VISUAL AND MOTION EFFECTS ON AN EXPERIMENTAL WIDE-ANGLE AIRCRAFT SIMULATOR

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INTRODUCTION

Traditionally the piloting of an aircraft was considered essentially a visual process. This is because the eye, coupled with the computational ability of the brain, provides the human with his most powerful sensor. Although much information is available on an individual area, such as visual, much of the information on the various sensory cues are fragmentary. (Cues being defined here as information which is useful to the operator in controlling a vehicle and in making decisions as to the state of the vehicle). It was due to the prohibitive and complicated nature of combining cues that little information had been obtained on the interaction of visual and motion cues in the control of aircraft. For this reason past motion system performance and pilot's vestibular reaction to motion were not adequately defined, nor fully understood. The early trainers were limited to attempts to create realism effects such as engine induced vibration or low intensity rough air. These movements were not correlated with pilot control, nor with the visual display. Hence, false or conflicting motion cues would be introduced with resulting negative training effects. One of the objectives of continuing research would be to consider techniques which would avoid conflicting or false cues imposed by the limitation of simulation equipment. However, as described in recent Human Factor reports,[1,2], the subject of the interaction of visual and motion cues is complex and difficult. This difficulty stems partly from the limitations of the hardware, but to a great extent it stems from the complexity of the human factor elements, and lack of information on their interactions.

HUMAN FACTOR PARAMETERS

The human factor elements(6) shown in figures 1, 2 and 3 indicate the visual and motion parameters which provide the sensory information. The visual parameters are given in figure 1 starting with solid angle from the subject's eye within which cues are contained. Brightness, resolution and contrast are not considered cues, but enable cue identification. Exit pupil defines the volume of space over which the displayed image may be viewed by an observer. Range of maneuverability incorporates ground area, altitude and rotational degrees of freedom. Registration and correlation refers to control action resulting in position, rate and acceleration. It also refers to the degree of specified accuracy for training device design. The Image Distance and Depth Cues are shown to consist of monocular and binocular cues. It should be noted that except for light and shade and accommodation (which refers to eye focussing) the monocular cues are amenable to quantitative or geometrical descriptions. The binocular cues are related to near distant cues such as for helicopter landings. Special effects refers to such things as variations in weather and visibility.

Proceeding further with figure 2 we can see some of the effects of various conditions on the threshold characteristics of a cue. These illustrate the effect of variables in detecting movement on a visual scene. Here we see

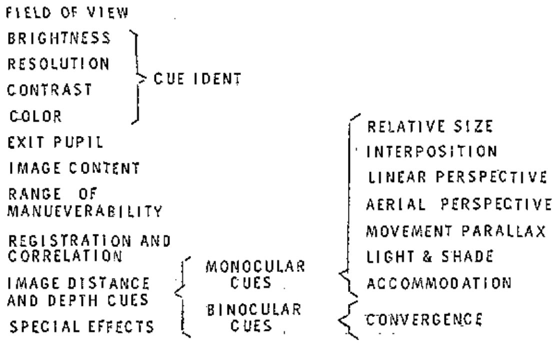


Figure 1. Visual Parameters

VARIABLE	FUNCTION	THRESHOLD EFFECT
VELOCITY	INCREASE	INCREASE
DURATION	INCREASE	DECREASE
FIELD	INCREASE	DECREASE
ILLUMINATION	INCREASE	DECREASE
RETINAL AREA	INCREASE PERIPHERY	INCREASE
ACUITY		
(MONOCULAR)	NEAR DISTANCE	INCREASE
(BINOCULAR)	NEAR DISTANCE	NO CHANGE

Figure 2. Variable Conditions Influencing Threshold Values for Discrimination of Movement

