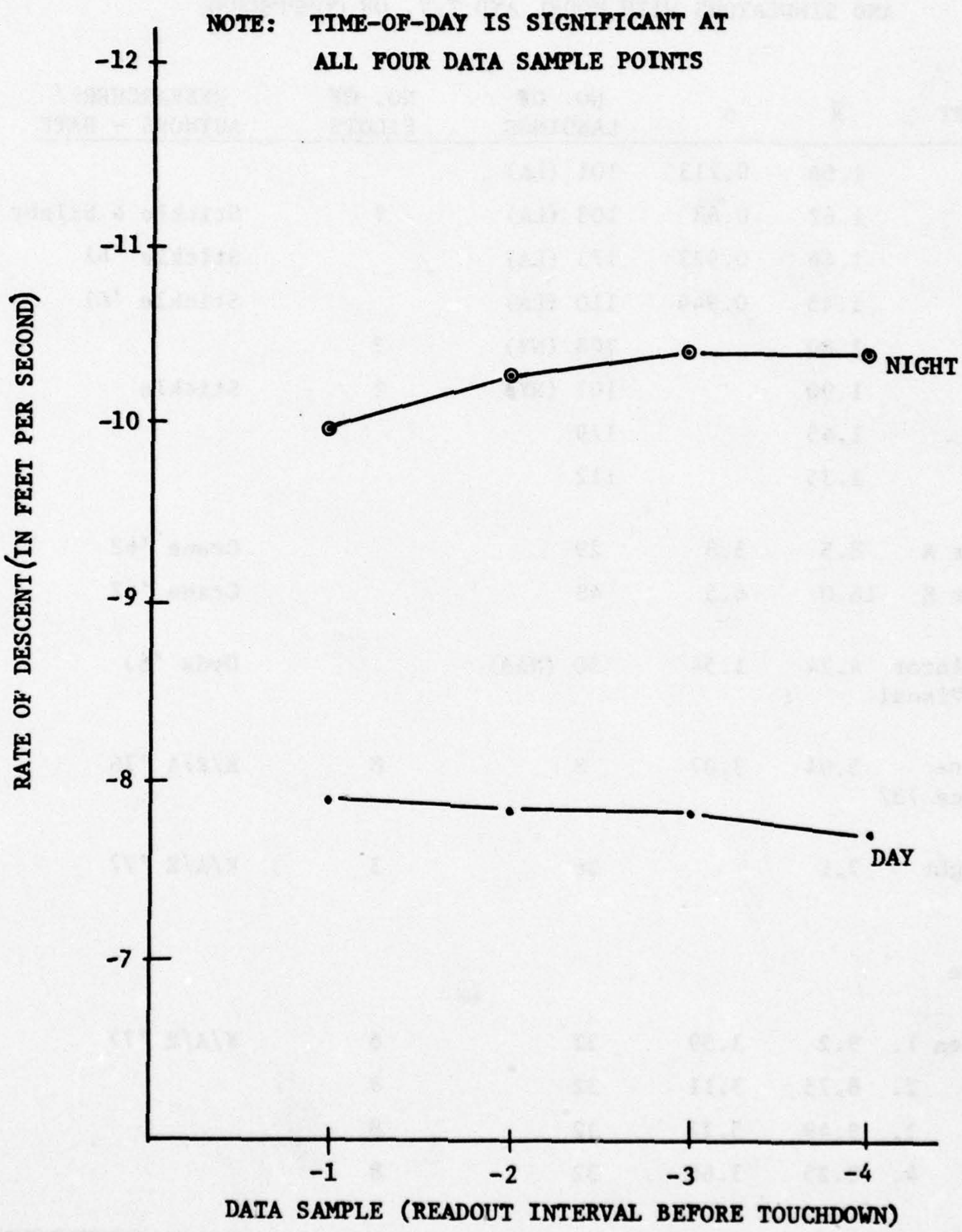


Figure 9. Effect of Time-of-Day on Rate of Descent Near Touchdown (Phase I)

TABLE 3

RATE OF DESCENT AT TOUCHDOWN: COMPARISON OF AIRCRAFT AND SIMULATORS WITH MODEL AND T.V. OR COMPUSCENE

AIRCRAFT	$\bar{X}$	σ	NO. OF LANDINGS	NO. OF PILOTS	RESEARCHERS/ AUTHORS - DATE
L-188	1.06	0.713	101 (LA)		
707-120	1.62	0.88	103 (LA)	?	Stickle & Silsby
707-120	1.46	0.923	173 (LA)		Stickle '61
DC-8	1.45	0.944	110 (LA)		Stickle '61
DC-8	1.80		108 (NY)	?	
707-320	1.90		107 (NY)	?	Stickle
Type I	1.45		179		
Type II	1.35		112		
Simulator A	8.5	3.8	29		Crane '62
Simulator B	16.0	6.5	48		Crane '62
707 Simulator + FN TV Visual	4.24	1.54	50 (NAA)		Dyda '63
Compuscene Acceptance 737	5.04	3.07	8	8	K/E/A '76
Point Light 727	7.2		36	3	K/A/E '77
Air Force Pilots					
Windscreen 1.	9.2	3.59	32	8	K/A/E '77
2.	8.75	3.11	32	8	
3.	9.49	5.22	32	8	
4.	8.25	3.66	32	8	

This assumption seems warranted when one refers to figure 10. The average altitude at the runway threshold, on the 1010 ft. sampling distance, is depicted as a function of time-of-day, combined with visibility vs. windscreen quality. The 2.5° glide slope from the visual touchdown point passes through distance 1010 at 44 ft. of altitude. The "Good" and "Fair" windscreens, in combination with the night scene, are associated with pilots' crossing of the threshold at this altitude. The approach to the day scene, with one exception, is flown at a lower runway threshold altitude regardless of windscreen image quality. The exception appears to be an artifact in these data, as all medians match the means for each of the daylight conditions except the "Good" windscreen under the clear/day condition.

The influence of the "Poor" and "Bad" windows is different for the night scene. The poor quality of the image visible through these windows makes the limited visual information of the night scene less reliable, and therefore the pilot may be even more cautious than with the better windows. This may be the case, as he does fly higher, and statistically significantly higher, to each of the four night x low quality windscreen combinations. Figure 11 illustrates that windscreen and time-of-day interact to influence touchdown position along the runway. Only the clear window does not impose a later touchdown point as a function of day versus night. Each of the image-quality-attenuating windscreens increases the distance of the touchdown from the visual touchdown reference mark on the runway for the night scene as compared to the day scene.

The effect of lowered visibility is, in itself, not a significant independent variable; however it interacts with windscreens to become a significant interaction that affects touchdown distance (figure 12). Whenever haze exists, the longer down the runway the touchdown occurs, and the poorer the quality of the windscreen, the greater the combined effect. This finding is also consistent with the hypothesis that as there is less visual information provided, or if it appears to be less reliable due to haze or blur, the higher the flight and the further down the runway the pilot tends to land.

Windscreen quality and time-of-day have another interactive effect on rate of descent at touchdown. The quality of the windscreen does not change rate of descent at touchdown for daytime approaches. Night scenes are associated with greater rates of descent, as described earlier, with the exception of the "bad" windscreen. With this windscreen, no difference occurred between night and day (figure 13). One observable feature about this windscreen may serve as an untested explanation. From an observation position behind the pilot, viewing the scene through this windscreen, the view from the right side of the pilot's head gave the impression that everything on the right side of the scene was sloping downward. From a viewing position to the left of the pilot's head everything on the left side of the scene appeared to slope downward. Thus, from the pilot's eye position, using both eyes, the runway appeared "crowned" with a high center, and this appeared more severe when no side texture was available to the right and left beyond the runway edge lights. This may have been perceived by the pilots as though they were approaching "the high crown" earlier with the "bad" windscreen, and therefore they reduced their rate of descent.

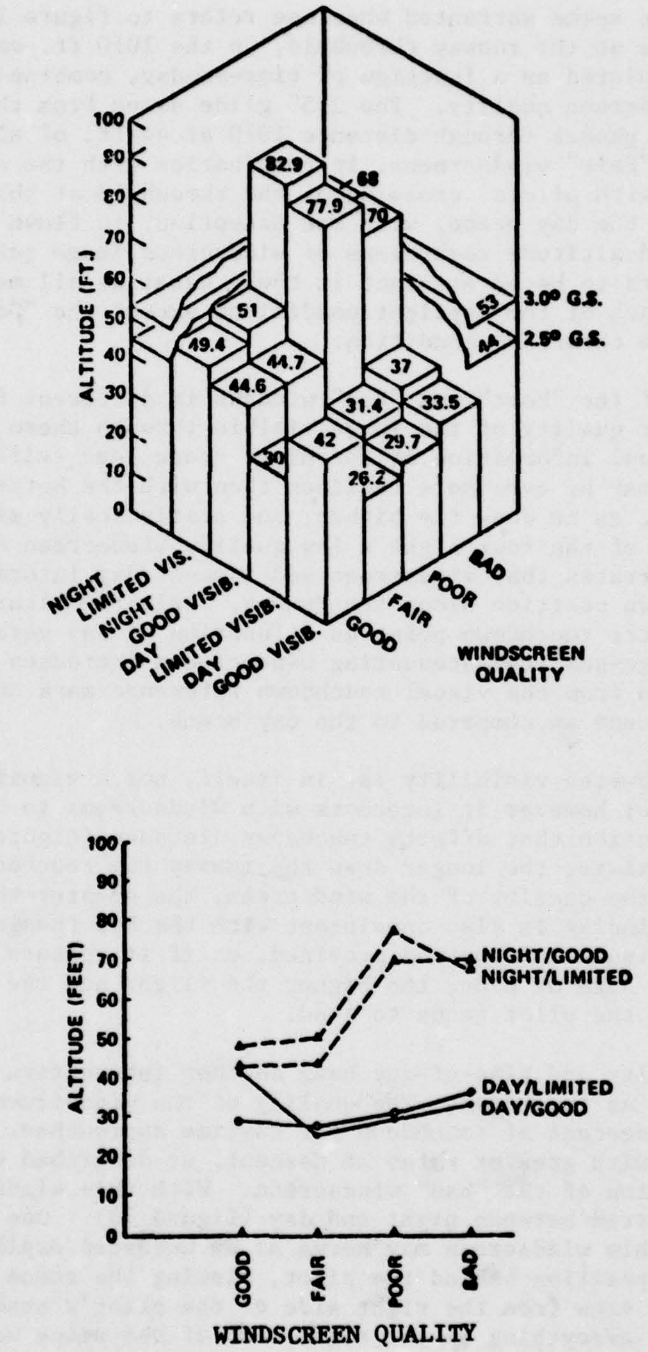


Figure 10. Altitude Over Runway Threshold as a Function of Windscreen Optical Quality, Time-of-Day and Atmospheric Attenuated Visibility (Phase I)

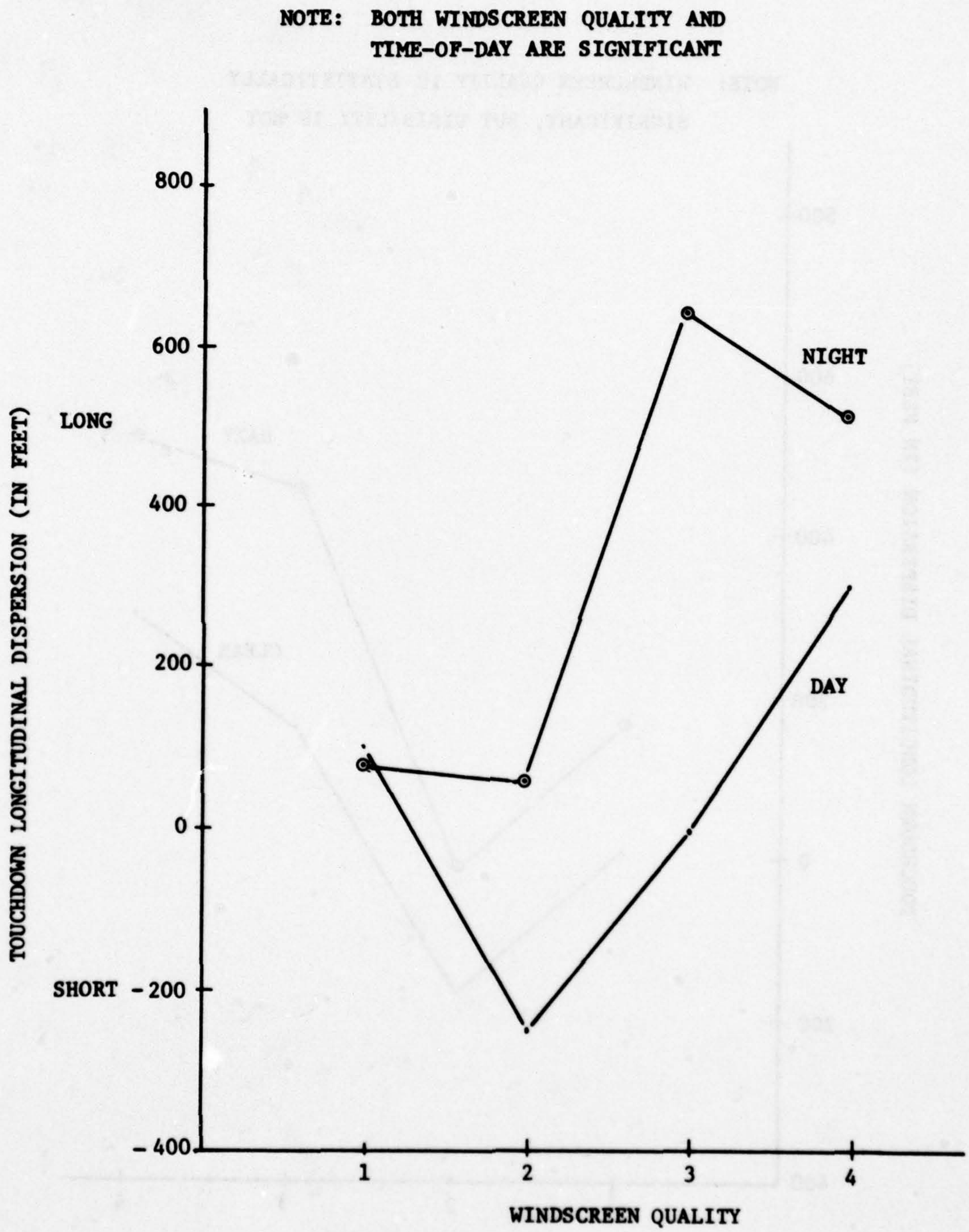


Figure 11. Interaction of Windscreens and Time-of-Day on Touchdown Point (Phase I)

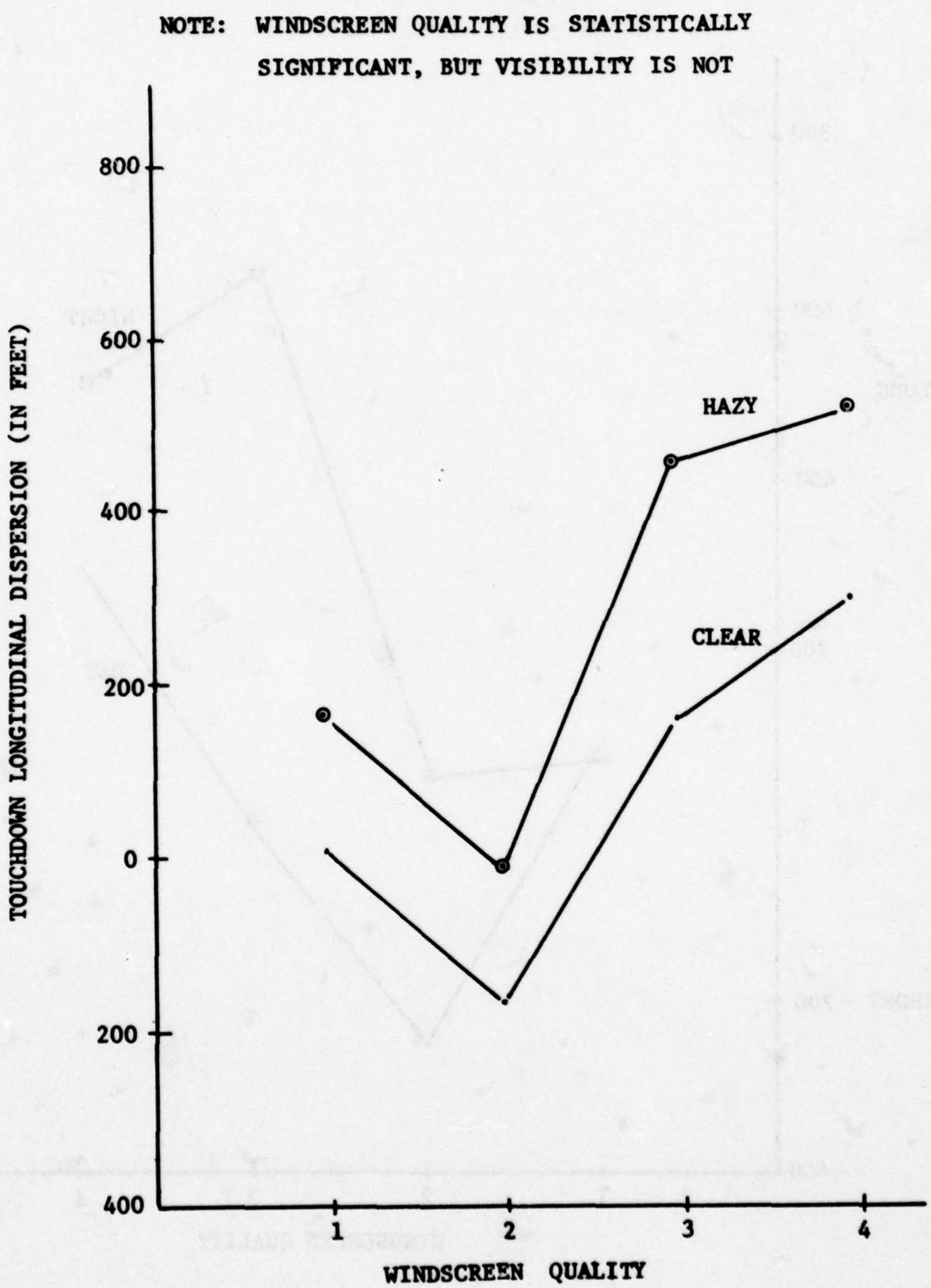


Figure 12. The Interaction Between Windscreens and Visibility (Phase I)

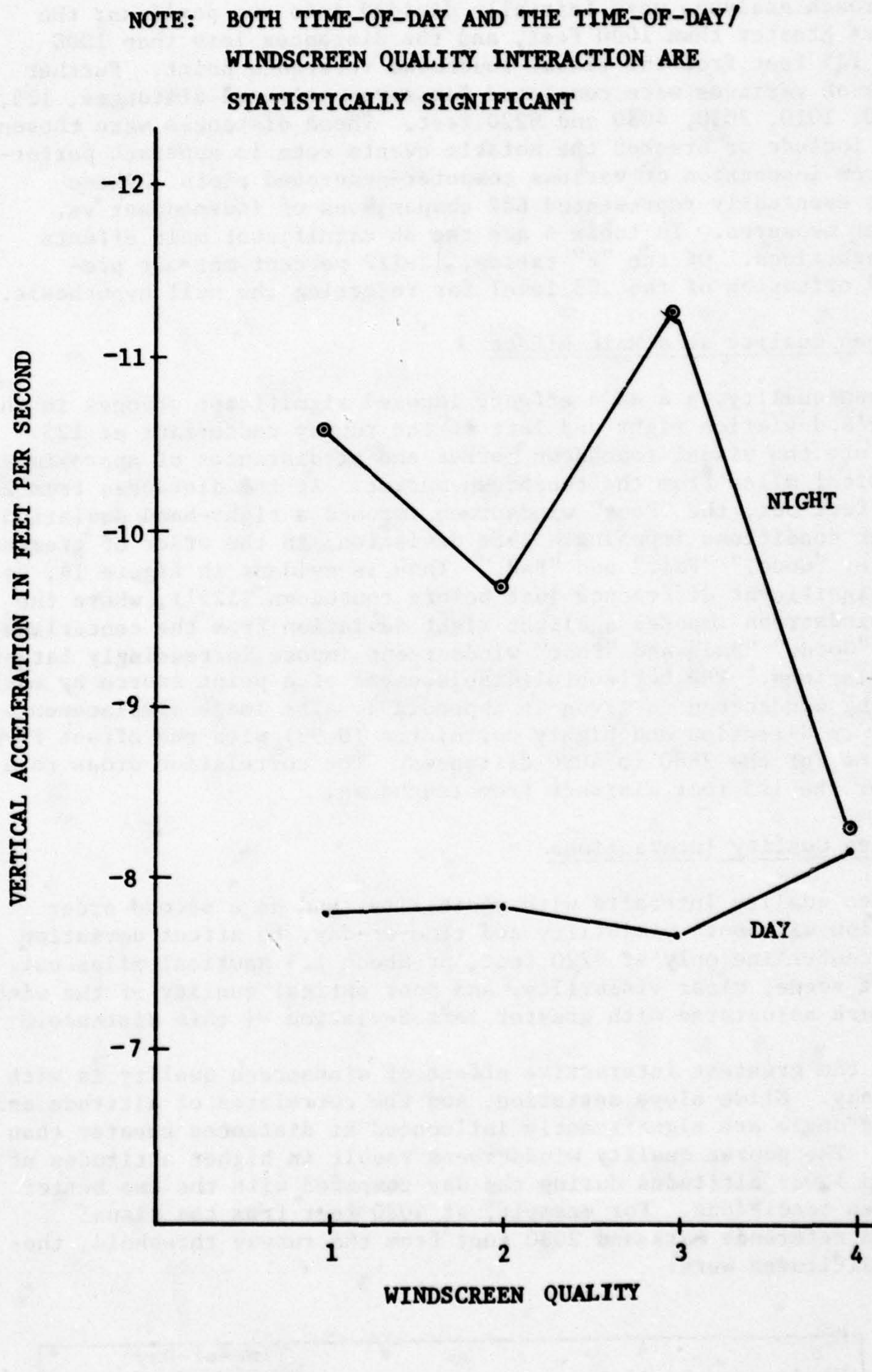


Figure 13. Time-of-Day and Windscreen Interactive Effect on Rate of Descent (Phase I)

ANALYSIS OF APPROACH DATA (PHASE I)

The approach analyses were initially divided into two portions: the distances greater than 1000 feet, and the distances less than 1000 feet in 125 feet from the visual touchdown reference point. Further analyses of variance were completed for seven selected distances, 125, 250, 500, 1010, 2030, 4080 and 8220 feet. These distances were chosen as they include or bracket the notable events seen in approach performance from inspection of various computer-generated plots. These analyses eventually represented 682 comparisons of independent vs. dependent measures. In table 4 are the 86 significant main effects and interactions. Of the "F" ratios, 12-1/2 percent met our pre-selected criterion of the .05 level for rejecting the null hypothesis.