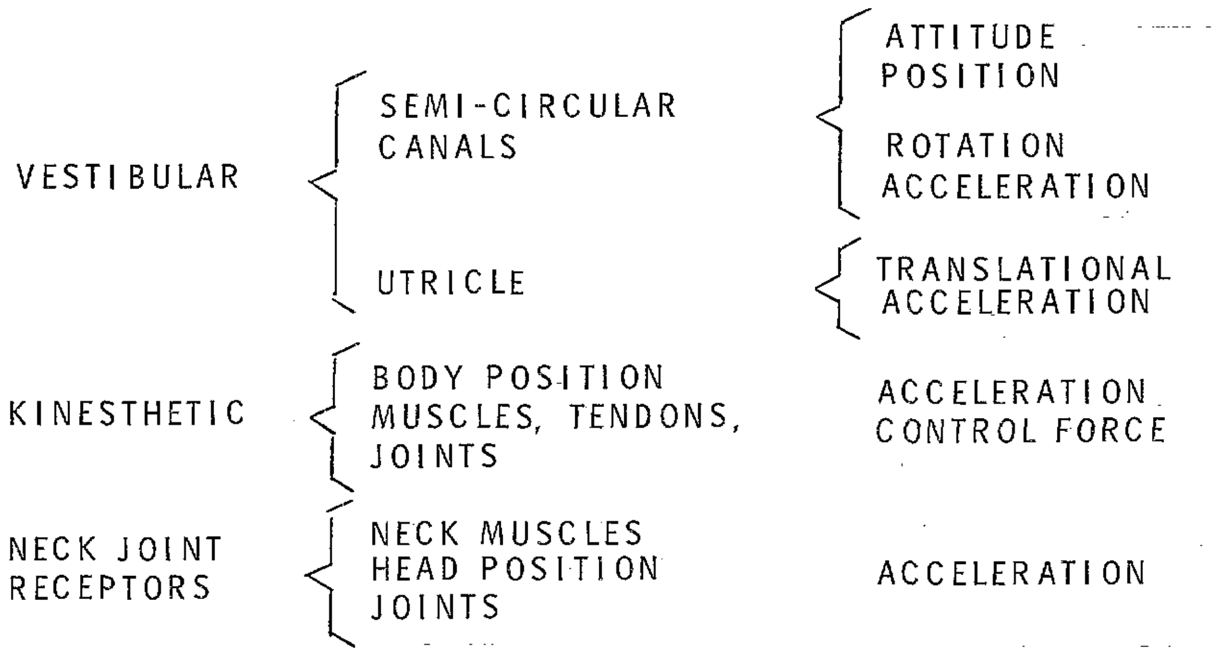


Figure 3. Motion Cues

that threshold increases for increases in velocity. An increase in duration of the visual scene lowers the threshold. Increasing the field-of-view or increasing illumination, decreases threshold (these two parameters are of particular interest because they are a vital consideration in effective utilization of the point light and wide-angle visual system in the NAVTRA-DEVCEN Visual Simulation Laboratory). The remaining are effects of the retinal area of the eye, and monocular or binocular condition at near distances.

In addition to the visual parameters, the motion and kinesthetic cues[2] to be considered are indicated in figure 3. These motion cues are essentially those of acceleration and changes in attitude or angular position. The principal source of motion sense is the vestibular apparatus which consists of two sets of sensors, one set located in each inner ear. Each set is composed of an angular sensor or semi-circular canal and a linear acceleration sensor called the utricle. The vestibular systems behaves as a stable platform which first, senses static and dynamic orientation of the head, and second, stabilizes the eye so that clear vision is possible in spite of head motions. The kinesthetic cues are derived by the operator from the movement of his limbs as he actuates his controls in the vehicle, or as the vehicle is exposed to changes in acceleration. The kinesthetic or control force cues and their important interaction, with the vestibular and visual sensors, have attracted interest only recently and little information has been published on it. Of even more recent interest are the neck muscles and head combination as a motion sensing apparatus.[1,2] These respond to acceleration with resulting changes in muscle tension as the supported head is moved and acts as a motion receptor. This, in turn, interacts with the vestibular system in a way that is also as yet not completely understood. These type of interactions appear to typify a new trend in which the combinations of sensory characteristics and simulator are considered as a unit rather than just the simulator by itself.