Windscreen Quality as a Main Effect

Windscreen quality, a a main effect, imposed significant changes in the aircraft's deviation right and left of the runway centerline at 125 feet before the visual touchdown marker and at distances of approximately 1/3 nautical miles from the touchdown marker. At the distances from 2030 to 8220 feet out, the "Poor" windscreen imposed a right-hand deviation, all other conditions imposing a left deviation, in the order of greater magnitude, "Good," "Fair" and "Bad." This is evident in figure 14, as is the significant difference just before touchdown (125'), where the "Fair" windscreen imposes a slight right deviation from the centerline and the "Good," "Bad" and "Poor" windscreens impose increasingly larger left deviations. The horizontal displacement of a point source by each distorting windscreen is given in appendix 1. The image displacements is opposite in direction and highly correlated (0.99) with the offset from the centerline for the 2880 to 4080 distances. The correlation drops to a -0.06 for the 125 foot distance from touchdown.

Windscreen Quality Interactions

Windscreen quality interacts with visibility, and as a second order interaction with both visibility and time-of-day, to affect deviation off the centerline only at 8220 feet, or about 1.3 nautical miles out. The night scene, clear visibility, and poor optical quality of the windscreens are associated with greater left deviation at this distance.

However, the greatest interactive effect of windscreen quality is with time-of-day. Glide slope deviation, and the correlates of altitude and deviation angle are significantly influenced at distances greater than 1000 ft. The poorer quality windscreens result in higher altitudes at night and lower altitudes during the day compared with the two better windscreen conditions. For example, at 4080 feet from the visual touchdown reference mark and 3080 feet from the runway threshold, the average altitudes were:

Windscreen Quality	Time-of-Day: Day	Time-of-Day: Night
2 Better Windscreens	140 ft.	178 ft.
2 Poorer Windscreens	129 ft.	209 ft.

TABLE 4

AREAS OF STATISTICAL SIGNIFICANCE IN APPROACH ANOVAs (Phase I)

INDEPENDENT VARIABLES	DEPENDENT VARIABLES						
	Y DEV.	Z DOT	VEL.	PITCH	G.S. DEV.	ALT.	DEV. ANGLE
SCREENS (S)	>1000 2030 4180 8220 125						
TIME OF DAY (T)		>1000< 500 1010 2030 4080		>1000 1010 2030	>1000 <1000 125 250 1010 2030 4080 8220	>1000 <1000 125 250 1010 2030 4080 8220	>1000 125 250 500 1010 2030 4080 8220
VISIBILITY (V)			<1000 125 250	4080	8220	8220	8220
DISTANCE FROM VISUAL TOUCH-DOWN POINT.			>1000		>1000 <1000	>1000 <1000	
S x T			<1000 8220	>1000 <1000	>1000 2030 4080	>1000 2030 4080 8220	>1000 2030 4080 8220
S x V	8220						
S x X-RNG	>1000 <1000		>1000				
T x V						125	
T x X-RNG		>1000 <1000	>1000 <1000	>1000 <1000	>1000	>1000 <1000	>1000
V x X-RNG							
S x T x V	8220	500			500		500

LEGEND ON VARIABLES: X-RNG = Distance from Visual Touchdown Point. Z DOT = Vertical Speed.

LEGEND ON ANOVAS: 1000 = Anova including all distances greater than 1000 feet.
1000 = Anova including all distances less than 1000 feet.
125, 250, 500, 1010, 2030, 4080 and 8220 = Anovas at these single distances.

NOTE: No <1000 analysis was calculated for DEV. ANGLE.
For X-RNG only included in > and < 1000 analysis.

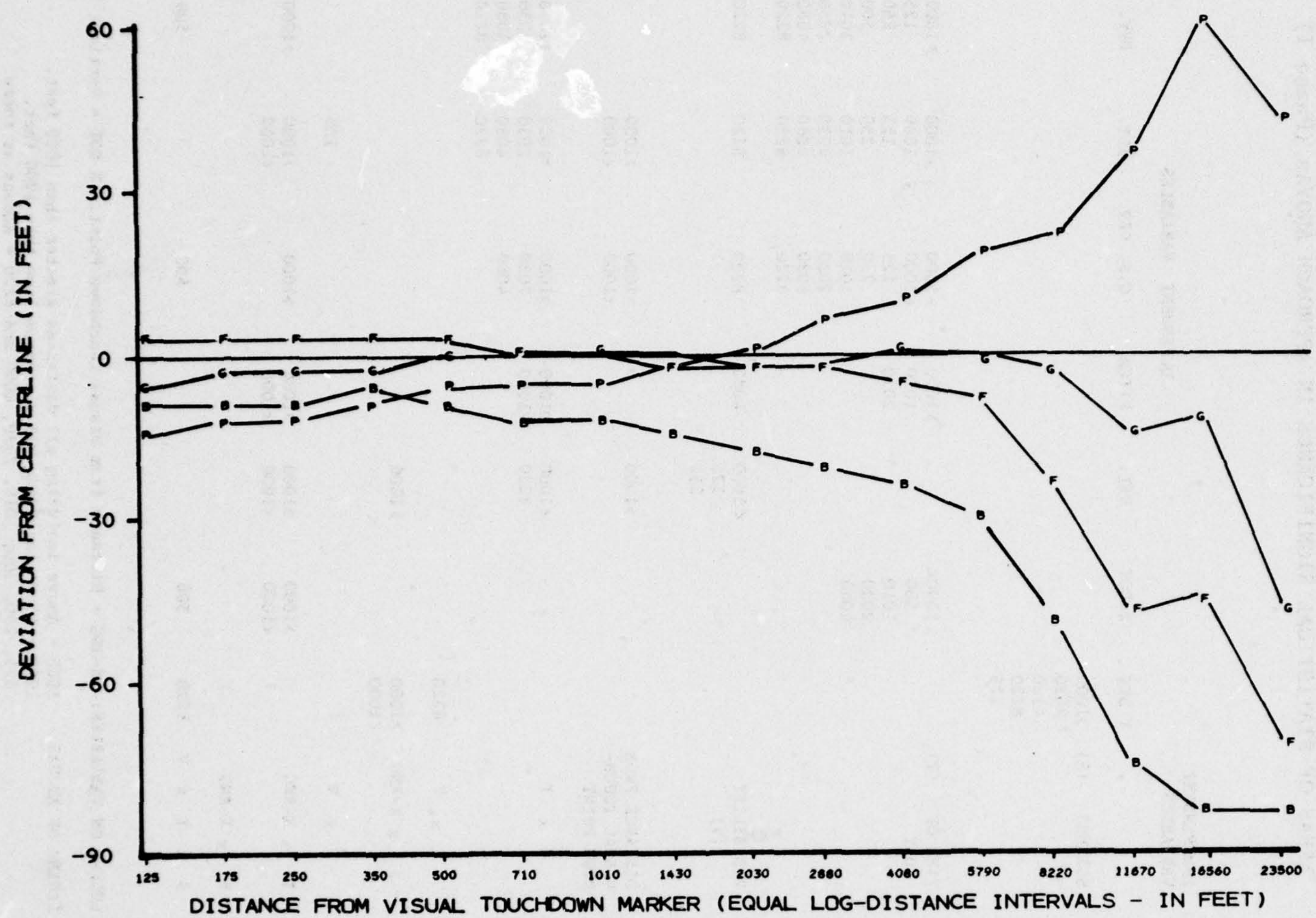


Figure 14. Centerline Deviations Versus Distance From Visual Touchdown Point for Four Windscreen Quality Conditions (Phase I)

The effect of windscreen quality on glide slope deviation angle as a function of distance is illustrated in figure 15. Comparing figure 15 with figure 16, a plot of deviation angle as a function of the night versus day scenes, one may clearly see that the combined influence of poor quality windscreens and the less visual information available in the night scene may summate to give a higher altitude profile at night with poor windscreen conditions.

Time-of-Day as a Main Effect

Time-of-day, in addition to interacting with windscreen quality has a significant effect as a separate independent variable of rate of descent, pitch, glide slope deviation, and altitude. This influence is consistently found for most of the analyses, as only the 500 ft. analysis is excluded from the statement for glide slope deviation and altitude, and the near distances 125 and 250 feet for rate of descent. Figure 17, a plot of altitude versus distance for day and night approaches, shows a clear and constant separation after 25 seconds of flight (23,500 ft. from visual reference) to 125 ft. from the touchdown marker. The night scene resulted in higher approach altitudes at all recorded distances.

The rate of descent becomes higher as the aircraft approaches the touchdown zone for night flights. This likely was caused by the higher approaches at night. Figure 18 illustrates this as a plot of descent rate versus distance for all day and night approaches.

Reference to glide slope deviation as a function of distance shows that there is a severe departure (70 ft. high) at 16,560 ft. with the night scene and an opposite (45 ft. low) departure at the 8220 ft. distance for the day approaches (figure 19). These points are followed by compensating actions in pitch (figure 20) with subsequent decreases in glide slope deviations. Reference to figure 21 illustrates that, for those trials with landings on or beyond the 1000 ft. visual reference mark ("completed runs only") these sharp deviations from the glide slope were also evident.

The airspeed that the pilots used during the day scene approaches dropped below that for the night scenes at around 8220 ft. out (figure 22), and continues to decrease until the aircraft reaches 710 ft. However, the approaches with landings beyond the 1000 ft. mark did not contribute to this decrease in airspeed during the day (figure 23).

The clearer the visibility, the greater the deceleration between 8220 and 710 ft. of distance, as shown in figure 24.

In figure 25, a plot of airspeed as a function of distance, the average airspeed decreases from 239'/sec. to 233'/sec. at a distance of 500 feet for "Good" and "Fair" windscreens. The interaction between windscreen quality and time-of-day is significant at the 8220 distance, indicating that for good quality windscreens and day scenes the pilots started fast, but continued to slow down. They descended too rapidly, pitched up to correct for descent rate, continued to fly slower and touched down earlier. For those trials continuing beyond the 1000 ft. mark, the airspeed difference as a function of windscreen quality is even more pronounced (figure 26).

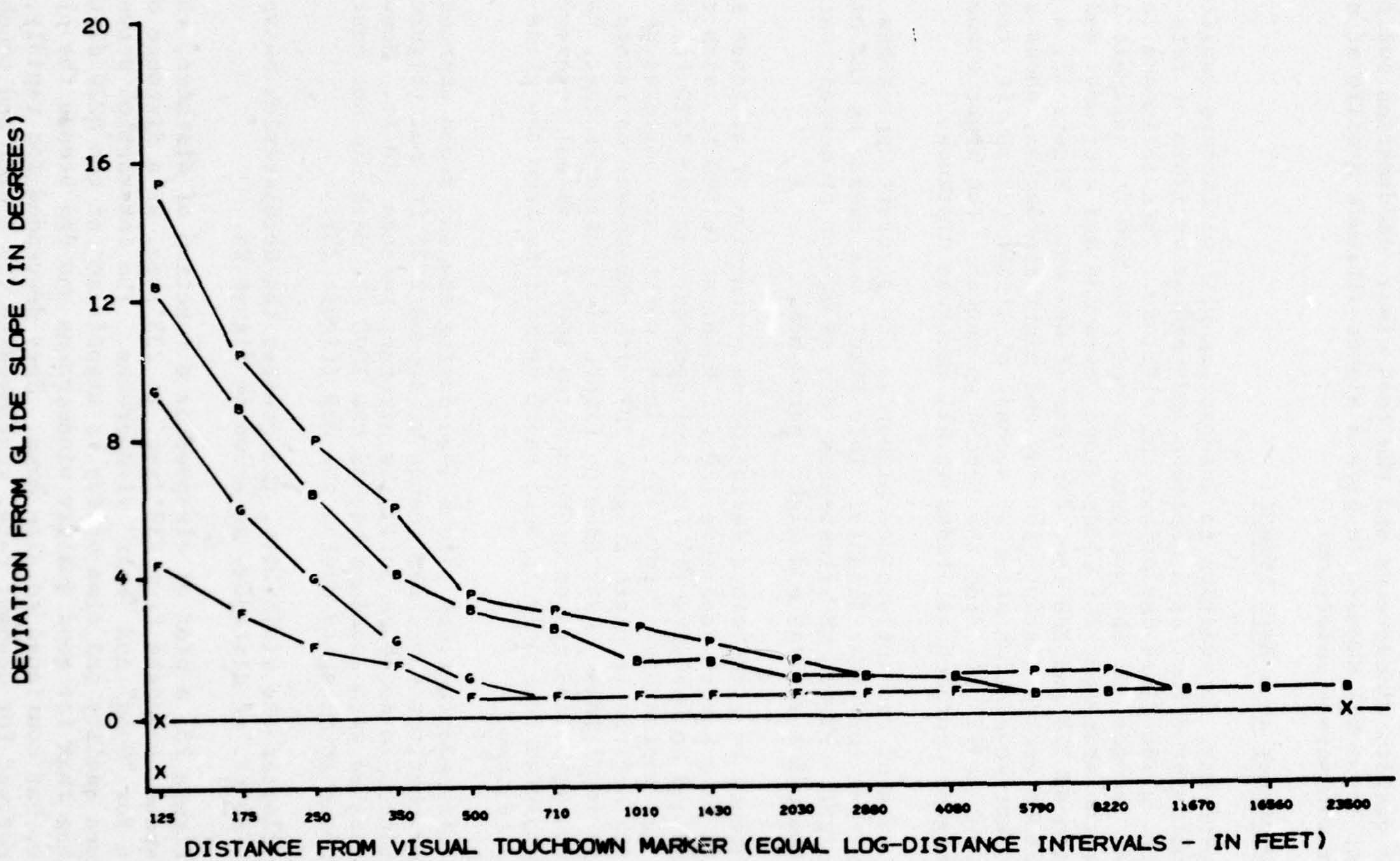


Figure 15. Glide Slope Deviation Versus Distance From Touchdown Marker At Night for Four Windscreens (Phase I)

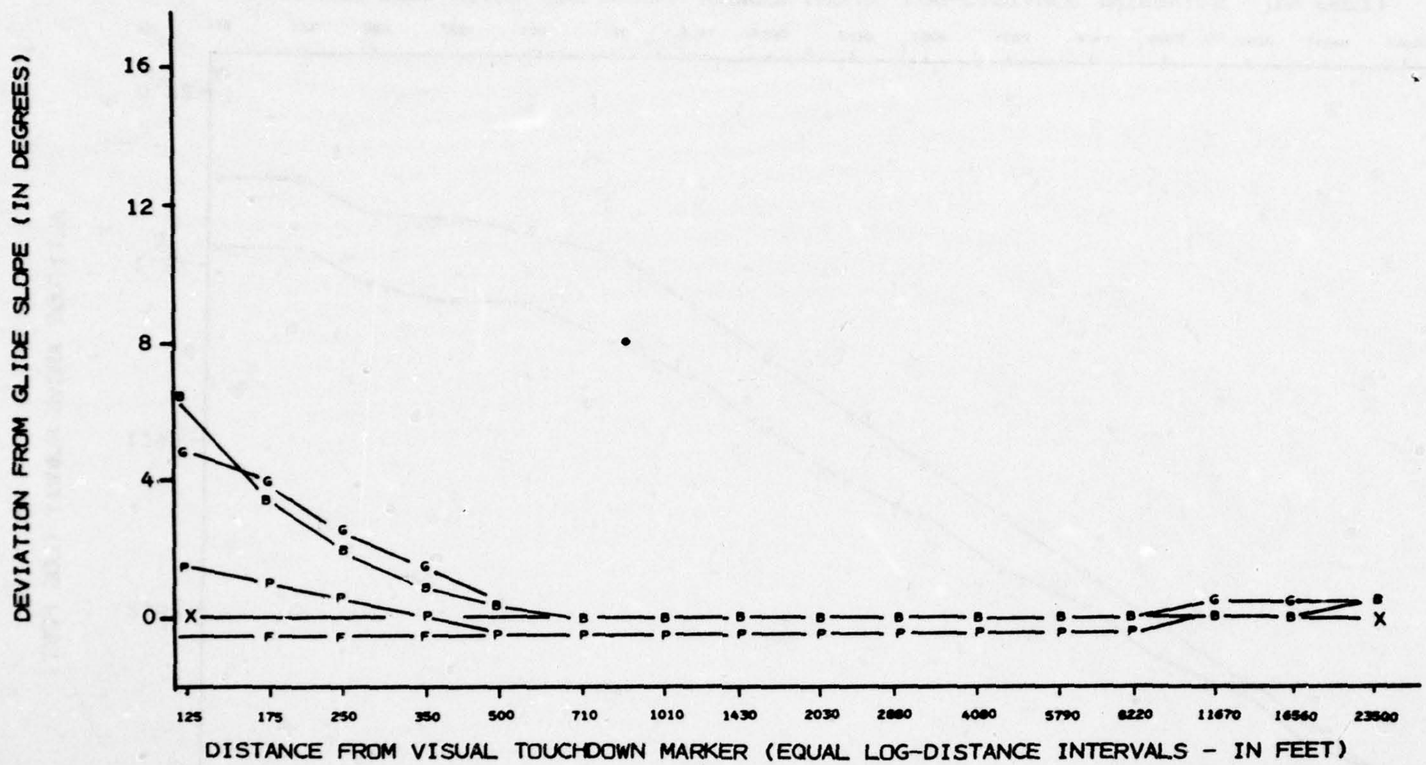


Figure 16. Glide Slope Deviation Angle Versus Distance From Touchdown Marker With Day Scene for Four Windscreens (Phase I)

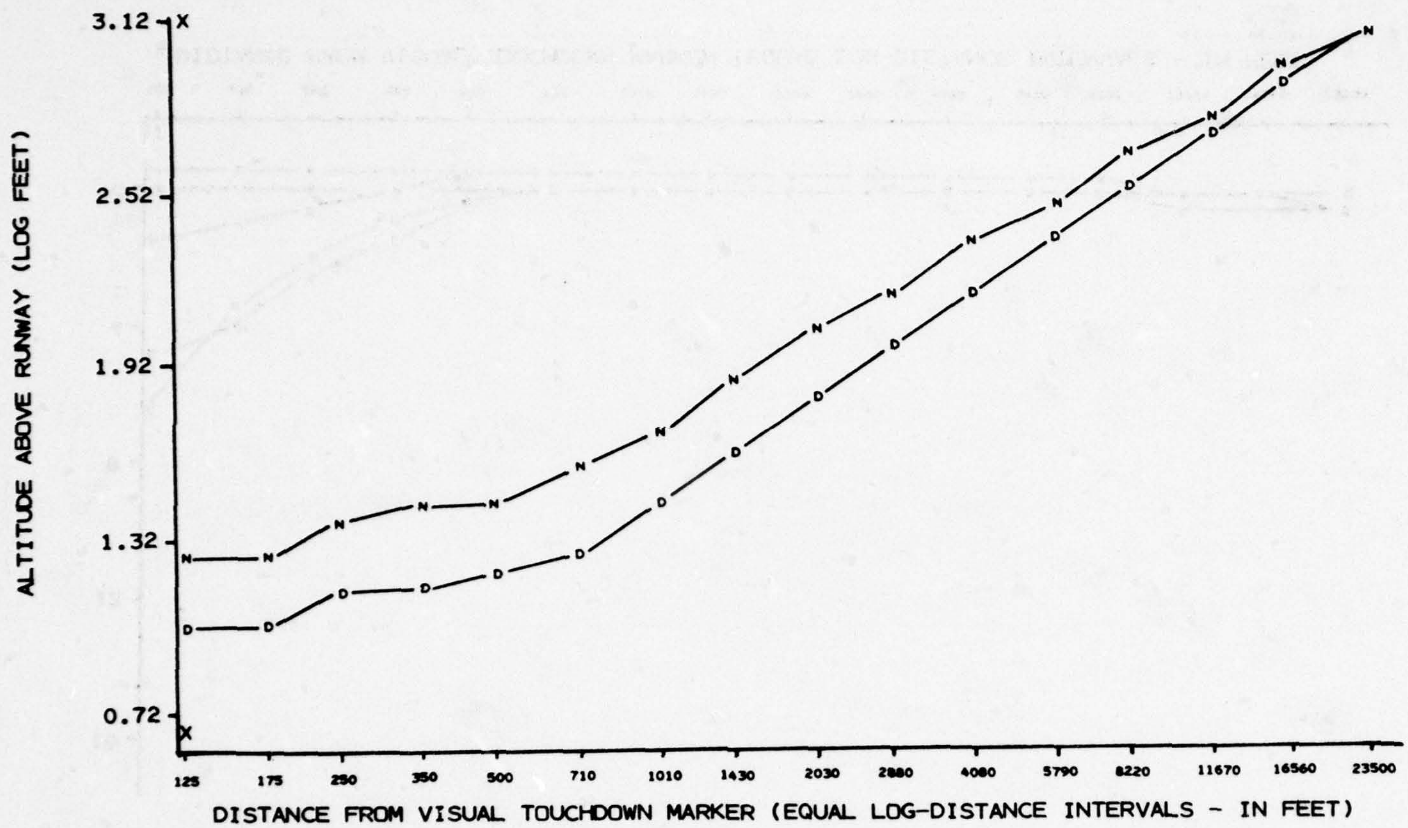


Figure 17. Altitude Versus Distance From Touchdown Marker With Day and Night Scenes (Phase I)