The classification of cues (whether they are primary, secondary conflicting or masking cues) depend on the responsive characteristics of the various sensors. For example, because of its frequency bandwidth characteristics the vestibular sensors have a faster response than the visual sensors. The kinesthetic control force cues produce even quicker responses. Because of this these sensors would be superior for the higher order motion of accelerations and rates of acceleration onset cues. The visual cues on the other hand are on the lower end of the frequency spectrum but are indispensable in detecting vehicle position and other predominantly visual cues.

As we will discuss later, some of the more recent techniques[4] for the combined motion and visual simulator will be to take advantage of the characteristic frequency bandwidth of the motion and visual sensors to simplify motion platform requirements. These will include electrical filtering and washout techniques for separating the visual and motion cues in accordance with their appropriate frequency bandwidth.

In these techniques the motion receptors of man are matched to the appropriate portion of his environment in order to avoid illusions in the form of disorientations or false perceptions. Illusions are related to the loss of visual reference, however, a major contribution to disorientations occurs in those situations where frequencies of the motion environment are lower than those of the sensor frequency spectrum. Thus, for example, the semi-circular canals would be incapable of detecting a very slow roll error. If the pilot corrects his error rapidly and the original roll was not perceived, the pilot is forced to assume he has rolled in the opposite direction when, in fact, he is straight and level. Thus, in general, illusions may occur due to large motion excursions or slow continuous turns with prolonged mis-alignment with the inertial gravity vector. These illusions can take the form of diving when recovering from a turn, sensing a wrong tilt when in a skid, a nose high attitude during takeoff, and other illusions involving inversions, spirals, and spins.

Effects of motion sickness were reported with NTDC Device 2FH2, a fixed base cockpit and point light source wide-angle visual screen. Similar effects were reported on recent tests sponsored by the U.S. Army Aviation Material Laboratory on the Northrup wide angle point light source visual system. This particular system similar to the one with NAVTRADEVCEN Visual Simulation Laboratory, has inherent dynamic visual distortions which are also a probable cause of motion sickness. However, when motion cues were added, the occurrence of motion sickness was reduced drastically. In these cases it was the experienced pilots who became sick, due to lack of motion, but not the new trainee. This apparently was an indication of the habit pattern in utilizing motion cues. These particular phenomena were the basis for the incorporation of a motion platform with the point light source visual display installed in the Visual Simulation Laboratory. Other factors which may cause motion sickness are the previously mentioned lack of motion fidelity and poor optical performance.

NAVTRADEVCEN VISUAL SIMULATION LABORATORY POINT LIGHT SOURCE EQUIPMENT

Considerable effort has gone into the development of the point light transparency systems since about 1960. They are, in theory, capable of simulating the view from an operator aerial position of a two or three dimensional ground terrain in correct perspective without the use of sophisticated electronic equipment. Basically, this technique uses a point light source of high brightness which casts the "shadow" of a photographic transparency onto the wide screen surrounding the operator as shown in figure 4. The transparency is mounted on a servo-driven gimbal system, which translates and rotates with respect to the stationary point light source, for all six degrees of freedom, and portrays the motion of the simulated vehicle on the screen.

The relative position of the point light source to the transparency is analogous to the position of the actual vehicle with respect to the ground. This can be seen from the diagram in figure 5 by taking the ratio of similar triangles, one formed by the subtended scene and the other by the image on the transparency. The simulated altitude dimension "h" is subsequently found to be equal to the distance "d" from the point light source to the transparency times the transparency scale factor. Thus, it is possible to vary the simulated altitude in direct proportion to changing the distance between the light source and the transparency. It is also possible to change the transparency and scale factor depending on the altitude and scene resolution requirements of the mission intended for simulation.

An example of a visual scene from a transparency having three-dimensional models of transparent buildings, various structures and trees mounted on it is shown in figure 6. A scale factor of 100 to 1 is used for this transparency which gives an acceptable resolution for 3-D perspective missions close to the ground. For greater ranges in altitude and maneuverability a two-dimensional

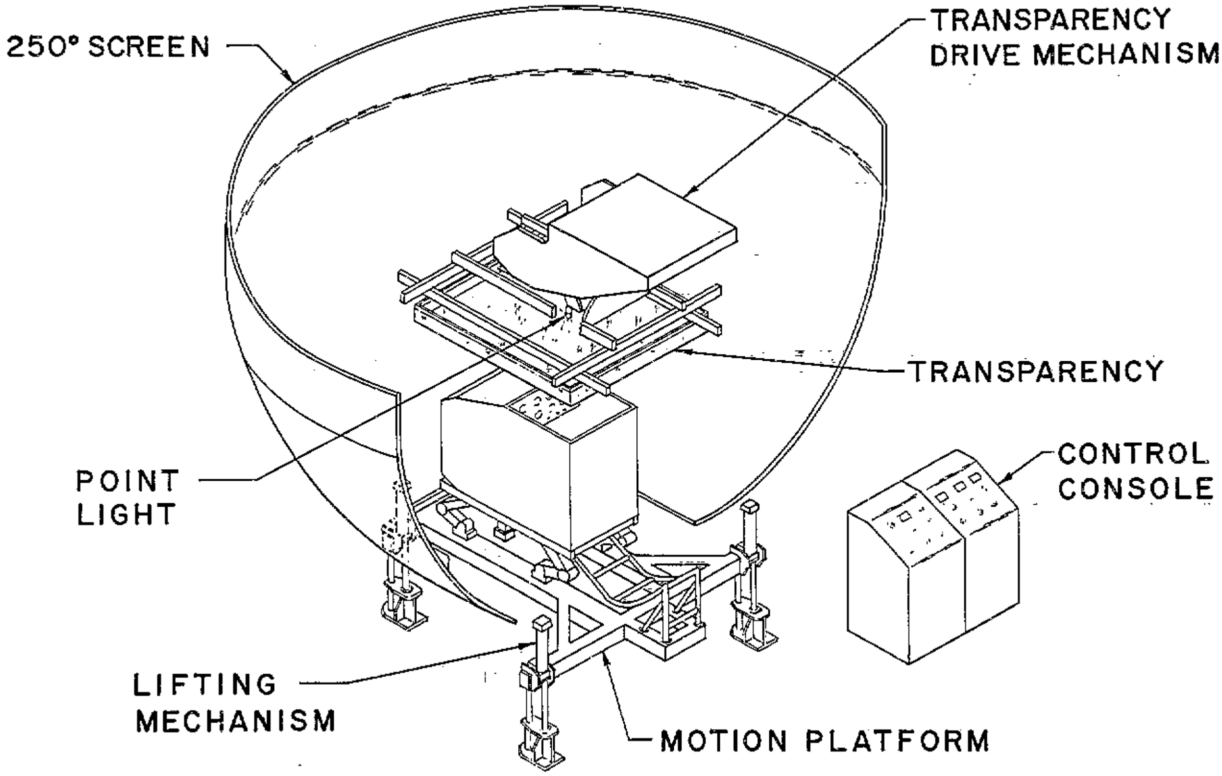


Figure 4. Point Light Source Visual System and Motion Platform

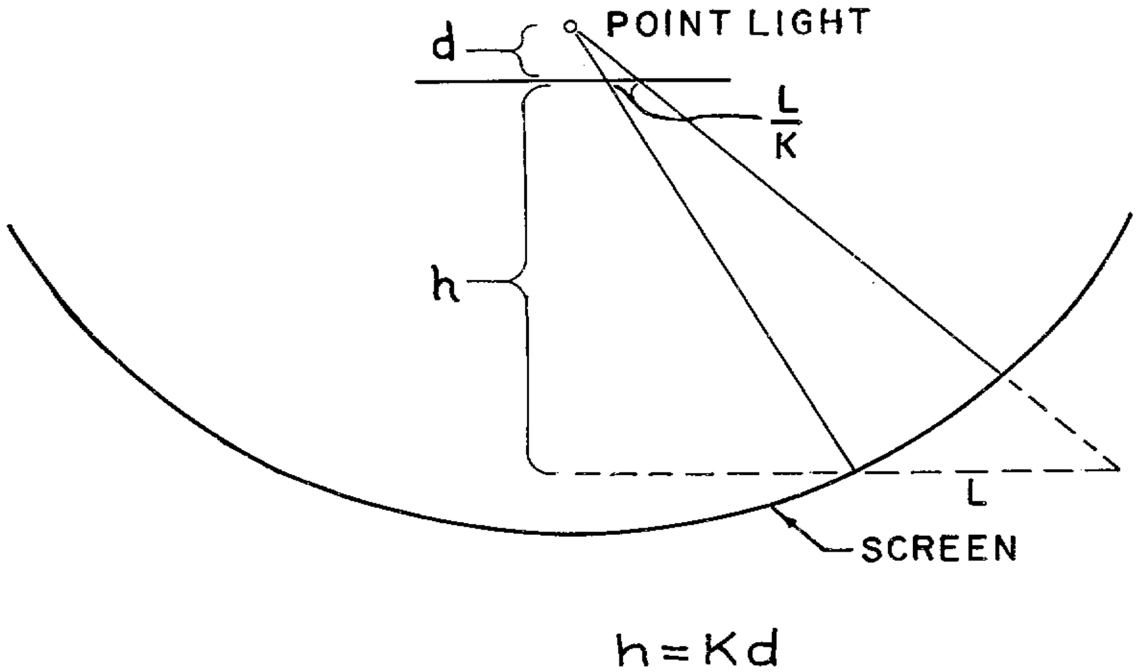


Figure 5. Point Light Source Scale Factor

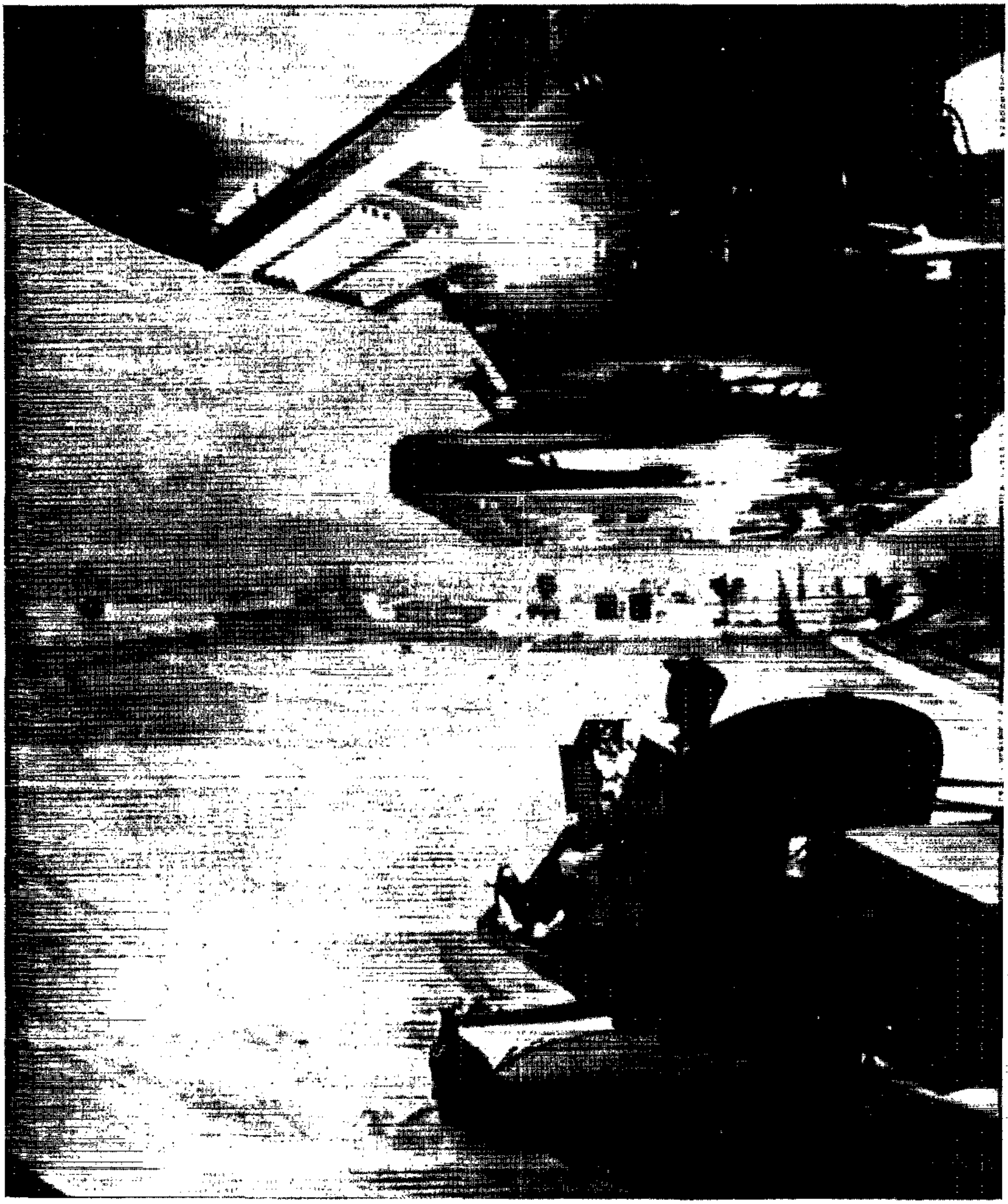


Figure 6. NAVTRADEVCEN Devide 2-FH-2 Point Light Source Helicopter Trainer

transparency is used with scale factors up to 2500:1 or larger. The photo of the scene, as shown, appears distorted since the camera used for taking the photo was located a considerable distance from the point light source location.

The NAVTRADEVCEN Visual Simulation Laboratory equipment indicated in figure 5 includes a point light source, a 250° wide screen, several semi-photographic color, and black and white transparency, a transparency drive mechanism, the hydraulic motion platform, hydraulic power supply, which is not shown, and the control consoles and associated electrical equipment. The