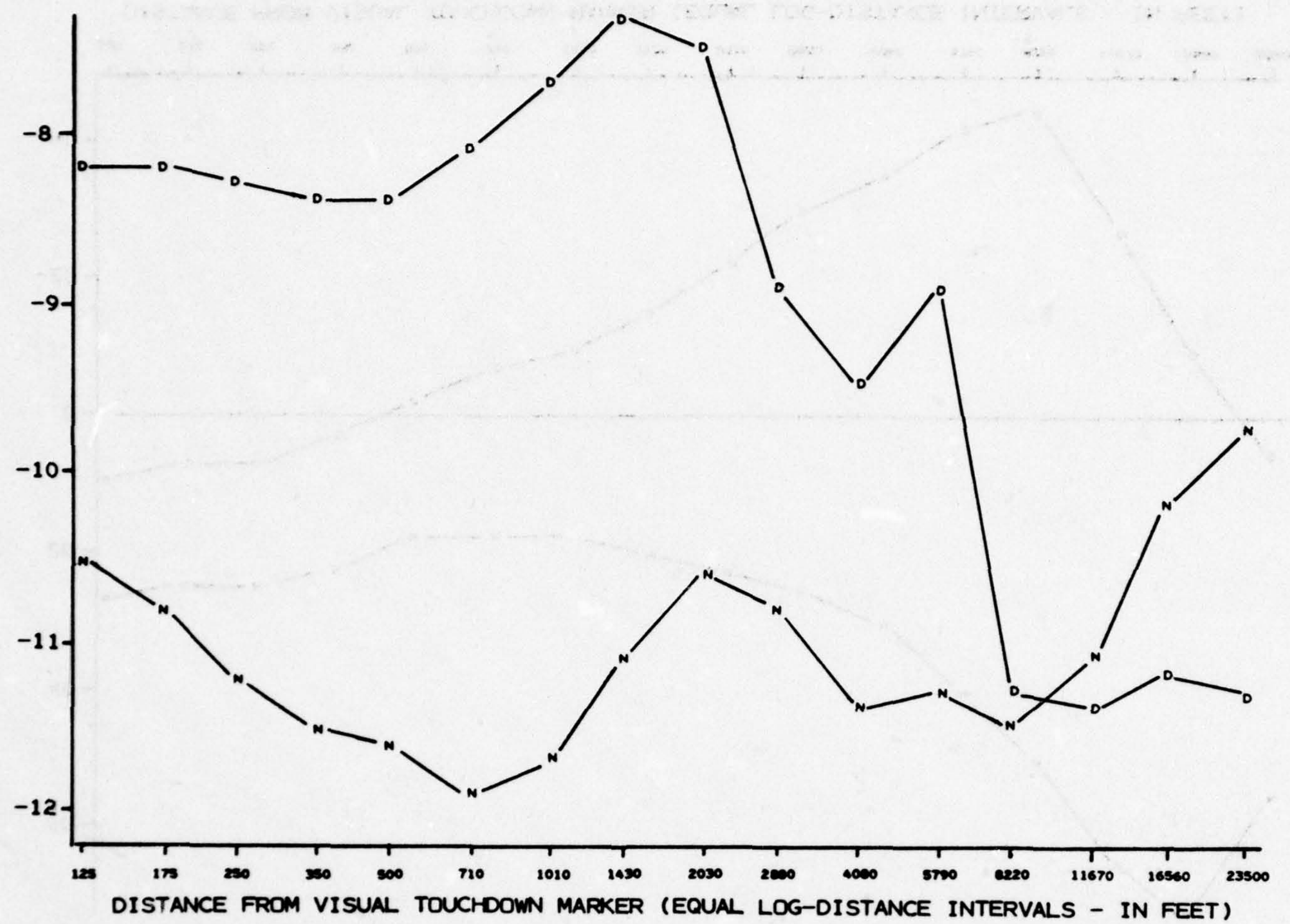


Figure 18. Descent Rate Versus Distance From Touchdown Marker With Day and Night Scenes (Phase I)

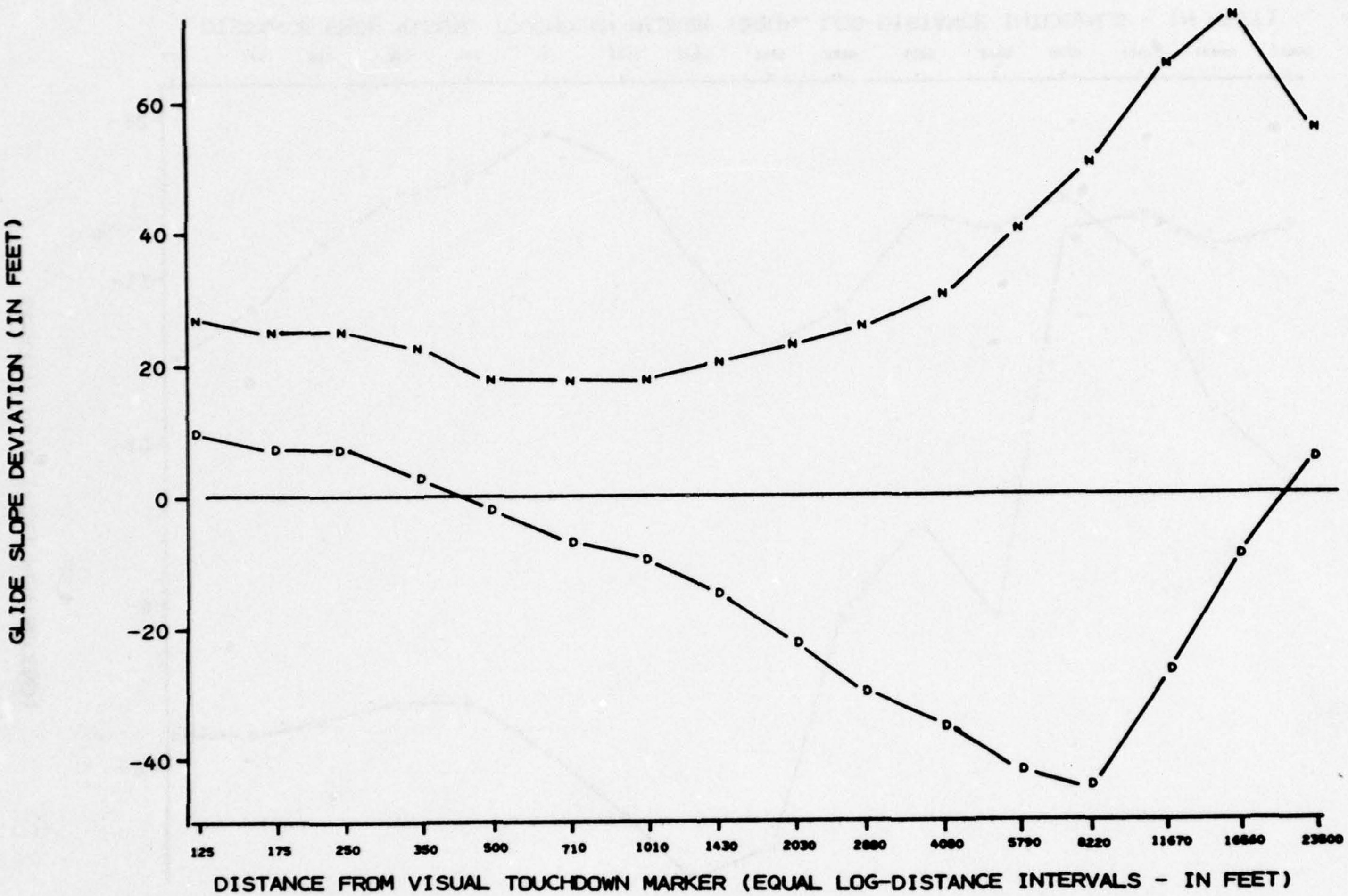


Figure 19. Deviation From Glide Slope Versus Distance From Touchdown Marker With Day and Night Scenes (Phase I)

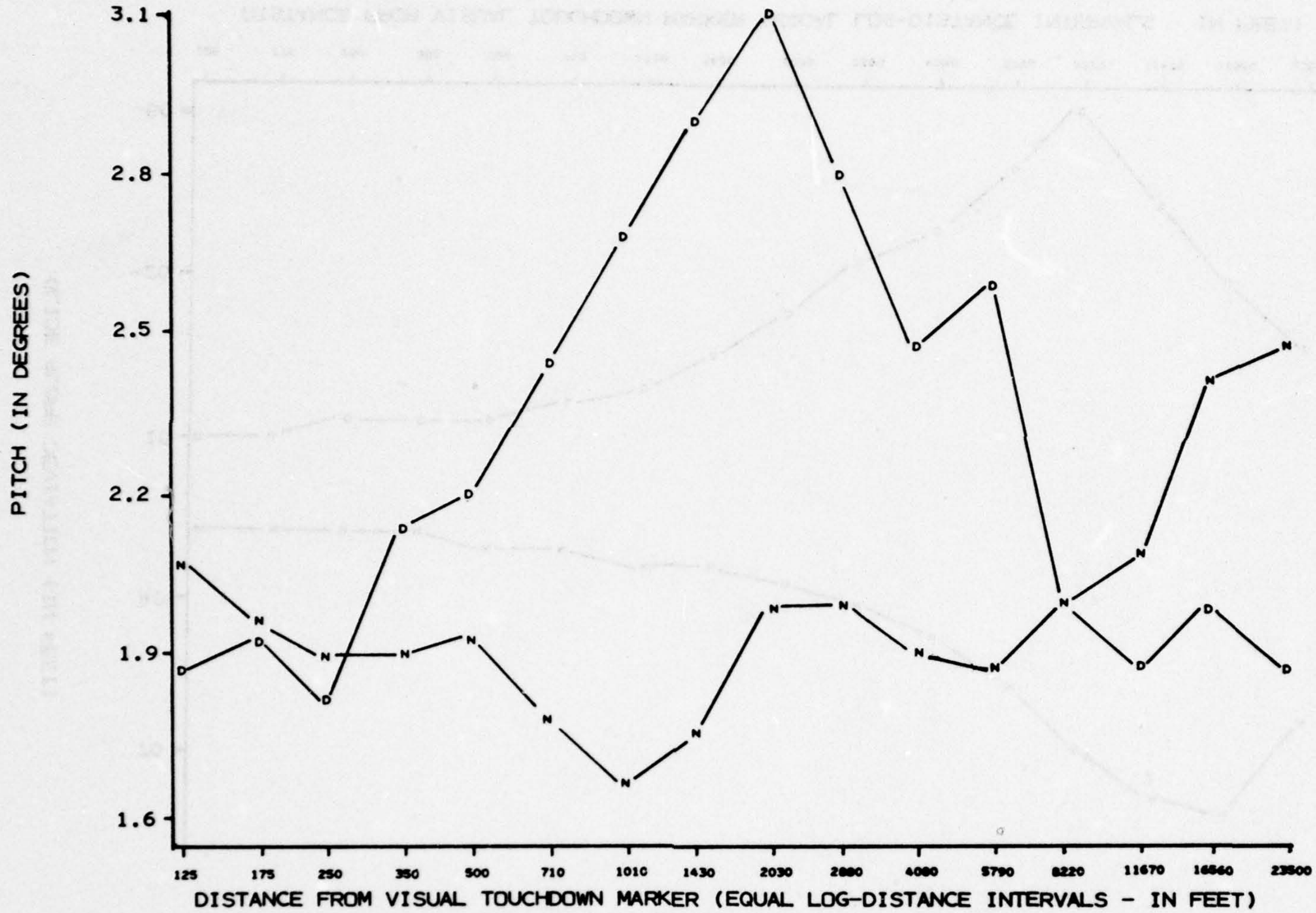


Figure 20. Aircraft Pitch Angle Versus Distance From Touchdown Marker With Day and Night Scenes (Phase I)

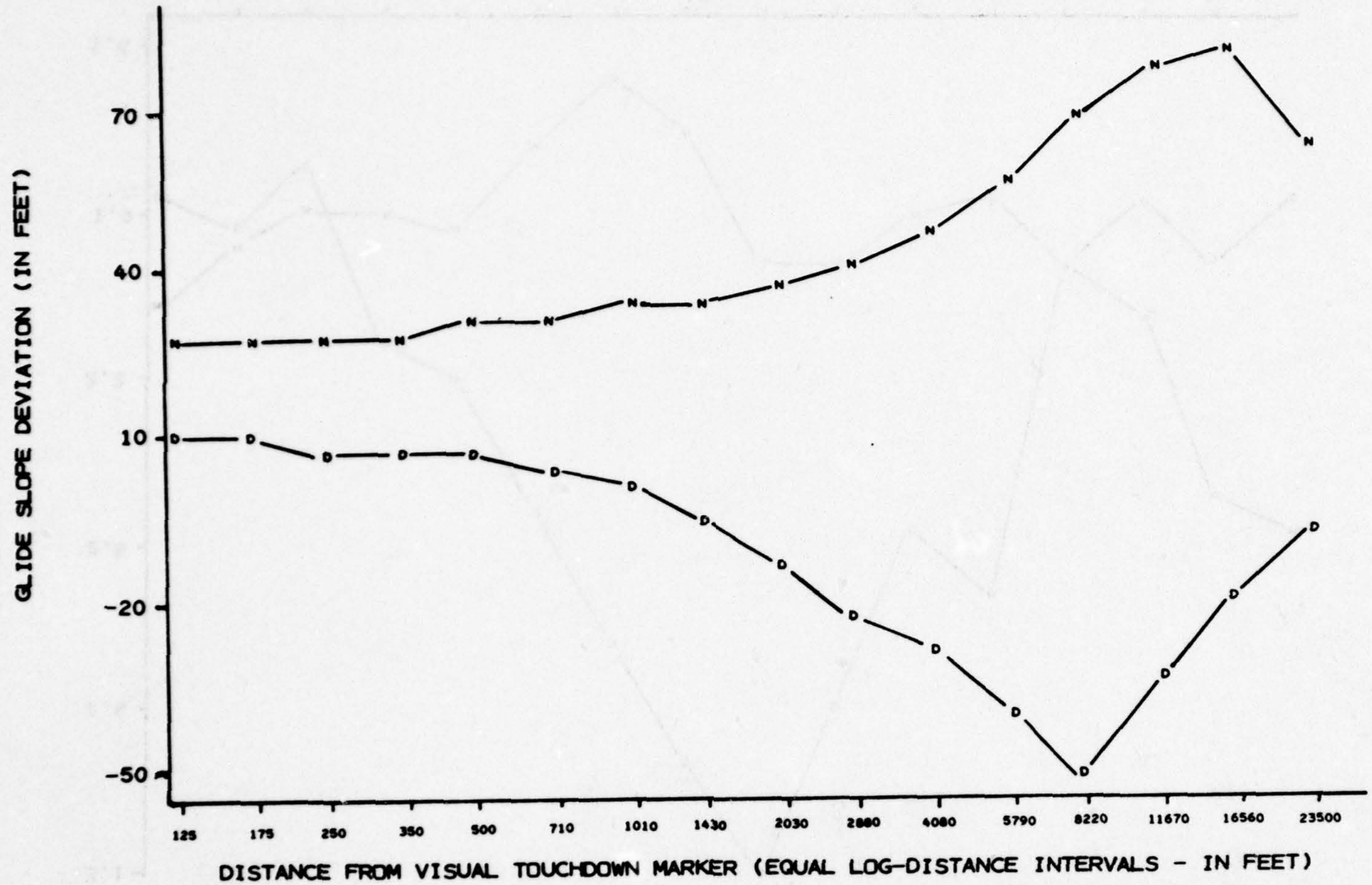


Figure 21. Glide Slope Deviation Versus Distance From Touchdown Marker With Day and Night Scenes for Completed Runs Only (Phase I)

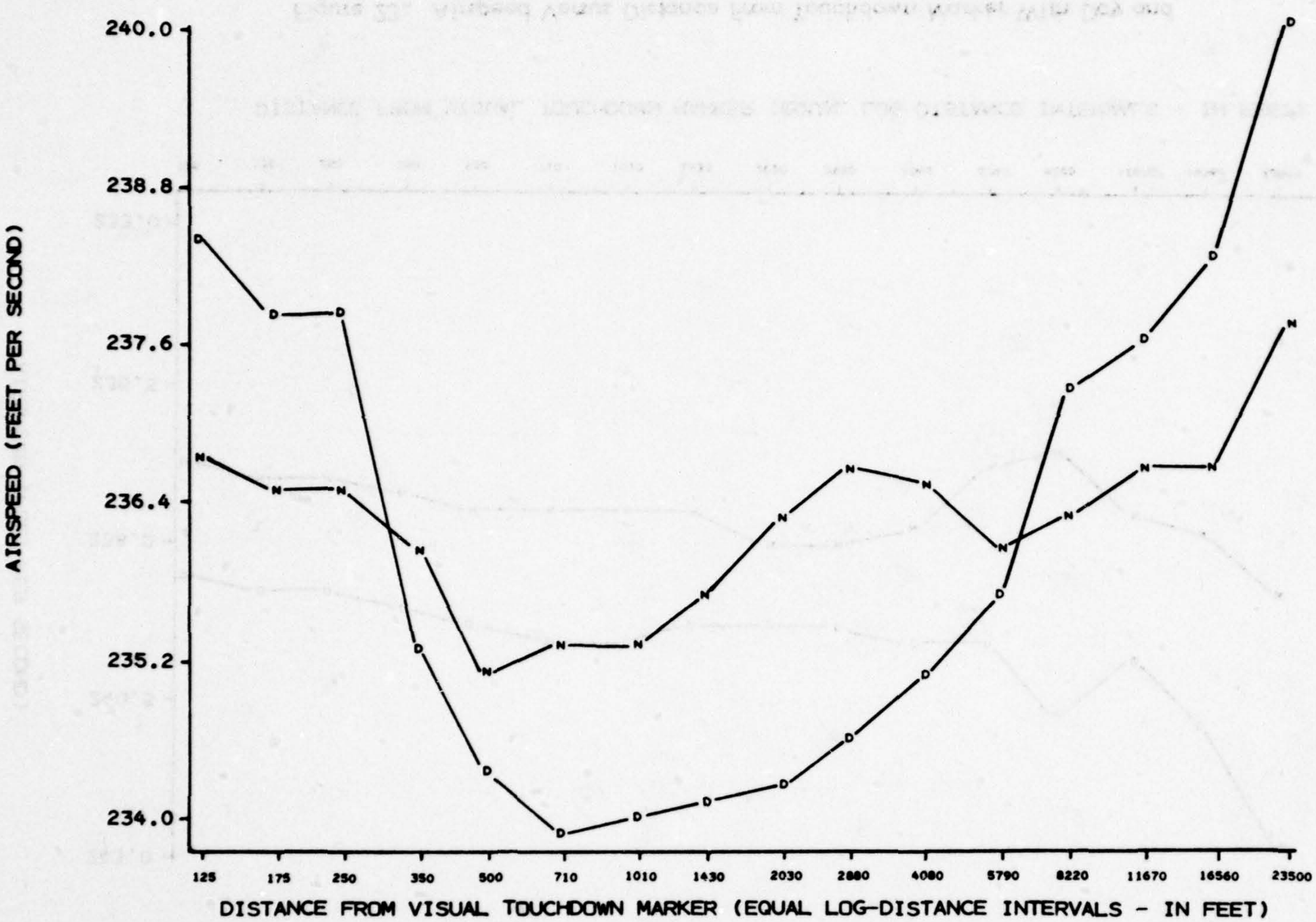


Figure 22. Airspeed Versus Distance From Touchdown Marker With Day and Night Scenes (Phase I)

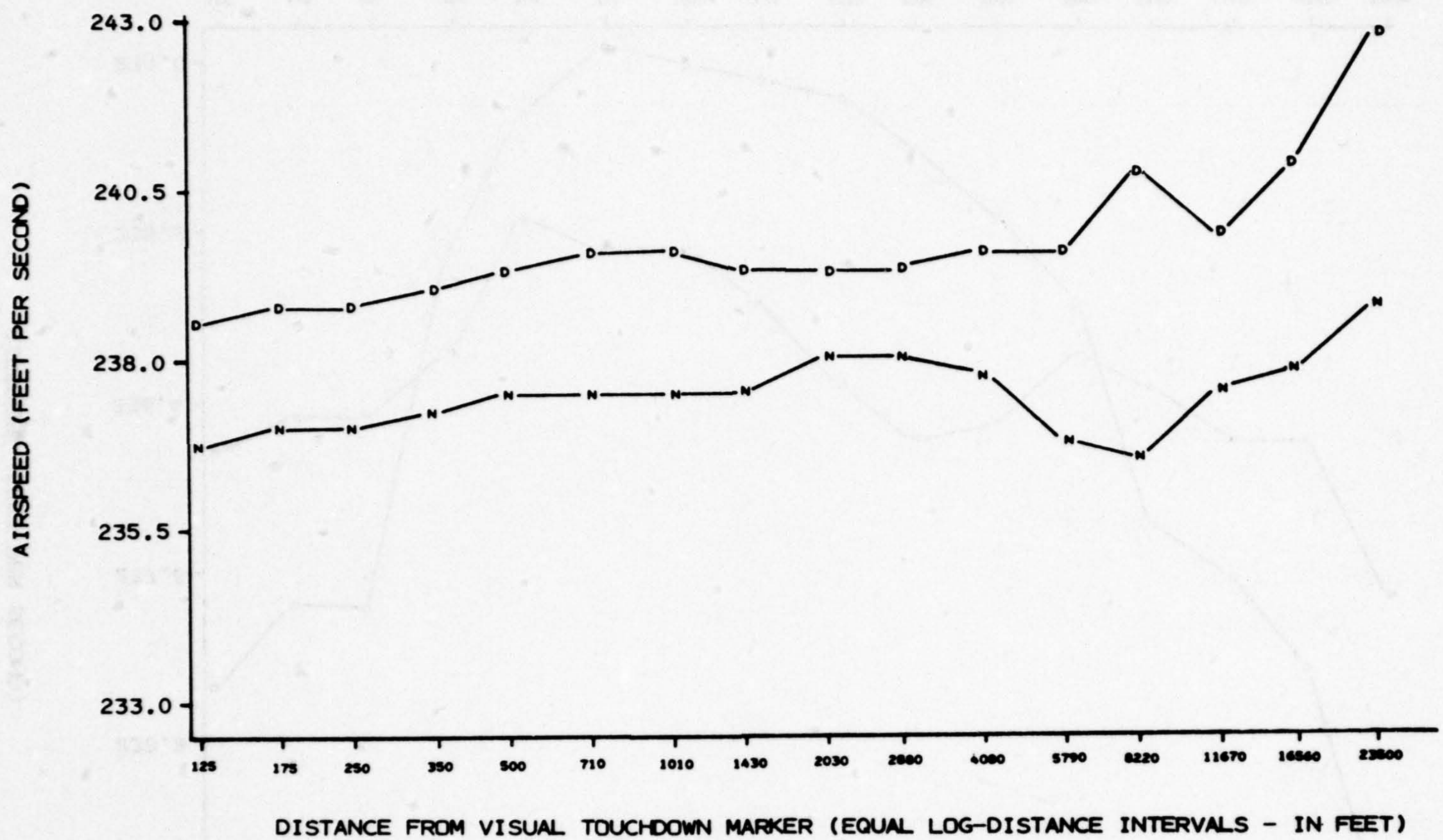


Figure 23. Airspeed Versus Distance From Touchdown Marker With Day and Night Scenes for Completed Runs Only (Phase I)

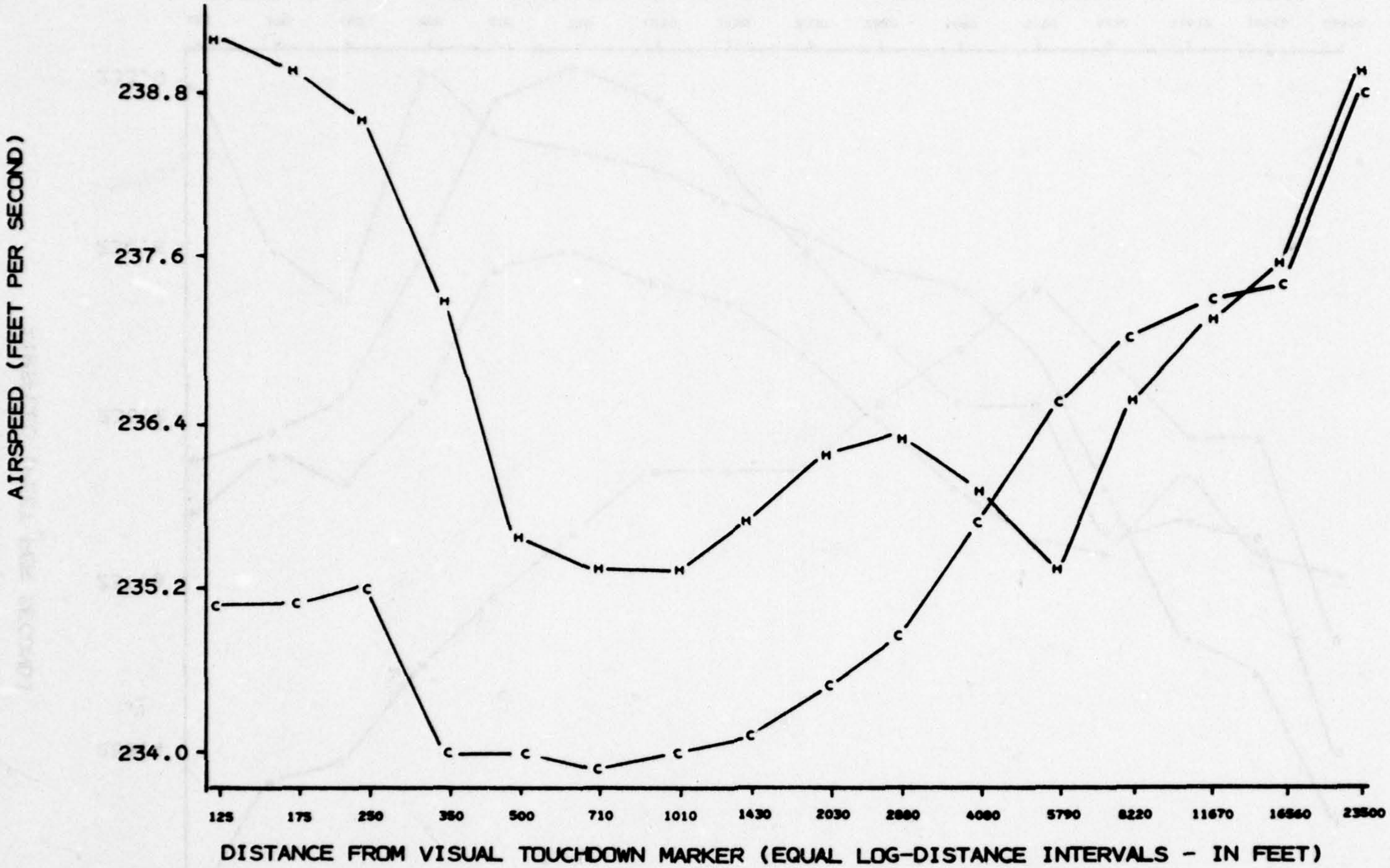


Figure 24. Airspeed Versus Distance From Touchdown Marker With Clear and Hazy Visibility Conditions (Phase I)

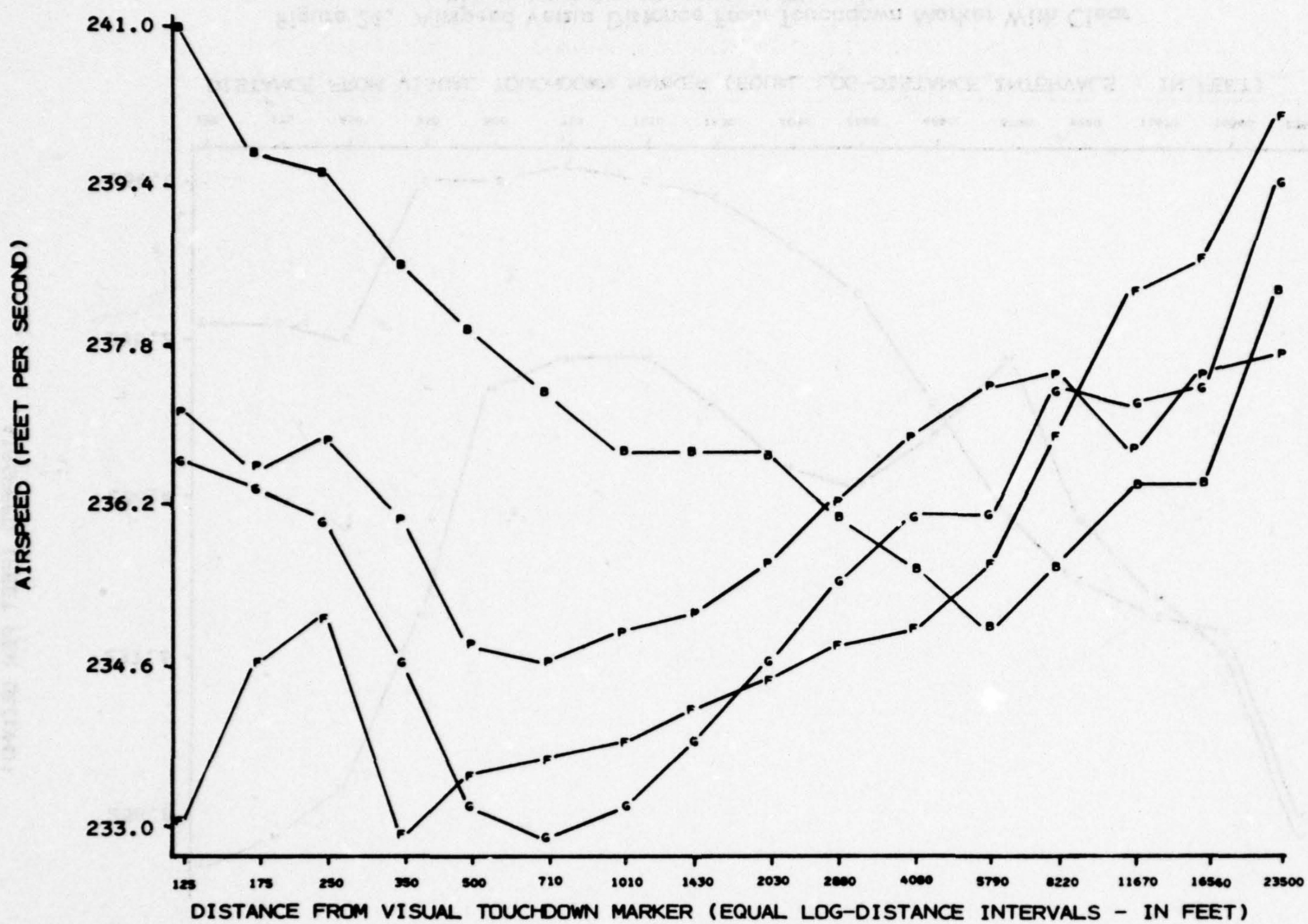


Figure 25. Airspeed Versus Distance From Touchdown Marker With Four Windscreen Quality Conditions (Phase I)

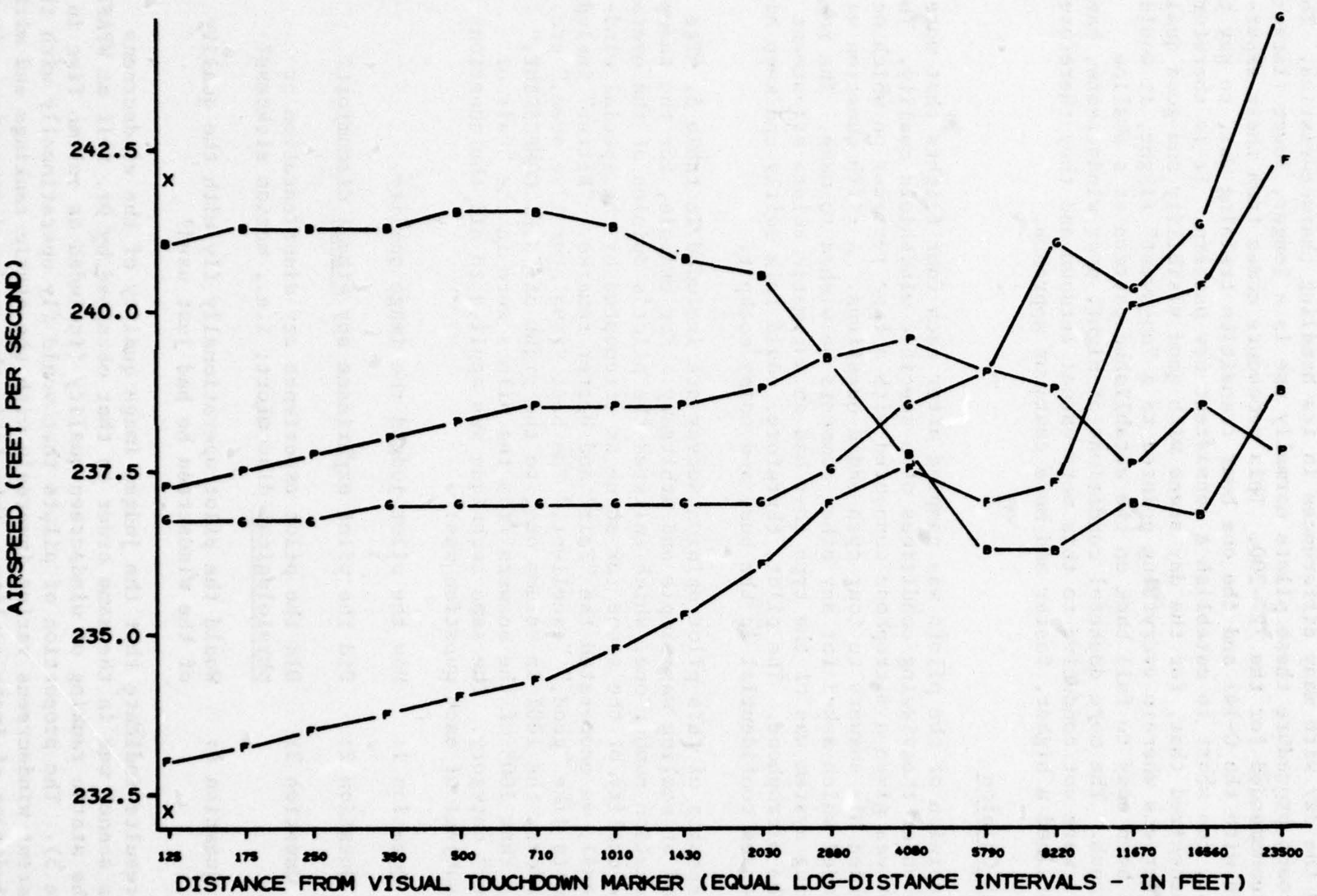


Figure 26. Airspeed Versus Distance From Touchdown Marker With Four Windscreen Quality Conditions for Completed Runs Only (Phase I)

It can only be conjectured as to the cause, but as these pilots were very skillful and experienced, the explanation may be in that the transition training was far from complete. The eight Air Force pilots were all C-141 rated, qualified and experienced. This is a much larger airplane than the 727 with many differences in its handling characteristics. The approach procedure these pilots normally use is a longer, lower flare than is recommended for the 727-200. This procedure comes from their experience with the C-141 and the one hour transition training was, to say the least, too short to establish a consistent new pattern. It is therefore hypothesized that, for the day scene with good visibility and good quality windscreens wherein everything pointed to a "no-sweat" flight, it would have been easy to fall back on the established pattern of a shallow approach. The more doubtful conditions of night, poor windscreens, haze, etc., were not conducive to this more casual letdown and they therefore maintained a higher, faster and more cautious approach.

Pilot Opinion

The opinion of the pilots was sampled after each four flights that were made under the viewing conditions of a specific windshield quality. The pilot was given a microphone connected with a tape recorder on which he recorded his answers to four open-ended questions. A fifth question was included which asked for any other comments he wished to make. The recording system was of the type that had an automatic volume adjustment on the microphone. The pilot, therefore, could talk softly and keep his responses confidential in the busy and noisy cockpit.

The results of this pilot opinion survey are included in table 5. The method of scaling was simple and arbitrary. For example, for the answers to question number one, which enlisted the pilot's opinion of the overall image quality of the scene (or scene as attenuated by the special windscreens), we enumerated the "Fair" and better remarks. "Better" included comments like "good," "excellent," The best visualator I've seen," etc. Therefore, the 100% in column one, to the right of "G.E. COMPUSCENE," means that 100% of the answers from the pilots were in the "fair or better" category. The same technique was applied to all the questions. The subject of each question was:

Question 1: How the pilot judged the image quality.

Question 2: Did the pilot experience any visual discomfort?

Question 3: Did the pilot experience any disorientation or physiological discomfort; i.e., motion sickness?

Question 4: Would the pilot operationally fly with the quality of the windscreen he had just used?

The results indicate that the judged image quality of the windscreens (plus scene) was in the same order as that obtained by Dr. Self at WPAFB in the static ranking of windscreen quality (included as column five in table 5). The proportion of pilots that would fly operationally with the different windscreens varies inversely with the static rankings and with the judgment of image quality. This is in the expected direction, since as image quality decreases, the number of pilots who believe they could tolerate the windscreen in operational situations also decreases.

TABLE 5

PILOT OPINIONS AFTER FLIGHTS

	Image Quality Better Than "Fair"	No Discomfort Comments	No Dis-Orientation or Motion Sickness	Would Fly With Windscreen	Ranking* of Windscreen	Variance of of Ranking
G. E. Compuscene	100 %	100 %	100 %	100 %	-	-
X-1 "Fair"	62.5 %	75 %	87.5 %	75 %	2.5	2.2
X-9 "Poor"	50 %	75 %	87.5 %	62.5%	5.7	3.3
X-3 "Bad"	12.5 %	12.5 %	100 %	37.5%	7.7	0.3

*Rank of 1.0 = Best 11.0 = Poorest Static Ranking of Distortion of Grid Pattern

Windscreen X-3, that judged to be of the poorest quality in the static rankings, imposed visual discomfort on 7 out of 8 pilots. However this windscreen did not impose any disorientation of motion sickness on the pilots. The X-9 and X-1 windscreens did receive comments on disorientation or motion sickness from one pilot.

In summary, pilot opinion follows the order of the static ranking by visual observation of the cross-hatched test pattern by the 20 observers from WPAFB, by image quality and by the proportion who would not fly with the windscreens. The poorest engendered a significant number of visual discomfort comments.

SELECTION OF EXPERIMENTAL DESIGN

The results of the data analyses of the Phase I study were used to help define the independent variables, and their levels, which would be used in Phase II. The objective of this phase was to select an experimental design which would best demonstrate the effects of the distorted windscreens on approach and landing performance. For many of the dependent variables, performance with the "Fair" quality windscreen was as good or better than with the "Good" (no windscreen) condition. Improved performance with the "Fair" windscreen was quite likely due to increased effort on the part of the pilots, combined with a low level of distortion that may have affected only a small portion of the visual scene utilized in the approach. An increased effort or concentration by the pilots under the distorted windscreen conditions was difficult to prevent since the windscreens were located (and exchanged) in plain view of the pilots. In retrospect, it would perhaps have been desirable to have had a "placebo" window (plain glass with no distortion) constructed to the same dimensions as the distorted windscreens.

The difference in concentration or effort by the pilots, if actual, would make the estimates of differential windscreen quality effects on performance more conservative. The "Poor" and "Bad" windscreens provided little in the performance data to choose between. On several dependent measures (touchdown point, glide slope deviation, elapsed time, and altitude, for example) their effects were nearly identical. The ranking study of image quality done by AMRL provided the only objective measure on which to choose between these two windscreens as to a "worst" condition. Photographs through these windscreens did show, however, that the distortions ran through opposing diagonals in these two windscreens. In view of this, and since the "Fair" windscreen gave results similar to the "Good" condition, the "Poor" and "Bad" windscreens, along with the "Good" condition, were chosen for inclusion in Phase II. As with the "Poor" and "Bad" windscreens, the two levels of visibility, "clear" and "hazy," did not show differential effects on many of the dependent variables. While there were some interesting trends, it was thought that the increased sensitivity in Phase II could be acquired by deleting visibility as an independent variable and adding replications to the design, thus providing a direct test of pilot differences.

Only six of the eight pilots from Phase I were available for the Phase II study. This had an undesirable effect of reducing the degrees of freedom for the error terms in tests of significance for the main effects. However, this effect was partially offset by the increase in replications to a total of four. This resulted in the basic experimental design shown in figure 27.

Compatibility With Flight Test Conditions

In a concurrent phase of the overall AF Windscreen Program, a flight test was initiated by AMRL and support personnel to evaluate three windscreens similar in quality to those used in this study. In discussions with AMRL, it was agreed that greater benefits would accrue to the program if the

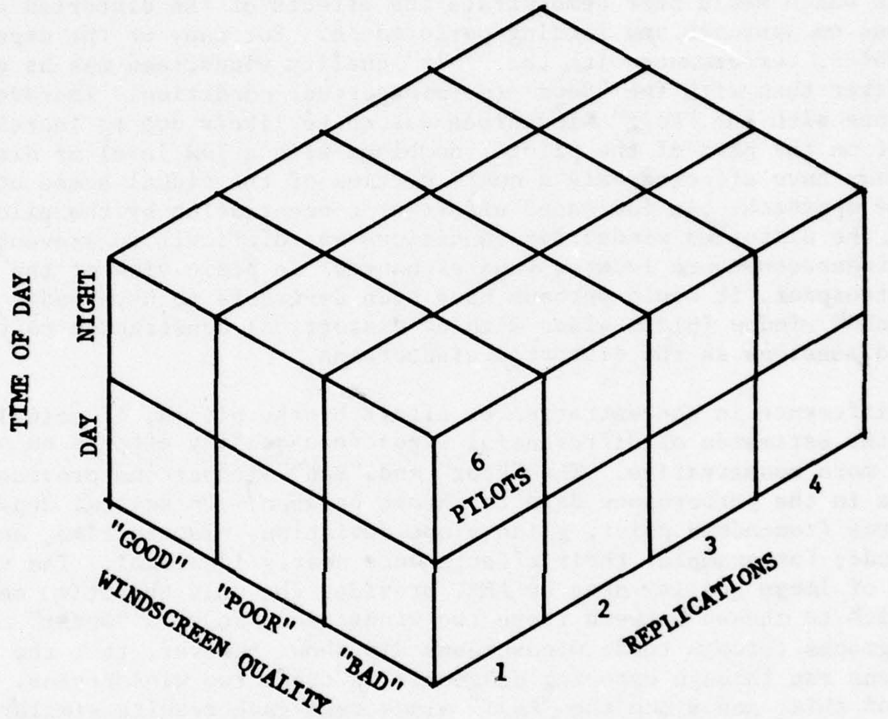


Figure 27. Experimental Design for Phase II

simulator study replicated, as much as practicable, the conditions of the flight test. Although there were already many common characteristics between the two studies, two additional modifications were made to Phase I conditions to correspond to the flight test: (1) The approach start point was brought in from 4.7 miles out to 2.0 miles; (2) Each approach was started with an offset from the localizer (runway centerline), two of the replicates starting from 2° (420 feet) left, and two from 2° right of the centerline. Starting altitude above runway was 525 feet. The appearance of the Moses Lake runway from each offset starting point, four distances and two weather conditions are shown in figure 28a and b.

With these initial offsets, it was felt that the first part of the approach would consist of a major correction of the offset and would be too variable to assess effects of the other independent variables. Therefore, data sampling was begun at 4080 feet (middle marker) from the visual touchdown point and included 11 equal log-distance steps in to 125 feet.

Selection of Dependent Variables for Phase II

For Phase I, the values of eight dependent variables were printed out on the line printer. These included:

1. Time from start of approach
2. Distance out from glide slope shack
3. Deviation from centerline of runway
4. Altitude above runway, taken halfway between main gear assemblies
5. Descent rate
6. Airspeed
7. Pitch angle in degrees
8. Gear loading on the main gear assembly

Gear loading was selected to provide two types of information: (1) initial gear loading would be a positive indication of touchdown; and (2) the degree of gear loading (force over time) would provide a second indication, in addition to descent rate, of the "hardness" of the touchdown. However, this variable was not utilized for either of these functions as it was found that: (a) the loading was being taken off the left gear only, thus not providing positive touchdown information for right-gear first landings; (b) for the same situations, the degree of gear loading was not a valid indicator, since right gear loading was not included.

In addition to these dependent variables, it had been planned to output two others (wind velocity and glide slope deviation), but problems with the internal computation of the latter produced spurious results, so it was not included. It was decided not to include wind as a variable, obviating the requirement for its printout. In the computer interpolation program, the values for glide slope deviation were calculated from altitude and distance.

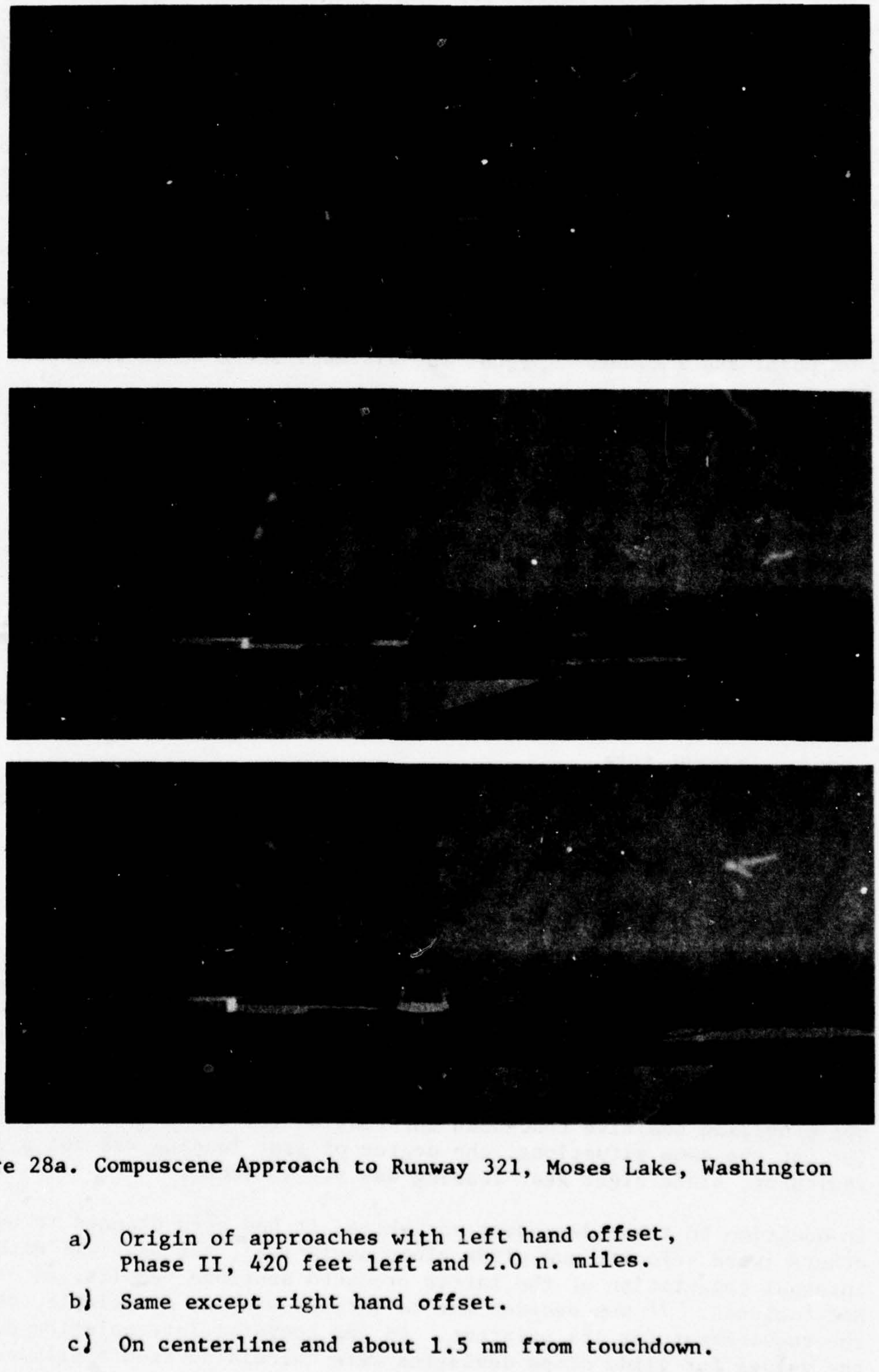


Figure 28a. Compuscene Approach to Runway 321, Moses Lake, Washington

a) Origin of approaches with left hand offset, Phase II, 420 feet left and 2.0 n. miles.

b) Same except right hand offset.

c) On centerline and about 1.5 nm from touchdown.

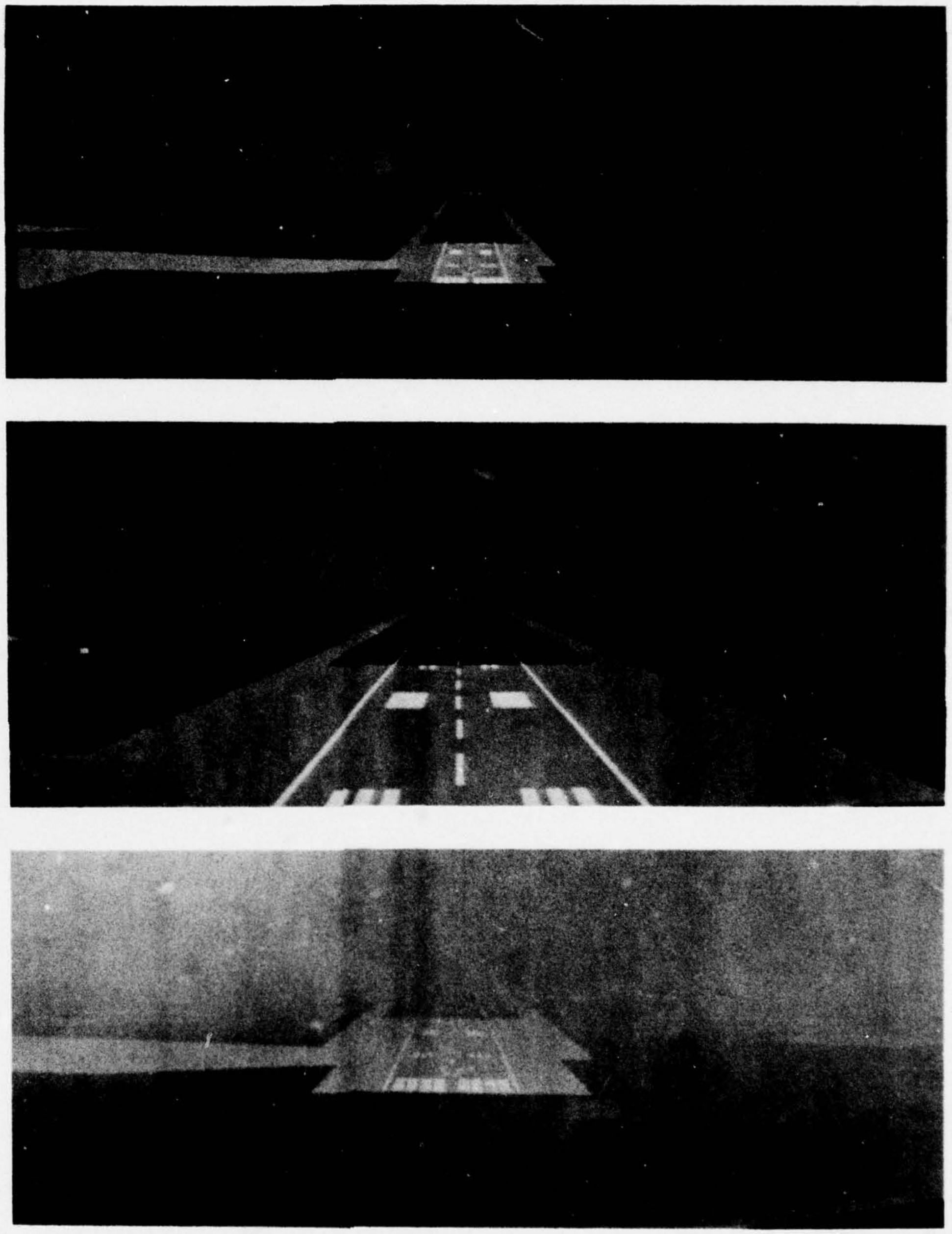


Figure 28b. Compuscene Approach to Runway 321, Moses Lake, Washington

d) About the middle marker.

e) At threshold.

f) Weather conditions used in Phase II experiment.

Since the line printer could output ten variables at the .8 second rate, this opened up three channels for the output of additional dependent variables. Therefore, the following variables were added to the printout for Phase II: (1) roll in degrees; (2) and (3) throttle settings. Both left and right throttle settings were read and these were later converted to: (a) "AT" = Average throttle setting, and (b) "TD" = Difference between throttle settings.

In addition to these ten dependent variables, the instructor pilot rated, on a 7-point scale, each approach/landing, with a rating of "1" given for top performance. These general performance ratings were made after each run, with the rating philosophy left up to the instructor pilot.

RESULTS - PHASE II

DATA ANALYSIS

The same data analysis procedures were employed for the Phase II results as were used for Phase I, with one noteworthy addition. It was found in Phase I that the interpretation of the approach data was made more difficult by the progressive reduction in "N" during the latter half of the approach due to early touchdowns. Often these would be biased toward (due to differential effects of) one or more of the independent variables. In addition, the four consecutive readouts of descent rate and pitch data were insufficient to show a reasonable clear picture of "flare." Therefore, in transcribing the data from Phase II printouts, sufficient readouts were recorded to provide data at equal log-distances (the same intervals as for the approach data) from the actual touchdown point. It was felt this could give a better representation of flare and would have the advantage of complete data at each internal point. The following analyses were completed on the Phase II data.

(A) Touchdown Data

1. Order Effects ANOVAs (2 sets)
2. Main Effects ANOVAs (2 sets)
3. Correlation Matrix
4. ANOVAs with Transformations of the dependent variables

(B) Approach Data

1. Main Effect ANOVAs - At distances from visual touchdown point of 125, 250, 500, 1010, 2030, and 4080 feet.
2. Means and standard deviations

(C) Flare Data

1. Main Effect ANOVAs - At distances from actual touchdown point of 125, 250, 500, 1010, 2030, and 4080 feet.
2. Means and standard deviations

ANALYSIS OF TOUCHDOWN DATA

The touchdown data of Phase II were analyzed for the following 11 dependent variables:

1. Instructor Pilot Rating of Approach/Landing Performance
2. Touchdown Distance From Visual I.D. Marker
3. Deviation from Centerline

4. Glide Slope Deviation

5. Descent Rate

6. Airspeed

7. Average Throttle Setting

8. Throttle Setting Difference

9. Pitch Angle

10. Roll Angle

11. Elapsed Time to Touchdown

Each of these dependent variables were analyzed initially with two different ANOVA configurations, one with the initial centerline offset for the beginning of each run included as an independent variable, and one without this distinction. The independent variable designs for these two ANOVAs were:

1. Windscreen (3) x Time-of-day (2) x Pilots (6)
   x Replications (W,T,P) (4)

2. Windscreen (3) x Time-of-day (2) x Pilots (6)
   x Offset (2) x Replications (Within) (2)

The tests for pilot differences (using the highest order interaction) consistently showed significant differences in the preformance of the six pilots on all dependent measures and for both ANOVA designs. Out of the 22 tests, only three showed non-significance, "roll angle" for both designs, and "descent rate" for T.D. ANOVA #1.

One statistically significant interaction involving offset occurred. It was the second-order interaction effect between windscreen quality, time-of-day and offset, as measured by aircraft roll angle. This does not seem to be a very obvious relationship at touchdown. These were the only differential effects between the two ANOVA designs.

The touchdown ANOVAs indicated that the main effect for the windscreen quality variable included no significant shifts in any of the dependent measures. However, the dependent measure of "distance from the visual touchdown reference point" duplicated a trend found in Phase I. The "Good" (clear) windscreen resulted in a mean touchdown distance of 79 feet in front of the visual touchdown mark. The extremely distorted windscreen called the "Bad" window (X3), gave a mean touchdown 41 feet beyond the visual reference point. The "Poor" windscreen resulted in a mean touchdown point 100 feet beyond the visual touchdown point. The differences among these means are not statistically significant, but the common trend with the Phase I data was that the two poorer quality windscreens are associated with touchdowns further down the runway.

The rate of descent at touchdown appears to be of quite practical significance, but it does not reach the point of being statistically significant at the .05 level. The day scene resulted in a descent rate of -6.5 feet per second and in the average night descent this increased to -9.4 feet per second.

Airspeed as Modulated by Windscreen x Time-of-Day Interaction

Airspeed was common for night and day approaches with the "Good" windscreen with the averages differing by only 0.5 ft. per second. Interactions occurred for the "Poor" and "Bad" windscreens with time-of-day, but are opposite in direction for the two windscreens. The pilots flew with higher airspeed during the day with the "Bad" windscreen (237 ft. per sec.) intermediate for the "Good" windscreen (236.0 ft. per sec.) and slower with the "Poor" windscreen (234.2 ft. per sec.). The relative airspeeds were reversed for the night approaches for the "Poor" and "Bad" windscreens. In a side-by-side comparison:

Day	Night
"Bad" Windscreen 237.0	"Poor" Windscreen 237.9
"Good" 236.0	"Good" 235.5
"Poor" 234.2	"Bad" 234.0

These data are consistent with the hypothesis that with visible distortions of the visual scenes, the pilots fly more cautiously. When the visual scene is made up of point sources, the same optical attenuation is less apparent, and the caution of higher airspeed is not observed. The "Poor" windscreen distorted the whole scene less but changed the shape and clearness of the runway in the central portion of the visual field. Therefore during the day approaches this optical attenuator appeared to distort the whole image less than did the "Bad" windscreen. However the "Poor" windscreen's central distortion was more evident for the night approaches, as the dominant information source was the runway, and this was in the central area of the windscreen. The "Poor" windscreen has a symmetrical distortion that, when viewed binocularly, gives the impression of a slightly crowned runway for the night scene, but a large area distortion for the day scene. These observations on the interaction of these two windscreens with the day scene are supported by the pilots' rating of the windscreens in direct proportion to the scaled image quality judgments conducted at WPAFB. See table 5, columns 4 vs. 5. The hypothesis is further supported by other dependent measures that are associated with cautious flight procedures being utilized when the visual information is limited in quantity or reliability.

Correlations Among Touchdown Data

A correlation matrix provided some insight about the relationships among touchdown data for all of the dependent measures including the ratings by the instructor pilot. These correlations are shown in the matrix in table 6. The values that are above .165 are significant at the .05 level and only these are included in the table. In this matrix, the only correlation which does not seem to have some logical relationship is that of "right wing down" being associated with a more rapid descent at touchdown (-.17).

The correlation (-.17) of trials with instructor pilot ratings probably reflects a "learning curve" effect over trials. The correlations of the ratings with deviation from centerline (+.18) and descent rate (-.24) reflect the emphasis the instructor pilot gave these variables in making his ratings.

The correlation of +1.00 between glide slope deviation and touchdown distance is primarily a check on the correlation program and data entry since these two variables (at touchdown) are, by definition, perfect correlates.

The relationship of elapsed time with touchdown distance (also G.S.D.) (+.93) was to be expected, as longer approaches naturally took more time. The correlations of elapsed time with average throttle setting (-.28) and with pitch (-.33) are probably reflective of attempts of the pilots to "get it down" more quickly for the long, high approaches as compared with those who are "on glide slope" during the altter part of the approach. Conversely, when the pilot finds himself low and short, his correction would likely involve increased pitch and throttles. This hypothesis would also explain the correlations of touchdown distance (and G.S.D.) with airspeed, average throttle settings, and pitch angle. The intercorrelations of these latter three variables are also consistent with this hypothesis with the exception of airspeed with average throttle setting (+.32). For these two variables, the natural positive relationship between throttle setting and airspeed has more than compensated for the more restrictive touchdown actions hypothesized above.

Since deviation from centerline was recorded with left deviations as negative values and right as positive, the correlation with roll angle (-.42), which was positive for right-wing down, is in the expected direction.

The correlation of time-of-day with descent rate (-.40) may be considered also a reflection of the "landing long" hypothesis, as differentiated by the two different scenes. Typically the night approaches were flown high and long, with the expected result that the long landings would be associated with "harder" touchdowns (again, the "get it down" hypothesis). Elapsed time also correlated positively with time-of-day (+.16), but did not quite reach statistical significance at the .05 level.

TABLE 6

CORRELATIONS AMONG INDEPENDENT AND DEPENDENT VARIABLES PHASE II STUDY TOUCHDOWN DATA

		1 Trial	2 Time of Day	3 Offset	4 W/S	5 Rating	6 XR	7 YR	8 GSD	9 Z·	10 VT	11 AT	12 Pitch	13 Roll	14 Time
INDEPENDENT	1-Trial	1				-.17									
	2-Time-ofDay		1							-.40					
	3-Offset			1											
	4-W/S				1										
DEPENDENT	5-Rating					1		+.18		-.24					
	6-XR						1		1.00		+.24	-.25	-.14		+.93
	7-YR							1						-.41	
	8-GSD								1		+.24	-.25	-.41		+.93
	9-Z·									1				-.17	
	10-VT										1	.32	-.24		
	11-AT											1	+.57		-.28
	12-Pitch												1		-.33
	13-Roll													1	
	14-Time														1

Test of significance for "r" using the distribution of "t": $t = r\sqrt{\frac{N-2}{1-r^2}}$

for an "r" of .165 and with 142 df, t = 1.99. At the 5 percent level a "t" of 1.98 is required.

RESULTS OF APPROACH DATA ANALYSES

Windscreens as a Main Effect

It may not be surprising that the touchdown data do not reflect the same number of significant effects as those of Phase I. The Phase II approaches were shorter by 2.7 miles and the total elapsed time was approximately 50 seconds of flight. The independent analyses at 125, 250, 500, 1010, 2030 and 4080 feet from the visual touchdown reference do indicate that the windscreen quality variable had a significant effect on deviations to the left and right of the runway centerline just before touchdown. The "Good" and "Poor" windscreens, at both the 2030 and 1010 ft. distances, produced a slight "to the right of centerline" approach, the magnitude of which is almost equal at the smaller distance. However, the "Bad" windscreen produced a 36.5 ft. offset to the left at 2030 ft. which decreased to 24.5 ft. to the left at threshold. This average offset was not significant for the windscreen quality variable at 125 ft. from touchdown. However, there was a significant interaction between windscreen quality and time-of-day at this short distance. For the day scene, the "Bad" windscreen had a 2 ft. offset to the left as compared with 5 ft. for the night scene. Each of the other two windscreens also had greater offset for the day scene than for the night. The explanation for this may lie in the highly visible centerline in the night scene, with little influence from the distortions of the visual surround of the runway. In the day scene however, the structure of the runway and the fields adjacent to the runway may exert some deviating influence, as they are modified by the inexact optics of the "Poor" and "Bad" windscreens (table 7).

The windscreens had two other main effects of significance. (1) For the analysis at 4080 feet, the greatest rate of descent occurs for the "Bad" window, a value of 11.6 feet/second. At this point in the approach, approaches with this windscreen were slightly higher than those with the other two conditions. Also at this point, the day scene was producing greater descent rates (though not significant) than the night scene. (2) The second main effect was on elapsed time. At 4080 ft., the differences in the elapsed time for the three windscreen conditions were within a range of only .13 second, with the slowest approaches being made with the "Poor" windscreen and the fastest with the "Bad" windscreen. By the 250 ft. point, this spread had grown to .31 second, with the same order, and had become statistically significant.

Time of Day as a Main Effect

Time-of-day affects deviation off the centerline at two separate distances, 250 and 2030 feet, but its consistent effect for most of the distances is on altitude, glide slope deviation, rate of descent, and elapsed time. The picture is a consistent one. For the day scene, the pilots flew below the glide slope between 4080 and 500 feet, then they decreased their rate of descent, passed above the glide slope before reaching 250 feet, and generally landed long. However, for the night scene, they were right on the glide slope at 4080 and remained on it to 2030 feet. By the time they reached the threshold of the runway at 1000 feet, they were above glide slope, gradually increasing this

TABLE 7

AREAS OF STATISTICAL SIGNIFICANCE IN PHASE II APPROACH ANOVAS

	YR	HM	GSD	ZD	VT	AT	TD	PD	ROLL	ELAPS TIME
WNDSCRN	1010 2030			4080						250
TIM	250 2030	125 250 500 1010 2030 4080	125 250 500 1010 2030 4080	125 500 1010	4080			4080		250 500 1010 2030 4080
OFF		250	250						4080	125 500
PIL	125 250 500 1010 2030 4080	500 1010 2030 4080	500 1010 2030 4080	500 1010 2030	125 250 500 1010 2030 4080	125 250 500 1010 2030 4080	500 1010 2030 4080	125 250 500 1010 2030 4080	250 500 1010	125 250 500 1010 2030 4080
WNDxTIM				125	125 250 500 1010 2030	4080		500		125 250
WNDxOFF									250	
TIMxOFF				500			1010 2030	1010	125 250	500
WNDxTIM xOFF	2030			4080		500				500 1010 2030

Legend on ANOVAS: 125, 250, 500, 1010, 2030 and 4080 refer to separate ANOVAS at these distances from visual touchdown reference mark.

deviation at 500 and 250 feet. They had slowed their rate of descent, thus going above, and increasing the difference from, the theoretical glide slope. The flight paths to the day and night scenes are illustrated in figure 29. The relationship of these paths to the 2.5° glide slope is also included. At the top of this figure are the averages for altitude, glide slope deviation and rate of descent. Note that the occurrence of non-significance on the rate of descent is where the flight paths nearly parallel each other in their slope.

At 4080, the elapsed time for the night scene was .3 second longer than for the day. This difference steadily increased at each of the other distances until it reached a differential of .72 second at 125 feet from the touchdown marker. These small differences in time are nevertheless significant in all of the analyses due to the small variation in this variable. Pilots also consistently took a longer time in making the night approaches. This was not entirely due to their landing further down the runway since elapsed time was already significant at 4080 feet from the visual reference point. The difference in time is only about 1.5% of the average elapsed time to touchdown and may not be of much practical significance except in its reflecting a stereotype of pilot's behavior as averaged over the three windscreens. This may also reflect a lower airspeed at night during the early part of the approach (airspeed is significant at 4080 feet).

The Interaction Between Windscreen Quality and Time-of-Day

Deviation right and left of the centerline at a distance of 125 feet, descent rate at the same distance, altitude 4080 feet, pitch at 500 feet, and elapsed time at 125 and 250 feet all measured significant variations from the interaction of windscreen quality with time-of-day. The influence of these two independent variables was consistent for the dependent measure of velocity at five distances, from 2030 feet in to 125 feet from the visual touchdown marker. The influence of the interaction is not noticeable between day and night for the "Good" window, the means being almost identical at each of these distances. The factor that makes this a significant interaction is that airspeed was consistently lower for the "Poor" windscreen day scene and the "Bad" windscreen night scene. The higher velocities were consistently found for the "Bad" windscreen day scene and the "Poor" windscreen night scene. This relationship is identical to that found (and discussed earlier) with the touchdown data.

It may be hypothesized that the type of distortion existing in the "Bad" window made the pilots more hesitant about their approaches to the day scene, and that the type of distortion in the "Poor" window made them more hesitant about their approaches to the night scene. This hypothesis assumes that pilots concerned about the approach tend to use a little higher speed, or, as the old saying goes: "A few knots for the wife and children."

Some Events at 500 Feet From Visual Touchdown Marker

Several events occurred at the 500 ft. distance and significant changes in some dependent variables appear only for this analysis. The average throttle setting was equal for day versus night with the "Good"

	125 DAY	125 NIGHT	250 DAY	250 NIGHT	500 DAY	500 NIGHT	1010 DAY	1010 NIGHT	2030 DAY	2030 NIGHT	4080 DAY	4080 NIGHT
• ALTITUDE	10.5'	21.2'	12.7	23.4	16.2	28.4	28.6	46.5	61.8	86.8	149.9	177.0
• GLIDE SLOPE DEVIATION	5.1'	15.9'	1.76	12.5	-5.6	6.6	-15.5	2.5	-26.9	-1.84	28.2	-0.3
• RATE OF DESCENT	6.7'	10.5'	(NS)		-6.8	-10.7	-7.35	-10.2	(NS)		(NS)	

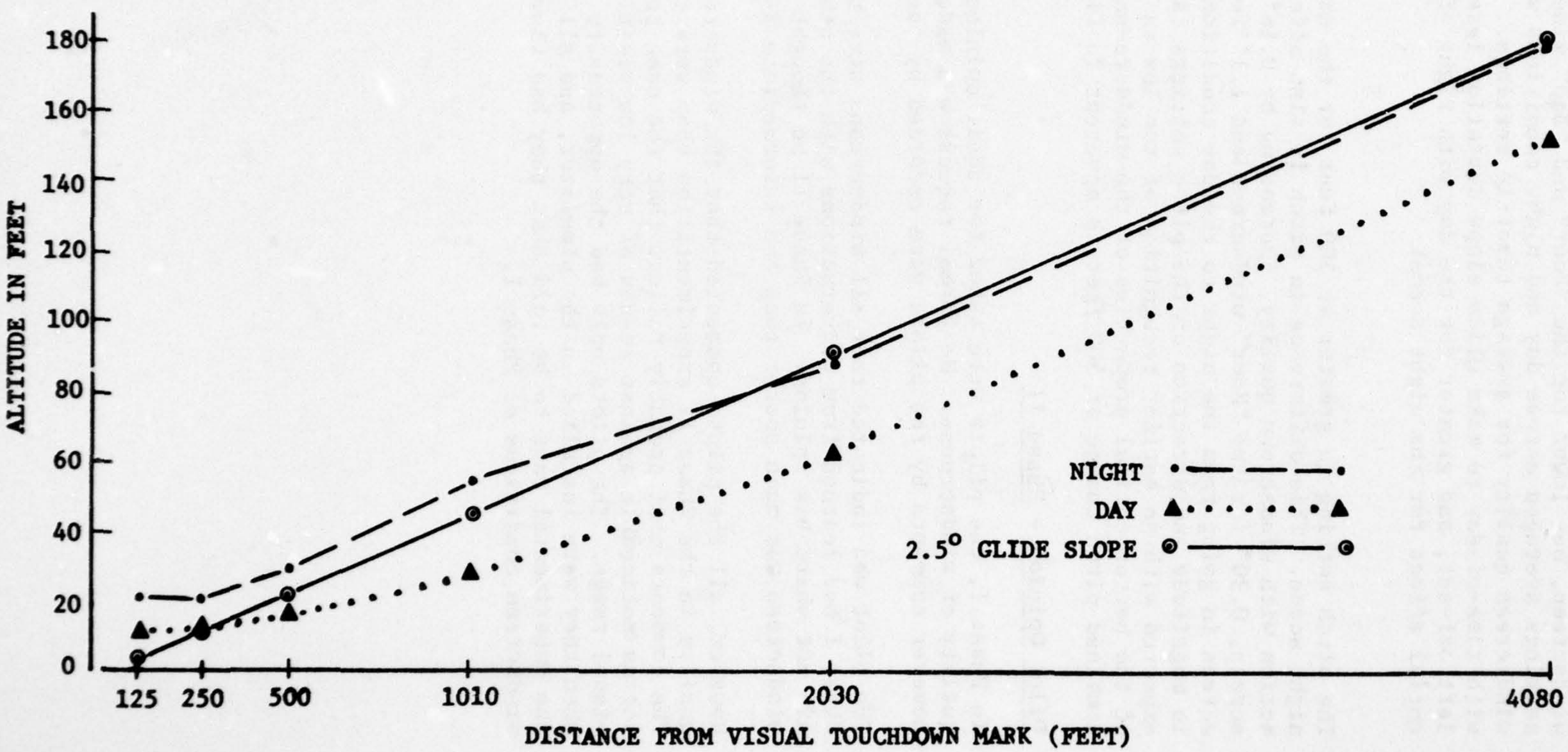


Figure 29. Effect of Windscreen on Altitude, Glide Slope Deviation and Rate of Descent, Phase II

windscreen, but lower for the "Poor" and "Bad" windows at night and the settings averaged across day and night conditions were lower for the "Bad" windscreen quality for average throttle settings. Offset also interacted with time-of-day to make glide slope deviation less for the day with the left off-set, and greater for the day with right offset, with no differential effect for the night scene.

The pitch setting is greater at 500 feet for the day scene than for the night scene. This difference in pitch is also affected by the interaction with windscreen quality, increasing by 0.16° for the "Bad" windscreen, 0.30° for the "Poor" windscreen and 1.1° for the "Good" windscreen in going from the night to the day condition. These differences in magnitude and direction of the pitch settings is what would be expected with an earlier recognition of too low an approach as a function of the better optical properties of the windscreens. The effect of the combined pitch change at 500 feet is apparent in figure 29.

Pilot Opinion - Phase II

In Phase I, the pilots were asked for their opinions about the image quality of windscreens. No formal request was made of them in Phase II, however comments by the pilots were recorded by the experimenters.

The pilot who indicated that all windscreens were relatively good in Phase I had learned from conversations with the other pilots that they did not share his opinion. In Phase II he thought that the X-3 ("Bad") windscreen was much poorer than the intermediate X-9 ("Poor") windscreen.

However, all the pilots commented that the windscreens were of better quality in the Phase II experimentation than were those of Phase I. The comments most probably reflect that the same poor image quality is not as noticeable against scenes of very low visibility and runway visual range. The pilots only had the opportunity to see the screens when they were installed in the simulator, and all were surprised after the experimental runs to be told that they had flown to three of the four windscreen conditions of Phase I.

SPECIAL PERFORMANCE TESTS

VISUAL SKILLS OF THE EIGHT PILOTS

All eight of the pilots were current in their rating as C-141 pilots and all were on active flight status. The optometric examination given them just before the Phase I data collection was for the purpose of assessing their visual state at the time of the experiment. Clarence Larry, O.D., administered the examination and refractions. The details of his examination and his comments are to be found in appendix 7.

Five of the eight pilots had exceptional vision on all skills included in the testing, and Dr. Larry commented that none of these individuals should experience any modification in pilot performance due to vision. The resolution of the best eye for each of these pilots met or exceeded the clinical norm of 20/20 Snellen, with a score of 20/15 for four of the pilots and one with a score of 20/20. The remaining three pilots <u>also</u> had 20/20 or 20/15 in their better eye. It was Dr. Larry's comments that set them apart from the other five. One was experiencing a cold and headache, slight esophoria (5 diopters), slight hyperopia (+.25 and -.50 diopters) and slight astigmatism (-.25, near 90°). A second pilot had slight uncorrected astigmatism (.37 and .12 diopter) and a tendency to suppress the left eye. Both of these individuals had a low accommodative amplitude which might have slowed their focusing time from looking at instruments (28 inches or .71 meter) to looking at the Compuscene image with its focusing distance of 40 feet or 10 meters. This change in accommodation of 0.3 diopters would also have required a longer time than that experienced by the other six pilots when focusing from the scene to the instruments.

One of the pilots had been wearing contact lenses for orthokeratological reasons (a systematic wearing of contact lenses to eliminate or decrease the need for ophthalmic correction). The optometric examination was conducted early in the morning and the gradual change in the surface of the cornea would be so slight, from not wearing these contact lenses during the day, that no change in performance should be expected. This pilot was asked not to wear his contacts until after the data collection was complete.

We mention each of these slight variations in the refractive state of these pilots to be comprehensive in this visual review. There was only a slight chance that these minor refractive differences from perfect vision would in any way alter the pilot performance with the different windscreens. We have not discovered any such relationship in our data in any reviews completed.

SPECIAL TESTS OF VISUAL STEREOSCOPIC PERFORMANCE

The Critical Limen Stereoscopic Test was conceived and developed in 1970 (Kraft and Elworth), first applied by Farrell, Anderson, Kraft and Boucek (1970), improved by Farrell, Anderson and Boucek (1975a) and evaluated by Kraft, Booth and Boucek (1972), and by Farrell, Anderson and Boucek (1975a). The test has proved to be reliable (.87), correlated with the better stereoscopic tests on the market (Keystone, D.C. series r=.66, and Verhoeff, r=.45) and sensitive, without as yet a critical validity study.

The test was designed to measure the ability of an individual to perceive depth in a stereo photograph in the presence of two confusion cues - size and brightness. The test consists of a set of eight stereoscopic pairs of photographs which were taken on a matrix of discs that varied in size, brightness and height. The test was administered in the American Optical Wottring Troposcope, producing disc disparities of 6, 13, 29 and 63 arc seconds. The stereoscopic skill of all eight of the pilots was found to be less than 13 arc seconds, averaging 9.4 arc seconds. This compares very favorably with the 32 arc second standard that the School of Aviation Medicine has for acceptance into pilot training.

The Critical Limen Stereoscopic Test may also be scored on the number of correct responses out of the 64 possible. This scoring method was used in establishing norms for the CLST-36 achromatic test using 96 college students (Farrell, Anderson and Boucek, 1975b). Figure 30 represents this data as a cumulative percent curve, along with the relative position of the eight pilots from this investigation. Table 8 gives the percentile associated with each pilot's score.

The threshold values indicate a very high skill in stereoscopic discrimination which was achieved by pilots 8, 2 and 7 at slower pace and some hesitancy. They could, within the allowable 70 seconds per pair, achieve thresholds of 13 arc seconds or less. The percentile score indicates that a similar <u>total</u> score is achieved by 28 percent of the college population.

MAGNIFICATION OR "LENSING" AND STEREOSCOPIC PERFORMANCE

Magnification errors in windscreens may result in differently sized images presented to the left and right eye of the pilot. Such a condition is reported by pilots as causing headaches or eye strain. It was desired to find out whether differential magnification would alter visual stereoscopic performance. A set of the Critical Limen Stereo Test was made with incremental size differences between the right and left members of the paired stimuli. Two stereoscopic pairs at each of four levels of size differences were made. Pairs A and B were printed so that there was zero difference between the two images, C and D had 1.72 percent increase of one image over the other, pairs G and H had 3.57 percent and E and F had 7.6 percent.

For each of the four groups of pairs, the threshold was calculated as a function of the mean size increase. The results indicated that, for this group of six pilots, the average threshold with equal-sized images was 8.2 arc seconds, while a 1.72 percent difference in size increased the threshold to 11.9 arc sec. For the 3.57 percent size difference, the threshold was 10.6 arc seconds. The 7.67 percent size change raised the threshold to 29.8 arc seconds. This 3.6 times increase in threshold by a magnification difference between the two eyes of 7.67 percent raises the threshold to almost the USAF pilot acceptance threshold of 32 arc seconds. If windscreen standards allowed a 8.0 percent difference in magnification between any horizontally separated (2.0 to 2.5 inches)

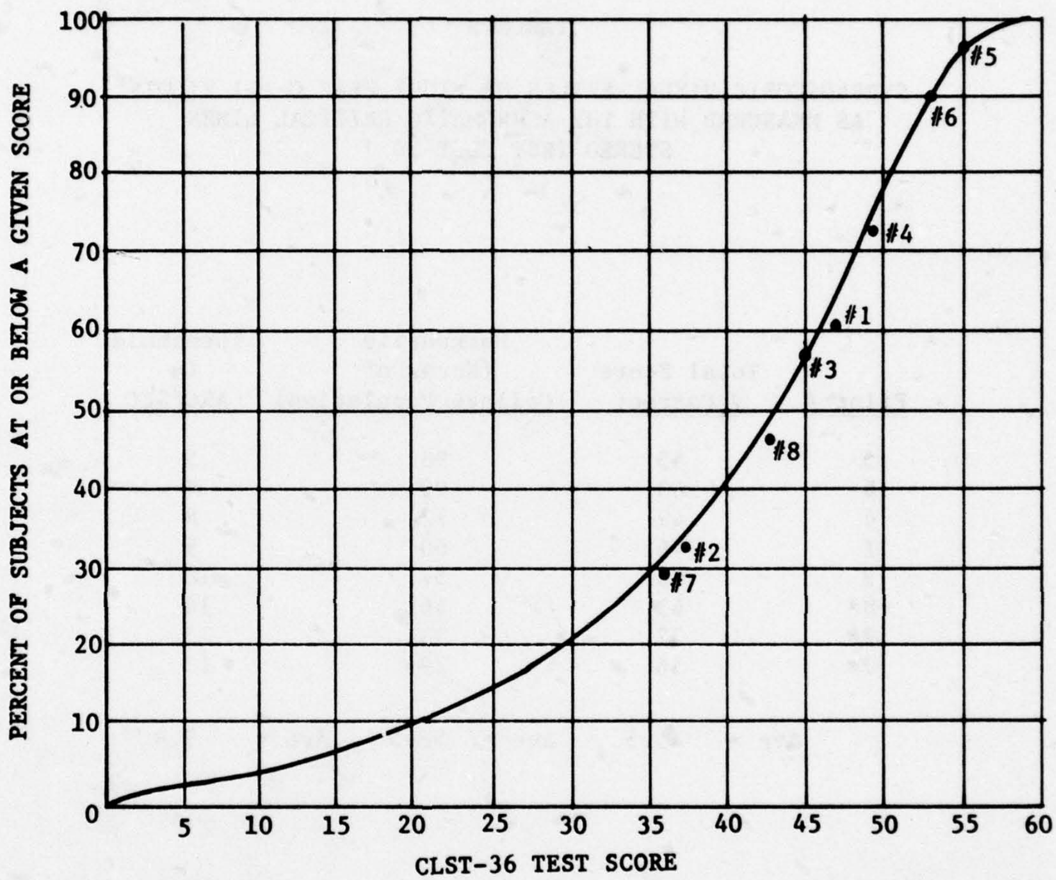


Figure 30. Comparative Stereoscopic Skill of Eight C-141 Pilots Compared With the Cumulative Percent of Subjects At Or Below a Given Score for the CLST-36 Test (N=96 College Students; Second or Third Trial)

TABLE 8

STEREOSCOPIC VISUAL SKILLS OF EIGHT USAF C-141 PILOTS
AS MEASURED WITH THE ACHROMATIC CRITICAL LIMEN
STEREO TEST CLST-36

Pilot #	Total Score # Correct	Percentile (Norms of College Population)	Threshold in ARC/SEC
5	55	96	5
6	53	90	7
4	49	72	8
1	46	60	9
3	45	57	10
8*	43	46	10
2*	37	33	13
7*	36	29	13
	Ave = 45.5	Ave = 58.5	Ave = 9.4

*During testing pilots commented that they had previous difficulty with some stereoscopic test while in USAF.

areas of the windscreen, a differential magnification between the pilot's right and left eyes would occur. This magnification difference should impose stereoscopic performance changes equivalent to that found in this study in raising the stereoscopic threshold (figure 31).

Another way of assessing the effect of this magnification is to convert these results into percentiles. The pilots performed on the zero size difference at the equivalent of the 94th percentile (equal to or better than 94 percent of the young college population). With the 1.72% change in image size, the percentile drops to the 57th. With the 3.57% change in size, the percentile continues to drop to the 53rd. The 7.6 percent size change indicates that the same pilots could not discriminate relative displaced images as having depth any better than the lower 5th of the college population (20th percentile).

Further data is required to establish the cutoff point in magnification errors that are acceptable in windscreens. Until such standards are established, the cautious procedure would be to use the 2% level. This small difference in size is still equivalent to a 37 percentile change in stereoscopic visual skill. In addition, the frequency of complaints about headaches and eye strain should be less frequent.

PERCEPTION OF THE FRONTAL PARALLEL PLANE AND APPROACH PERFORMANCE

Wulfeck, Queen and Kitz (1974), from their study of the effect of lighted deck shape on night carrier landings, saw support for their two-part hypothesis:

1. Non-pilots who bring to the experimental situation 18 to 23 years of "experience with the ground plane, refined by their educations and select perceptual abilities, seem to perform extraordinarily well when compared to subjects in other experiments."

2. "Absolute judgment of the horizontal in the frontal plane appears to be much more accurate than absolute judgment of the vertical in the frontal plane."

Wulfeck, et. al., data conform very closely with earlier data of Kraft and Elworth (1968), indicating that changes in the apparent slope of the ground plane are associated with higher and lower altitudes being generated during night approaches.

A test for determining whether an individual saw the forward vertical plane as perpendicular to his line of site was developed (Anderson and Kraft, 1977) for the USAF on a prior contract. This test, administered in a translighted stereoscope, uses cyclorotation of the images to tilt the forward plane. The system was not adaptable to generating a horizontal projection in the forward scene such as Wulfeck et al. report of the superior judgmental skill among their observers. We settled for attempting to predict how pilots might fly an approach if we could measure his perceptual error in judging verticality of the forward parallel plane. The hypothesis was that if this perception was related to approach and landing performance, we could measure the differences as the optical

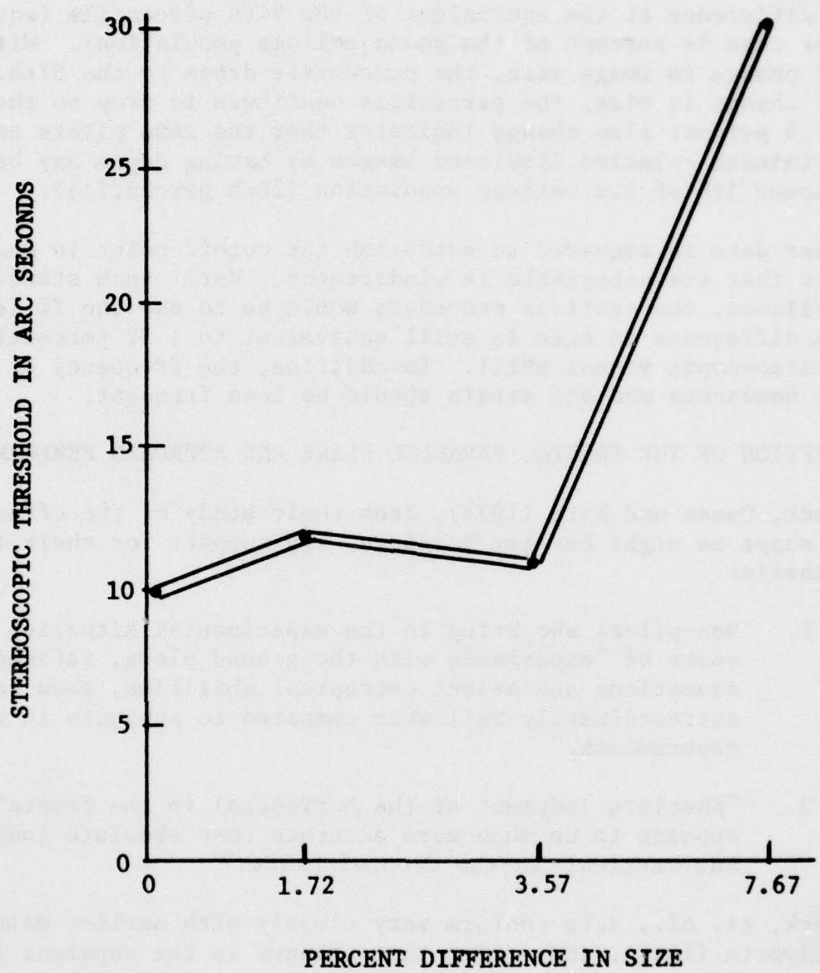


Figure 31. Effect of Different Retinal Image Sizes on Stereoscopic Performance of Six Air Force Pilots

attenuators interfered with perception of the ground plane. The results were as hypothesized:

1. The eight pilots differed as to how much cyclorotation was necessary to make the frontal parallel plane appear vertical. The proportional amount of cyclorotation correction is related to the height these pilots flew with the "Good" windscreen at 8220' from the touchdown mark. The relationship is smaller at nearer and greater distances. At 8220 ft. distance, the correlation is -.46 while at 16,560 ft. the r=-.39. The correlation would probably be highest at those distances where movement parallax does not contribute the runway details are sufficient to judge the ground plane projection. The 8220 ft. distance approximates these visual conditions in the Compuscene depiction of the Moses Lake approach to runway 321 (table 9 and figure 32).

TABLE 9

CORRELATIONS AND REGRESSIONS BETWEEN PILOTS' PERCEPTION OF VERTICALNESS IN THE FRONTAL PARALLEL PLANE AND HEIGHT OF APPROACH AT A DISTANCE OF 8220 FEET, AND AS ATTENUATED BY WINDSCREEN QUALITY

WINDSCREENS	Correlation	Regression Equation
"Good"	-.46	Y=.30X-406.4
"Fair"	-.16	Y=-.16X-399.3
"Poor"	-.25	Y=-.29X-387.4
"Bad"	-.37	Y=-.49X-418.9

2. The windscreen quality attenuations decreased the correlation, but not in direct proportion to their scaled quality. The negative sign of these correlations is only a product of how the authors ordered the cyclorotation values, greatest negative (top back) value to the greatest plus (top forward) value. Perception of the frontal plane with the top forward is associated with flying lower at 8220 feet from touchdown.

   These data suggest a relationship that should be explored further. The size of the correlation (.46) for the "Good" windscreen and the limited number of pilots (8) studied in this investigation both invite caution in drawing any conclusions. Support for this relationship is gained from three quarters.

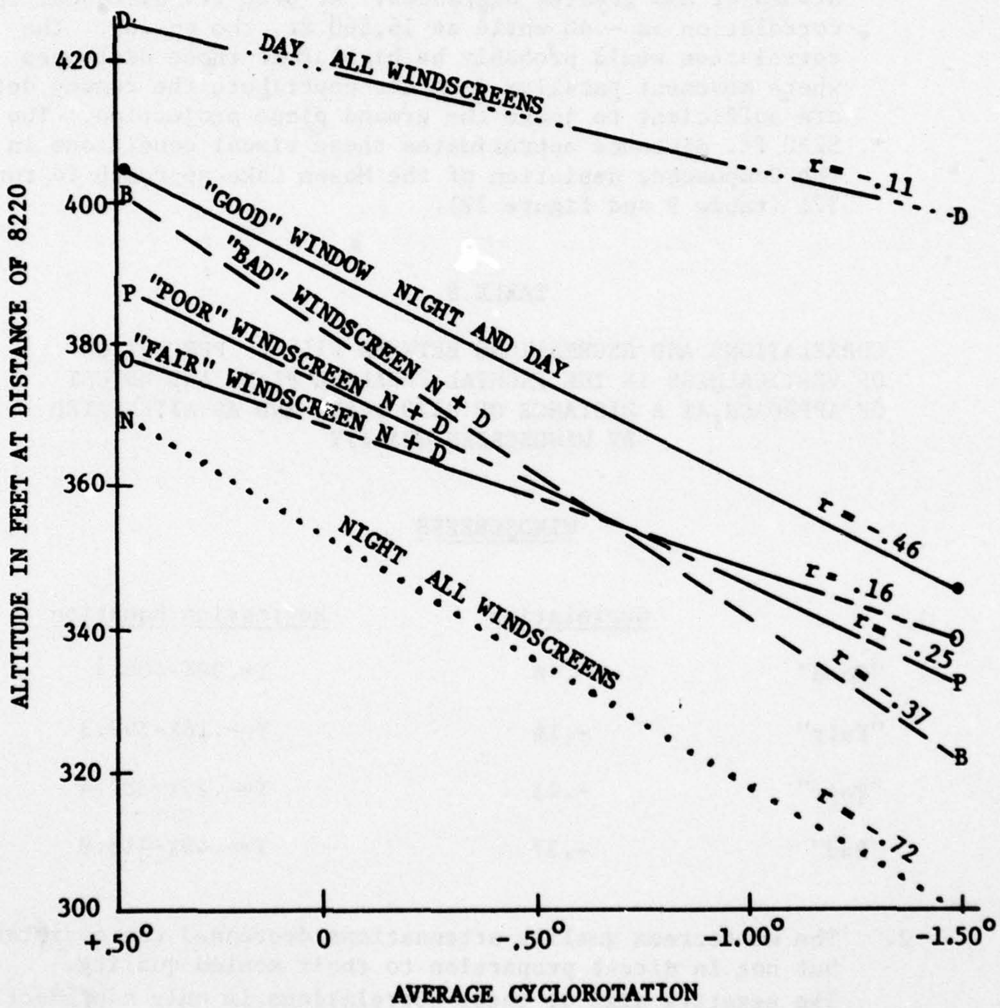


Figure 32. Prediction of Altitude at 8220' Distance From Pilot's Perception of Verticality in the Frontal Parallel Plane

(1) The correlations above are based on combined day and night letdowns. In our current analysis we can separate night and day effects but not time-of-day x windscreens x pilots as to the mean altitude at 8220 feet from touchdown. Looking at night approaches only, for all windscreens at this distance, the correlation rises to -.72. Prediction for the day scene only with all windscreen approaches, decreases to r-.11. The relationship for perception of the vertical in the frontal parallel plane and altitude at 8220 feet should be higher for night with the "Good" windscreen, and should be attenuated more with poorer image quality. (2) The direction of the perceived tipping of the frontal parallel plane is common with that of upward sloping terrain and both have mutual effect on night visual approaches. If the top of the frontal parallel plane is perceived nearer the pilot, and he required, in the troposcope, clockwise rotation of the right eye image and counterclockwise rotation of the left eye image to correct for his perception, he will fly lower. This is equivalent to his seeing the ground plane with the more distant objects on higher ground. The upward sloping terrain has been found to be associated with flying lower over darkness at night, by a number of investigators: Palmer, Stout and Wulfeck et al., in addition to Kraft and Elworth, 1968. (3) A prior experiment with eight instructor pilots flying letdowns under similar conditions in a 737 simulator provided similar correlations.

CONCLUSIONS

Scientific methods of measuring pilot performance, combined with a computer-generated image on a complete 727-200 simulator, provide a method of measuring the effect of different optical qualities of windscreens on flight performance. The procedures should include night and day approaches and touchdowns by a number of skilled pilots. Approaches should be made without reference to altimetry, glide slope, and vertical velocity, and records of quantitative data should be taken from the host computer, these data to be submitted to analysis of variance at logarithmically spaced distances from the visual touchdown reference. The dependent measures most sensitive are: left and right azimuth deviation at near distances, rate of descent at most intervals out to 1.5 nautical miles, altitude, deviation angle and velocity.

Recommended distances for analyses of variance are at touchdown, 125, 250, 500, 1010, 2030, 4080, 8220 and 16,560 feet if the touchdown reference point is 1,000 feet beyond threshold, and the approach is over no obstructions.

The term "degrees of freedom" should be considered not only in the statistical analysis but also in the planned flight path used in these investigations. The flight path should have sufficient duration and complexity to assure that the pilot has enough degrees of freedom to reflect the influence of image quality on general aspects of his performance.

Analyses of variance that include distance from touchdown as an independent variable should not be given the priority assigned to analyses at specific distances.

Windscreen quality, time-of-day, and their interactions should be included as independent variables in future investigations. Visibility as attenuated by atmosphere should be a parameter. Replications should be four or more.

Pilot training on the particular simulator and procedure should be as complete as time and efficiency may allow. The resulting reduction in variance will increase sensitivity to more than offset any reduction in the differences in the means.

Pilot vision is generally very good among USAF pilots and careful testing prior to data collection primarily avoids assuming that individual performance differences may be due to vision.

Main Effects of Windscreen Quality

Windscreen quality acted to impose an offset from the centerline of greater magnitude at touchdown and within 4080 feet of touchdown. Measures of optical lateral displacement of the image have a positive relationship of opposite sign with offset from centerline at distances of 2880 and 4080 feet. At a distance of 125 feet from touchdown almost no correlation exists between these two measures.

Rate of descent was significantly altered at a distance of 4080 feet for the 2-mile approaches that began with an offset.

Main Interactions of Windscreen Quality

Windscreen quality and time-of-day interact significantly at approach distances out to 8220 feet. The dependent measures of Glide Slope Deviation, Altitude, and Deviation Angle were significantly altered on straight-in approaches from 4.7 miles out. Velocity was significantly altered at five distances for the 2-mile offset approaches. The "Good" windscreen did not interact with the day and night scenes, however lower velocity was consistently found for the "Poor" windscreen for the day scene and the "Bad" windscreen for the night scene.

In the straight-in approaches from 4.7 miles out, windscreen quality interacted with time-of-day, affecting altitude over the runway threshold. Day approaches were flown below the requested 2.5° glide slope regardless of windscreen quality. Night approaches with "Good" and "Fair" windscreens approximated the 2.5° glide slope. Night approaches with the "Poor" and "Bad" windscreens were flown significantly higher at runway threshold with longer touchdowns than those with the better quality windscreens.

Time-of-Day as a Main Effect

Day versus night scenes not only interact with windscreen quality, but also affect rate of descent, pitch, glide slope deviation, altitude and deviation angle significantly at most approach distances for straight-in approaches from 4.7 miles.

Altitude and glide slope deviation were affected at most distances for the 2-mile, offset approaches.

The night scene was consistently flown to with higher altitudes (above-glide-slope deviations). This higher altitude is recognized later by the pilots and their descent rates are greater all the way through touchdown.

General Effect of Windscreen Quality

Poor windscreen quality alters more general aspects of pilot performance, such as approach altitude at night. Some evidence was found that the perception of the horizontality of the ground plane was associated with altitudes flown with the good windscreen, and that windscreens of lesser quality reduced this relationship. This finding, and the general results, agree with the concept that there is less visual infomation in the night scene than in the day scene. With poor quality windscreens, the lesser information and the dynamic instability of the scene interact to make the visual information less valid and make it appear less reliable. The pilots, therefore, employ a stereotypical pattern of response, flying higher, a little faster, with a later, more rapid descent, and a harder and later touchdown, thus being extra cautious in situations where minimal and unreliable visual information is available in the approach to the runway.

Pilot opinion, as to the difficulty of flying to the different conditions, did not always agree with their performance, as when the pilots judged the day approaches to be more difficult than night approaches with the lower quality windscreens. This opinion was not commensurate with their more precise flying to the day scene. In contrast, their opinion of which windscreens were acceptable had a high correlation with AMRL's scaling of the distortion that existed in each windscreen.

Pilots have an exceptional skill in judging where the aircraft will be a few seconds into the future. This skill includes an ability to assimilate and integrated the effects of very large optical distortion while estimating the dynamic path through space. The aircraft's approach to a runway is, for the pilot, a series of perceptual assimilations and integrations of all the visual information. The visible distortions are given lower priorities during this perceptual task. The sequential series of perceptual integrations and adjustments of flight controls is astonishing to watch, especially when very distorted windscreens are involved. No special area of distortion will have an optical correlate with this overall performance, and it is not surprising that many attempts to measure pilot performance with specific distortions have been less than successful.

The differential effect of windscreen quality on night versus day approaches was probably due to the difference in amount of perceived distortions, allowing different subsamples of these distortions to control the perceptual integration.

These observations and the data reported within this report lead us to make these recommendations:

1. With more complete qualitative and quantitative analysis of the optical characteristics of the windscreens used in this report, further correlations with these performance measures should be undertaken.

2. Quantitative evaluation of pilot performance such as that utilized in this study should be used in future investigations of the effects of the optical characteristics of complex transparent cockpit enclosures.

APPENDIX I
DISTORTION PANELS OR WINDSCREENS AND THEIR POSITIONING

Position of Windscreens in 727 Aircraft: An Empirical Test

The experimental windscreens or distorting windscreens provided by the Air Force were cut in a specific fashion so that they could be inserted into the open window channel or the 727 simulator without modifying the simulator's physical structure. It was of concern to both the monitors and to the contract personnel as to whether the windscreens therefore were respositionable at the same point with the simple locking and registration mechanism. An empirical study was made to determine the circular error of positioning the windscreens, the slope and the left/right perpendicularness of the windscreens when they were withdrawn inserted five times. A Wild theodolite was positioned at the cyclopean eye position of the left forward seat of the 727 simulator. An image of the Moses Lake 321 runway was put on the General Electric Compuscene and the angle to the centerline at the far end of the runway was measured. The three windscreens were inserted and withdrawn five times each. The location of the eye reference point to runway centerline at the 13,500 foot distance was determined for each positioning. In addition the slope and perpendicularity of the windscreens were also determined, and their vertical and horizontal positioning recorded

	x-1	x-9	x-3
Centerline V	222.25 mm	212.73 mm	222.25 mm
Centerline H	327.03 mm	327.03 mm	327.03 mm
Max. Error V	2.5 mm	2.9 mm	2.3 mm
Max. Error H	8.1 mm	12.2 mm	8.2 mm
Slope (Top Back)	28 °	28 °	28 °
Error	None within the measurement limits of 1/2 degree.		
Left/Right perpendicularity (Ave)	90.2°	87.8°	90.2°
( )	0.13°	0.15°	0.15°
Movement of Image (H)	.0694° Right	.1642° Left	.5025° Right
(V)	.0089" Up	.1747" Down	.4325° Down
Shadow Mask Holes Visible at 30x	Barely	No	No
Effect on point sources at night	2' 52" V	2' 02" V	21' 37" V
Measured Size: 4' 58"(V) x 4' 22"(H)	11' 18" H	13' 37" H	0' 44" H

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WINDSHIELD QUALITY AND PILOT PERFORMANCE.(U)
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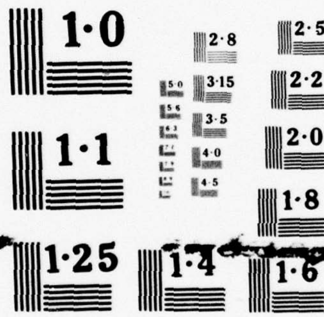

NATIONAL BUREAU OF STANDARDS
MICROCOPY RESOLUTION TEST CHART

Effect of Windows on Point Sources of Light

The effect on point source shape and size was measured in the Wild theodolite in degree, minutes and seconds. The principle width and height of the same point source was made through all windscreens. The point source was 6.5° to the left of the nominal angle of regard and represented one of the runway edge lights. This light in the clear window measured 4' 58" vertically and 4' 22" horizontally, was roughly circular and made up of 18 shadow mask holes, 6 of each primary color, red, blue and green. The x-1 windscreen stretched this image, elongating the 315° meridian. The x-9 stretched the image horizontally to a 3x elongation, and decreased its vertical dimension. The x-3 windscreen stretched the image to a vertical extent of 21' 37" and formed a very narrow line 44" wide 15° off vertical.

Repositioning Results

The windscreens could be repositioned with the cut-out notch and vertical reference taped within the simulator window frame. The slope was highly reproducible at 28°, the maximum error measured was 12.2 millimeter in one of the five positions obtained with x-9. The standard deviations were all about 4 mm in the horizontal direction. The reference center was measured from the lower left tip of the windscreen and perpendicular to the left lower base of the panel. Perpendicularity, in the left-right rotation, was very proximal for the x-1 and x-3 windows and highly reproducible. The ultra-thickness of the x-9 window shifted this value from 90.2° to 87.8°, a constant error of 2.4° from the orientation of the other windows. The difference of 2.4° had an effect, but it is small and in all probability does nothing to significantly alter results.

APPENDIX II

PORTION OF LINE PRINTER OUTPUT OF DEPENDENT VARIABLES FOR PHASE I

```
T1  XR   +3.040187E 04  YR   -1.250000E-01  HMHS +0.809968E 03  Z.  +2.662908E 01  VTRJ +2.530002E 02
    PCHD +1.111105E 01  TIME +4.316406E 00  FZL  +0.             VW  +0.            ZPBS -0.520367E 03

T1  XR   +3.040249E 04  YR   +1.250000E-01  HMHS +1.000812E 03  Z.  +3.053314E 01  VTRJ +2.500357E 02
    PCHD +1.241192E 01  TIME +1.095703E 01  FZL  +0.             VW  +0.            ZPBS -3.295312E 02

T1  XR   +3.040262E 04  YR   +0.            HMHS +1.025453E 03  Z.  +3.098077E 01  VTRJ +2.494409E 02
    PCHD +1.261123E 01  TIME +1.175390E 01  FZL  +0.             VW  +0.            ZPBS -3.046906E 02

T1  XR   +3.040262E 04  YR   +0.            HMHS +1.050468E 03  Z.  +3.143713E 01  VTRJ +2.487926E 02
    PCHD +1.278564E 01  TIME +1.255078E 01  FZL  +0.             VW  +0.            ZPBS -2.798749E 02

T1  XR   +3.040262E 04  YR   -1.250000E-01  HMHS +1.075828E 03  Z.  +3.182476E 01  VTRJ +2.481175E 02
    PCHD +1.284605E 01  TIME +1.334765E 01  FZL  +0.             VW  +0.            ZPBS -2.545156E 02

T1  XR   +3.040262E 04  YR   -1.250000E-01  HMHS +1.101328E 03  Z.  +3.198211E 01  VTRJ +2.474461E 02
    PCHD +1.266389E 01  TIME +1.414453E 01  FZL  +0.             VW  +0.            ZPBS -2.290156E 02

T1  XR   +3.040262E 04  YR   -1.250000E-01  HMHS +1.126828E 03  Z.  +3.193719E 01  VTRJ +2.467930E 02
    PCHD +1.265174E 01  TIME +1.494140E 01  FZL  +0.             VW  +0.            ZPBS -2.035234E 02

T1  XR   +3.040262E 04  YR   -1.250000E-01  HMHS +1.152171E 03  Z.  +3.156082E 01  VTRJ +2.461599E 02
    PCHD +1.264505E 01  TIME +1.573526E 01  FZL  +0.             VW  +0.            ZPBS -1.761796E 02

T1  XR   +3.040249E 04  YR   +0.            HMHS +1.177124E 03  Z.  +3.109204E 01  VTRJ +2.455573E 02
    PCHD +1.257385E 01  TIME +1.653515E 01  FZL  +0.             VW  +0.            ZPBS -1.532421E 02

T1  XR   +3.040249E 04  YR   +0.            HMHS +1.201546E 03  Z.  +3.043043E 01  VTRJ +2.451904E 02
    PCHD +1.247604E 01  TIME +1.733203E 01  FZL  +0.             VW  +0.            ZPBS -1.258203E 02

T1  XR   +3.040249E 04  YR   +1.250000E-01  HMHS +1.225406E 03  Z.  +2.971063E 01  VTRJ +2.446006E 02
    PCHD +1.231079E 01  TIME +1.812890E 01  FZL  +0.             VW  +0.            ZPBS -1.049609E 02

T1  XR   +3.040237E 04  YR   +1.250000E-01  HMHS +1.248656E 03  Z.  +2.887091E 01  VTRJ +2.445224E 02
    PCHD +1.200454E 01  TIME +1.892578E 01  FZL  +0.             VW  +0.            ZPBS -0.817109E 02
```

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APPENDIX III

PORTION OF COMPUTER PRINTOUT OF CALCULATED VALUES FOR DEPENDENT VARIABLES IN PHASE I

DISTORTED WINDSCREEN STUDY - PHASE I - TOUCHDOWN DATA

PILOT	TRIAL	ATV	XR1	YR1	HVHS1	VTFU1	TIME1	Z.4	Z.3	Z.2	Z.1	PCH4	PCH3	PCH2	PCH1	XRTD	GSDEV	TIMETD
1	1	111	-815.	12.	3.7	223.0	129.0	-1.5	-3.7	-5.1	-6.7	3.5	3.5	3.2	2.5	1778.	77.6	129.6
2	7	111	1444.	4.	1.2	234.7	118.7	-13.8	-10.8	-10.1	-8.3	2.2	2.4	2.9	3.7	-566.	-24.7	118.8
3	9	111	225.	9.	11.3	229.8	125.4	-17.3	-15.9	-15.1	-14.9	1.2	1.3	1.2	1.0	689.	37.1	126.2
4	15	111	1157.	14.	0.3	225.7	125.3	-14.3	-14.5	-14.7	-14.4	1.4	1.3	1.2	1.2	-312.	-13.6	125.3
5	16	111	911.	4.	3.6	227.7	124.4	-10.0	-9.9	-9.6	-9.3	2.7	2.9	2.9	2.7	28.	1.2	124.8
6	12	111	1174.	-21.	2.4	225.0	125.2	-6.5	-5.7	-5.0	-4.6	3.7	4.0	4.0	3.7	-217.	-9.5	125.7
7	8	111	1624.	1.	4.3	231.9	125.2	-9.5	-9.7	-7.1	-5.9	4.0	4.5	4.6	3.6	-615.	-26.9	125.9
8	4	111	1396.	8.	1.9	223.6	122.2	-9.9	-9.8	-10.0	-10.1	3.1	3.1	3.1	3.1	-514.	-22.4	122.4
1	2	112	-254.	24.	3.8	234.6	123.2	-0.7	-1.8	-3.7	-3.6	2.7	2.4	2.3	2.6	1942.	84.8	124.3
2	8	112	772.	-16.	2.3	239.4	120.6	-7.5	-7.2	-6.4	-5.3	2.2	2.2	2.1	2.1	165.	7.2	121.0
3	10	112	823.	39.	1.9	225.3	124.2	-6.3	-5.4	-4.5	-3.9	4.3	4.4	4.2	4.0	121.	5.3	124.7
4	16	112	1212.	26.	2.3	228.6	124.1	-12.0	-11.2	-10.9	-10.0	2.3	2.2	2.0	1.1	-319.	-13.9	124.3
5	15	112	889.	-17.	2.1	246.6	118.6	-9.1	-7.8	-6.4	-5.6	1.4	1.5	0.9	0.6	43.	1.9	119.0
6	11	112	1314.	-8.	3.9	225.1	123.8	-8.9	-8.6	-8.4	-8.5	3.2	3.3	3.2	2.8	-371.	-16.2	124.3
7	7	112	907.	-8.	5.0	252.3	127.8	3.2	1.3	2.4	-6.3	1.8	0.2	-0.9	-1.6	133.	5.8	128.6
8	3	112	1384.	3.	5.4	221.6	123.1	-8.7	-8.5	-7.9	-7.2	4.0	4.4	4.8	4.8	-378.	-16.5	123.8
1	3	121	721.	-22.	2.2	235.6	123.1	-6.5	-7.5	-7.3	-6.1	2.5	2.7	3.1	3.6	204.	8.9	123.5
2	5	121	1196.	-7.	0.6	226.6	122.5	-6.9	-6.7	-6.4	-6.1	3.6	3.7	3.7	3.1	-336.	-14.7	122.6
3	11	121	-7.	4.	8.8	227.7	130.4	-13.4	-14.4	-15.3	-15.6	1.1	0.9	1.0	1.0	975.	42.6	131.0
4	[illegible]	121	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

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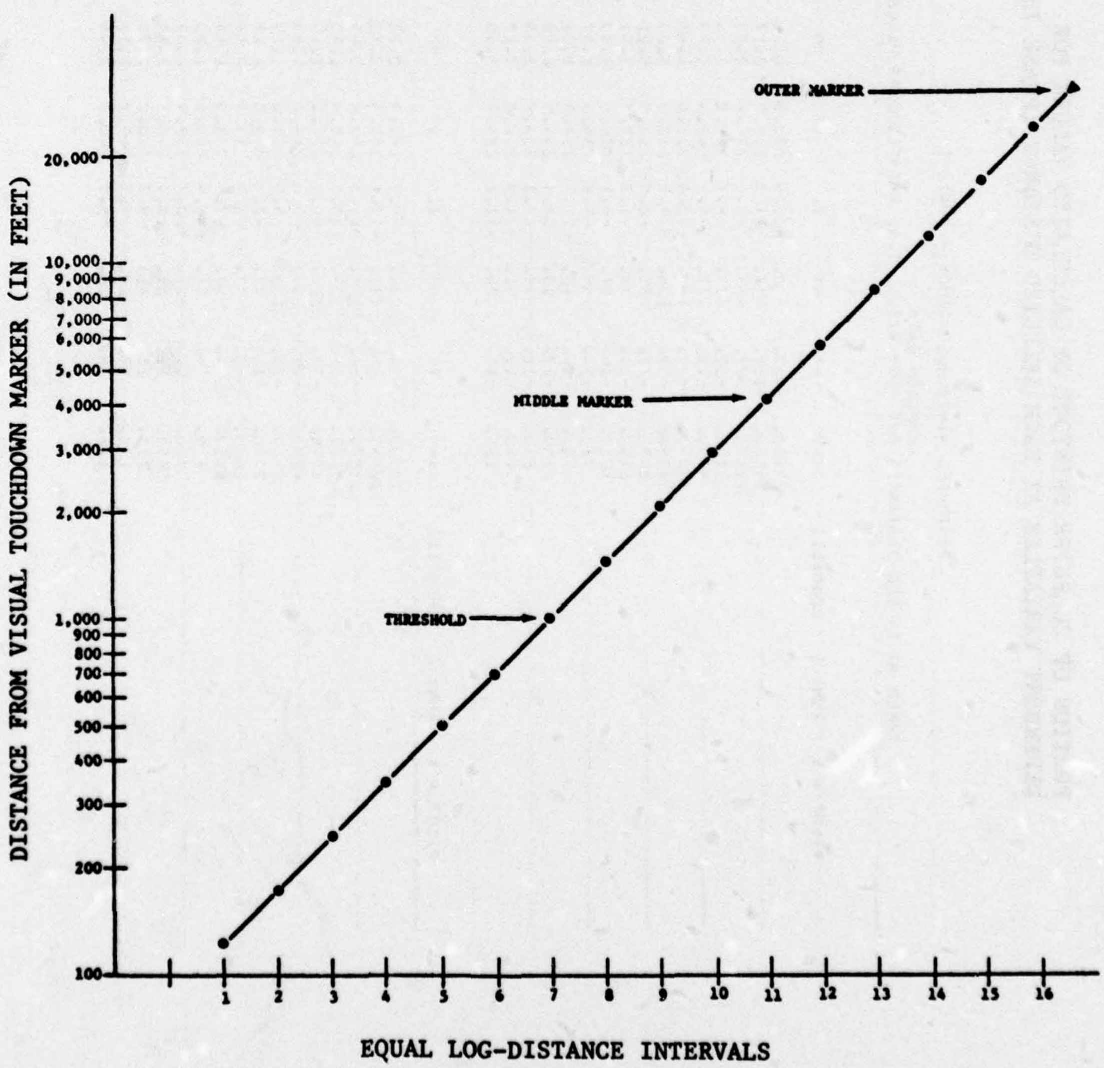
APPENDIX IV

DETERMINATION OF SELECTED DATA SAMPLING POINTS BASED ON EQUAL LOG-DISTANCE INTERVALS FROM VISUAL TOUCHDOWN MARKER



APPENDIX V

PORTION OF COMPUTER PRINTOUT OF CALCULATED VALUES FOR DEPENDENT VARIABLES AT EACH SELECTED DISTANCE (PHASE I)

DISTORTED WINDSCREEN STUDY - PHASE I

APPROACH DATA

TAKEN AT 16 LOG-DISTANCES OUT FROM VISUAL T.D. POINT(1000FT MARKER)

PILOT = 1 RUN: 1 COND:111

XRV	YR	HM	Z.	VT	PD	GSD
23500.	-428.	970.	-15.4	247.5	0.24	-56.
16500.	-131.	637.	-11.3	238.9	2.17	-36.
11670.	-28.	455.	-6.5	239.8	2.38	-54.
8220.	-15.	323.	-4.3	246.2	3.34	-36.
5790.	-15.	271.	-9.3	242.4	0.83	18.
4080.	-35.	180.	-13.4	235.6	1.49	1.
2990.	-33.	106.	-13.5	230.0	3.20	-20.
2030.	-26.	75.	-2.0	232.5	5.51	-14.
1430.	-19.	74.	-1.3	233.9	3.51	11.
1010.	-16.	67.	-6.1	234.6	2.00	23.
710.	-14.	59.	-9.8	234.6	1.37	27.
500.	-13.	48.	-11.7	234.8	1.62	26.
350.	-12.	40.	-12.4	234.9	2.15	25.
250.	-12.	35.	-12.1	234.8	2.79	24.
175.	-12.	31.	-11.8	234.8	3.27	23.
125.	-11.	29.	-11.2	234.7	3.65	23.

PILOT = 1 RUN: 2 COND:112

XRV	YR	HM	Z.	VT	PD	GSD
23500.	-34.	1034.	-9.2	247.3	-0.22	58.
16560.	-8.	730.	-13.2	257.4	-0.50	57.
11670.	-64.	500.	-11.5	250.6	0.63	-10.
8220.	-26.	307.	-12.0	245.4	1.40	-52.
5790.	-38.	212.	-9.0	237.0	2.19	-40.
4080.	-41.	150.	-9.8	238.9	1.63	-29.
2850.	-25.	100.	-9.5	241.0	2.29	-26.
2030.	-10.	77.	-2.3	240.0	4.18	-12.
1430.	-0.	72.	-3.3	238.7	2.36	9.
1010.	4.	52.	-7.9	238.9	1.44	18.
710.	8.	51.	-10.4	239.6	1.40	20.
500.	11.	41.	-10.7	239.9	2.07	19.
350.	12.	35.	-10.0	240.1	2.49	20.
250.	13.	31.	-9.3	240.2	2.70	20.
175.	13.	28.	-9.7	240.2	2.66	20.
125.	14.	26.	-8.3	240.2	2.95	20.

APPENDIX VI

PORTION OF ANOVA FOR TOUCHDOWN DISTANCE FROM VISUAL TD MARKER (PHASE I)

ANALYSIS OF VARIANCE FOR DEPENDENT VARIABLE 13 (XR_{TD}): TOUCHDOWN DISTANCE FROM VISUAL T.D. MARKER

SOURCE	ERROR TERM	F	SUM OF SQUARES	DEG. OF FREEDOM	MEAN SQUARE	EXPECTED MEAN SQUARE	
1 MEAN	P	1.4525	4113786.	1	4113786.	128.000(1)	16.000(5)
2 WINDSPEED	WP	3.8423*	4885101.	3	1628367.	32.000(2)	4.000(9)
3 TIME-OF-DAY	TP	15.2970*	2678744.	1	2678744.	64.000(3)	8.000(10)
4 VISIBILITY	VP	4.7757	1443937.	1	1443937.	64.000(4)	8.000(11)
5 PILOT		10.9516	.1982493E 08	7	2832132.	16.000(5)	
6 WT	WTP	1.9289	1826949.	3	608983.0	16.000(6)	2.000(13)
7 WV	WVP	0.0952	110326.0	3	36775.33	16.000(7)	2.000(14)
8 TV	TVP	0.2262	156031.0	1	156031.0	32.000(8)	4.000(15)
9 WP			8899656.	21	423802.6	4.000(9)	
10 TP			1225808.	7	175115.4	8.000(10)	
11 VP			2116464.	7	302352.0	8.000(11)	
12 WTV	WTVP	1.2129	940966.0	3	313655.3	8.000(12)	1.000(16)
13 WTP			6630059.	21	315717.1	2.000(13)	
14 WVP			8108224.	21	386105.9	2.000(14)	
15 TVP			4827777.	7	689682.4	4.000(15)	
16 WTVP			5430671.	21	258603.4	1.000(16)	

ESTIMATES OF VARIANCE COMPONENTS

(1)	1[illegible]12.92
(2)	37642.43
(3)	39119.19
(4)	17837.27
(5)	177009.3
(6)	18329.13
(7)	-21833.15
(8)	-16676.63
(9)	1[illegible]5950.6
(10)	21889.42
(11)	37734.33
(12)	6881.492
(13)	157858.5
(14)	193652.4
(15)	172420.6
(16)	258603.4

MEAN 179.27344

CELL MEANS

W =	1-GOOD	2-FAIR	3-POOR	4-BAD
	86.84375	-92.06250	314.62500	407.68750
T =	1-DAY	2-NIGHT		
	34.60938	323.93750		
V =	1-CLEAR	2-HAZY		
	73.06250	285.48438		

APPENDIX VII

RESULTS OF VISUAL TESTS AND EXAMINATIONS OF PILOTS

PILOT "A"

FAR POINT		RIGHT EYE		LEFT EYE
Correction Worn	(CW)	None		None
Visual Acuity	(CW)	20/15-3		20/15-2
Phoria	(CW)		3XO	
Refraction	(R)	Plano		PL -.12 x 122
Visual Acuity	(R)	20/15-2		20/15-2
Phoria	(R)		3XO	
NEAR POINT				
Correction Worn	(CW)	None		None
Visual Acuity	(CW)	20/20		20/20
Phoria	(CW)		9XO	
ACCOMMODATIVE AMPLITUDE		-5.25		-5.00

COMMENTS

Vision is expected to have little or no effect on performance.

APPENDIX VII
(Continued)

RESULTS OF VISUAL TESTS AND EXAMINATIONS OF PILOTS

PILOT "B"

FAR POINT		RIGHT EYE		LEFT EYE
Correction Worn	(CW)	None		None
Visual Acuity	(CW)	20/25+		20/20+3
Phoria	(CW)		Ø	
Refraction	(R)	-.251.00X15		+.25
Visual Acuity	(R)	20/20		20/20
Phoria	(R)		Ø	
NEAR POINT				
Correction Worn	(CW)	None		None
Visual Acuity	(CW)	20/20		20/20
Phoria	(CW)		5XO	
ACCOMMODATIVE AMPLITUDE		-6.25		-6.75

COMMENTS

The refractive state could have some effect on performance for the following reasons:

1. The type and magnitude of refractive error; and
2. Recent wear of contact lenses for orthokeratological reasons, systematic controlled wear of contact lenses to eliminate or decrease need for ophthalmic correction.

APPENDIX VII
(Continued)

RESULTS OF VISUAL TESTS AND EXAMINATIONS OF PILOTS

PILOT "C"

FAR POINT		RIGHT EYE		LEFT EYE
Correction Worn	(CW)	None		None
Visual Acuity	(CW)	20/20+3		20/20+3
Phoria	(CW)		3XO	
Refraction	(R)	+.25-.37X105		+.50-.12X75
Visual Acuity	(R)	20/20		20/20
Phoria	(R)		3XO	
NEAR POINT				
Correction Worn	(CW)	None		None
Visual Acuity	(CW)	20/25		20/20
Phoria	(CW)		Ø	
ACCOMMODATIVE AMPLITUDE		-3.75		-4.25

COMMENTS

Pilot performance could be affected slightly for the following reasons:

1. Tendency toward suppression of the left eye,
2. Uncorrected astigmatism and hyperopia;
3. Low accommodative amplitude; and
4. Need for slight correction at near.

APPENDIX VII
(Continued)

RESULTS OF VISUAL TESTS AND EXAMINATIONS OF PILOTS

PILOT "D"

FAR POINT		RIGHT EYE		LEFT EYE
Correction Worn	(CW)	None		None
Visual Acuity	(CW)	20/15-1		20/15
Phoria	(CW)		5 eso	
Refraction	(R)	+.50-.25X90		+.25-.25X85
Visual Acuity	(R)	20/15		20/15
Phoria	(R)		3-1/2 eso	

NEAR POINT		RIGHT EYE		LEFT EYE
Correction Worn	(CW)	None		None
Visual Acuity	(CW)	20/20		20/20
Phoria	(CW)		1 eso	
ACCOMMODATIVE AMPLITUDE		-4.25		-4.25

COMMENTS

Slight effects in performance may be recognized because:

1. The pilot was experiencing a cold and headache;

2. Esophoria;

3. Slight hyperopia and astigmatism; and

4. Low accommodative amplitude; and

5. Need for slight correction at near.

APPENDIX VII
(Continued)

RESULTS OF VISUAL TESTS AND EXAMINATIONS OF PILOTS

PILOT "E"

FAR POINT		RIGHT EYE		LEFT EYE
Correction Worn	(CW)	None		None
Visual Acuity	(CW)	20/15-3		20/20+4
Phoria	(CW)		1XO	
Refraction	(R)	+.25-.37X10		+.25
Visual Acuity	(R)	20/15		20/15
Phoria	(R)		1/2 eso	
NEAR POINT				
Correction Worn	(CW)	None		None
Visual Acuity	(CW)	20/20		20/20
Phoria	(CW)		2 eso	
ACCOMMODATIVE AMPLITUDE		-5.25		-5.25

COMMENTS

Slight astigmatism and hyperopia are expected to have negligible to no effects on pilot performance.

APPENDIX VII
(Continued)

RESULTS OF VISUAL TESTS AND EXAMINATIONS OF PILOTS

PILOT "F"

FAR POINT		RIGHT EYE		LEFT EYE
Correction Worn	(CW)	None		None
Visual Acuity	(CW)	20/15		20/15
Phoria	(CW)		3X0	
Refraction	(R)	Plano		PL-.37X165
Visual Acuity	(R)	20/15		20/15
Phoria	(R)		4X0	
NEAR POINT				
Correction Worn	(CW)	None		None
Visual Acuity	(CW)	20/20		20/20
Phoria	(CW)		13X0	
ACCOMMODATIVE AMPLITUDE		-5.50		-5.50

COMMENTS

Excellent vision capabilities. Vision is not expected to adversely affect performance.

APPENDIX VII
(Continued)

RESULTS OF VISUAL TESTS AND EXAMINATIONS OF PILOTS

PILOT "G"

FAR POINT		RIGHT EYE		LEFT EYE
Correction Worn	(CW)	None		None
Visual Acuity	(CW)	20/20+4		20/20
Phoria	(CW)		2 eso	
Refraction	(R)	Plano		Plano
Visual Acuity	(R)	20/20+		20/20
Phoria	(R)		2 eso	
NEAR POINT				
Correction Worn	(CW)	None		None
Visual Acuity	(CW)	20/20		20/20
Phoria	(CW)		2 eso	
ACCOMMODATIVE AMPLITUDE		-5.50		-5.50

COMMENTS

Excellent vision capabilities. Slight esophoria is not expected to adversely affect performance.

APPENDIX VII
(Continued)

RESULTS OF VISUAL TESTS AND EXAMINATIONS OF PILOTS

PILOT "H"

FAR POINT		RIGHT EYE		LEFT EYE
Correction Worn	(CW)	None		None
Visual Acuity	(CW)	20/15-2		20/15-2
Phoria	(CW)		1 eso	
Refraction	(R)	Plano		Plano-.25X8
Visual Acuity	(R)	20/15-2		20/15
Phoria	(R)		2 eso	
NEAR POINT				
Correction Worn	(CW)	None		None
Visual Acuity	(CW)	20/20		20/20
Phoria	(CW)		1 eso	
ACCOMMODATIVE AMPLITUDE		-5.75		-5.75

COMMENTS

Excellent vision capabilities. Vision is not expected to adversely affect performance.

APPENDIX VIII

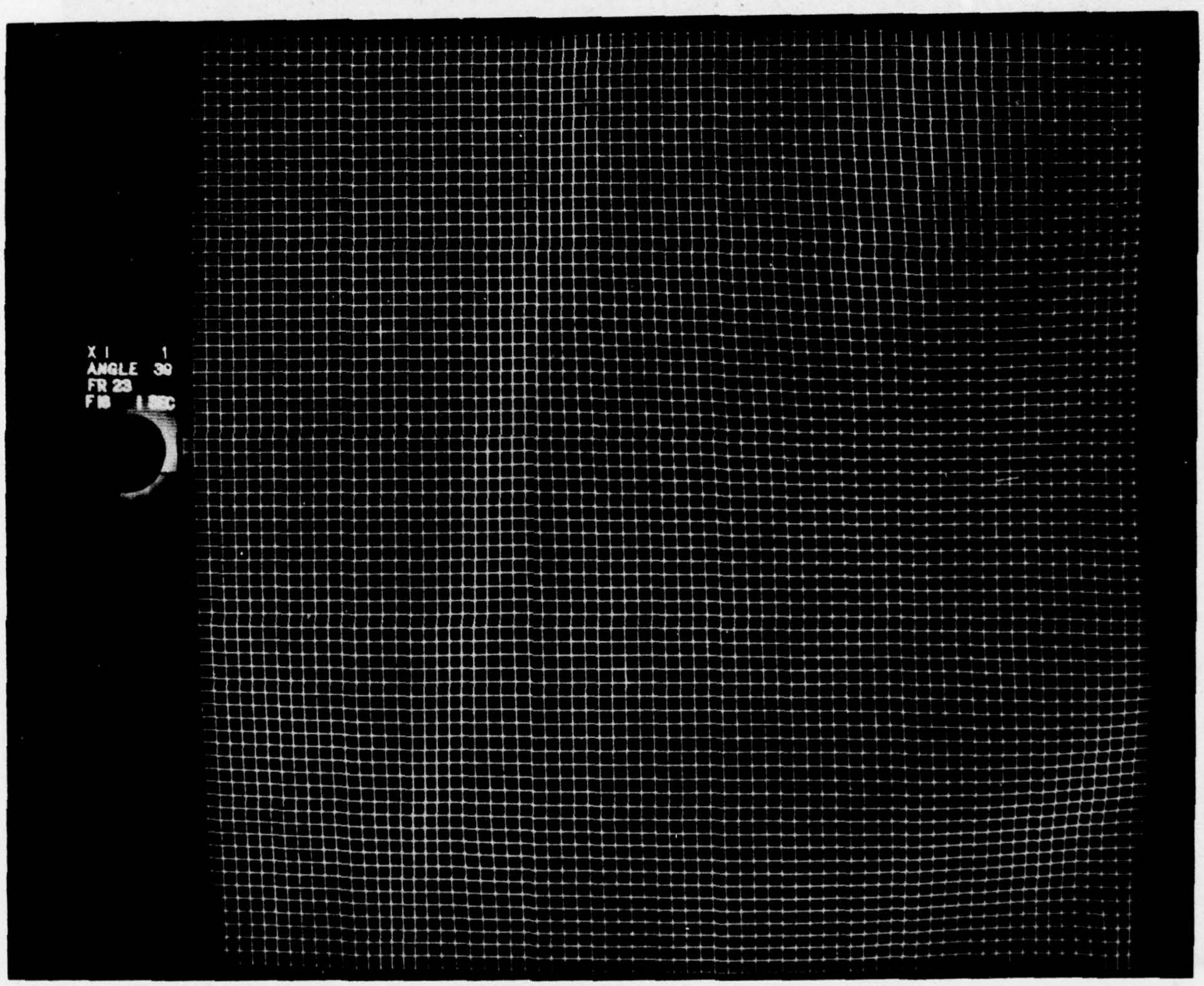
DEPICTIONS FOR "FAIR" (X-1), "POOR" (X-9) AND "BAD" (X-3) WINDSCREENS

The following three illustrations are representative of the distortions to be seen through three attenuating windscreens used in this experimental investigation. A white cross-hatched series of lines against a black background were photographed from the eye reference point of the pilot through each of the distorting transparencies. These photographs were made by AMRL personnel prior to the shipment of the windscreens to Boeing Aerospace Company.

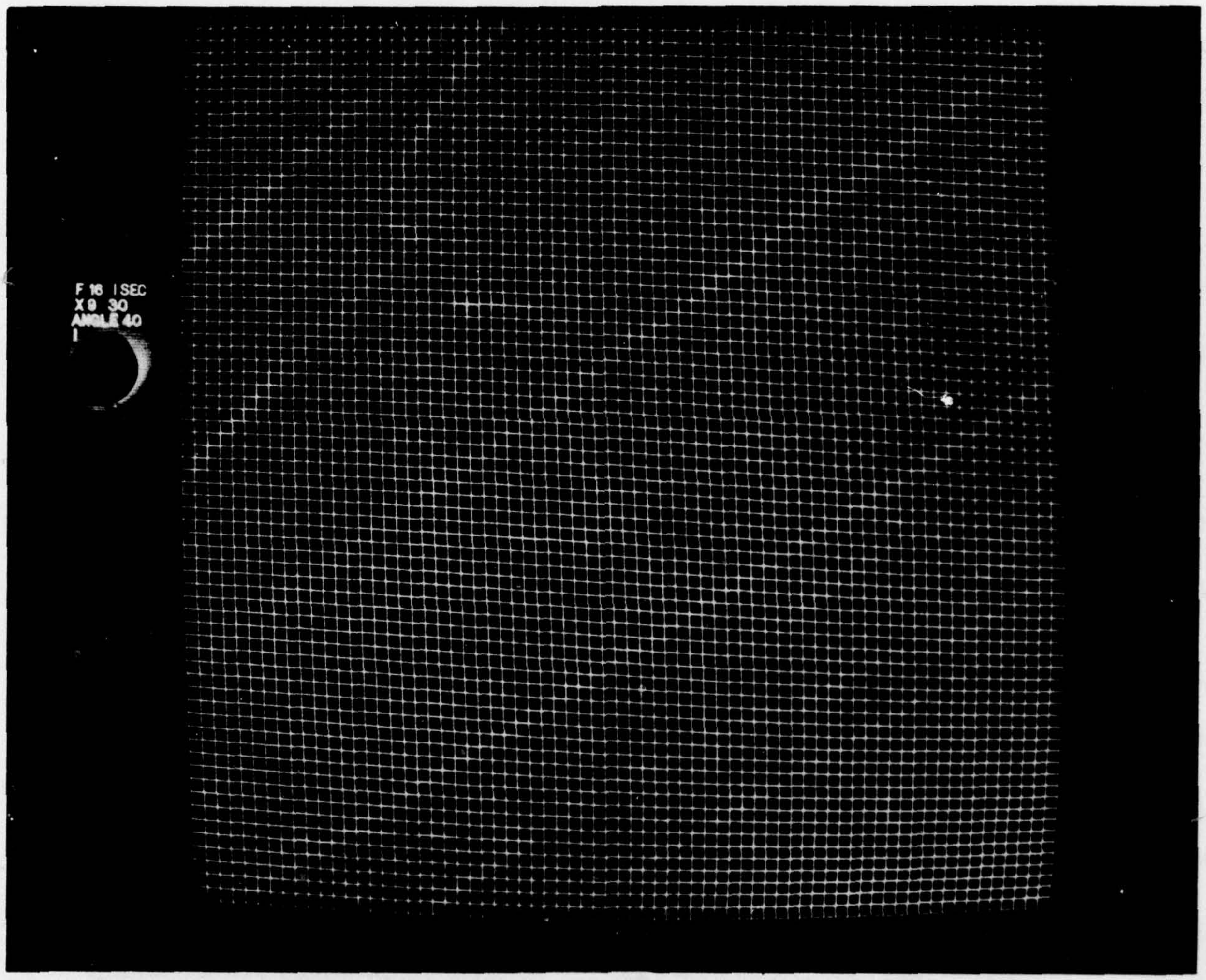
These are three of the photographs used by Dr. Self of AMRL in the scaling of distortion for each of the 11 special panels made under contract by Pittsburgh Plate Glass Company. These three were selected after the scaling as representing low, medium, and high degrees of distortion.

These photographs differ slightly from the conditions utilized in experimental situation in that the photographs were taken with 40° of top-back inclination, while in the experimental study, the same panels were inserted with a 28° top-back inclination.

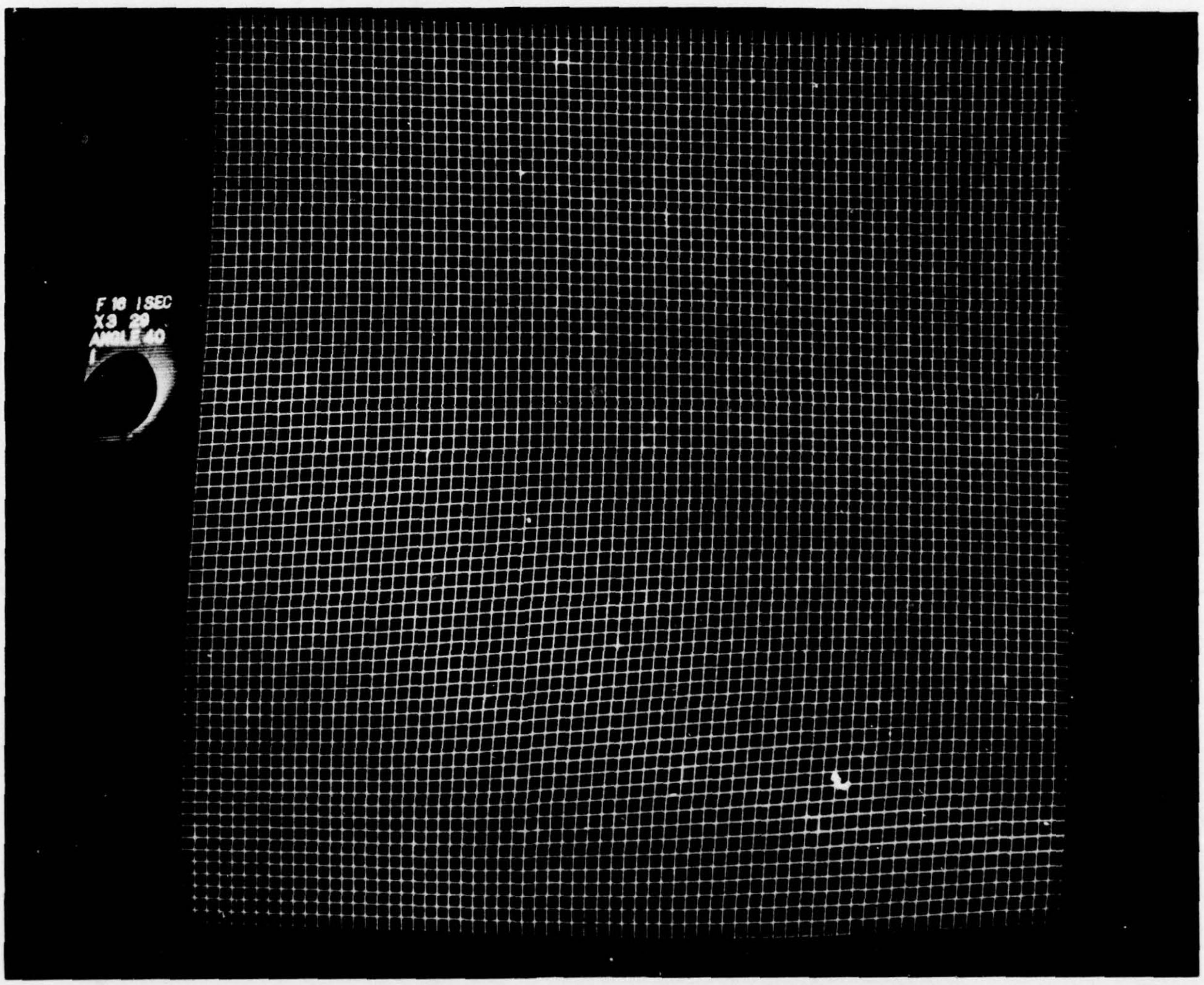
APPENDIX VIII "FAIR" (X-1) Grid Photograph



APPENDIX VIII "POOR" (X-9) Grid Photograph



APPENDIX VIII "BAD" (X-3) Grid Photograph



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