motion platform is a compact design and is mounted on a hydraulic lifting mechanism. Quick disconnects are used to break the hydraulic lines so that the motion platform can be lowered onto a dolly and easily transported to another location, where it can be used with the wide-angle TV projection, for a future assault boat motion simulation. The motion platform was originally constructed by the NAVTRADEVCEN Laboratory Services Department from a Melpar design for Device 2F75 for a helicopter simulation project.

The motion platform shown in figure 7 has capability for ±15° pitch, ±15° roll, and ±6" vertical translation. The motion platform features a booster actuator to balance out the static load. It also has an important feature - an adjustable point of rotation in pitch. This is important because the direction of pitch acceleration and the nature of the pitch motion cue is highly dependent on the point of rotation. This is accomplished by the combined actions of the two pitch and heave actuators, which can be pre-programmed to represent the point of rotation of the simulated aircraft. They also provide vertical translation when they operate in unison. The point of rotation in roll is fixed and it is independently actuated from pitch and heave.

IMAGE QUALITY PARAMETERS

The quality of the projected scene, which can affect operator performance, depends on the resolution, brightness, and distortion of the projected image. The most important factor affecting resolution is the size of the point light, which for the Visual Simulation Laboratory light source is about .004 of an inch diameter. Other factors affecting resolution are the photographic resolution of the transparency and the magnification or the distance between the light source and the transparency. The image brightness depends on the projection distance, screen gain characteristics, the point light optical system, and the total radiant energy of the light source.

The two parameters of resolution and brightness have limitations which are a characteristic of the point light source system. The distortion problems(3), however, are more general and would apply for any visual system where the observer's eye is displaced from the light source position. These consist of size, position, and velocity distortion.

As shown in figure 8, size distortion results, since the observer views the screen from a point, just below the transparency close to the point light source. The image, however, is not exact due to distortions which depend on geometrical relationship between the observer and the point light source

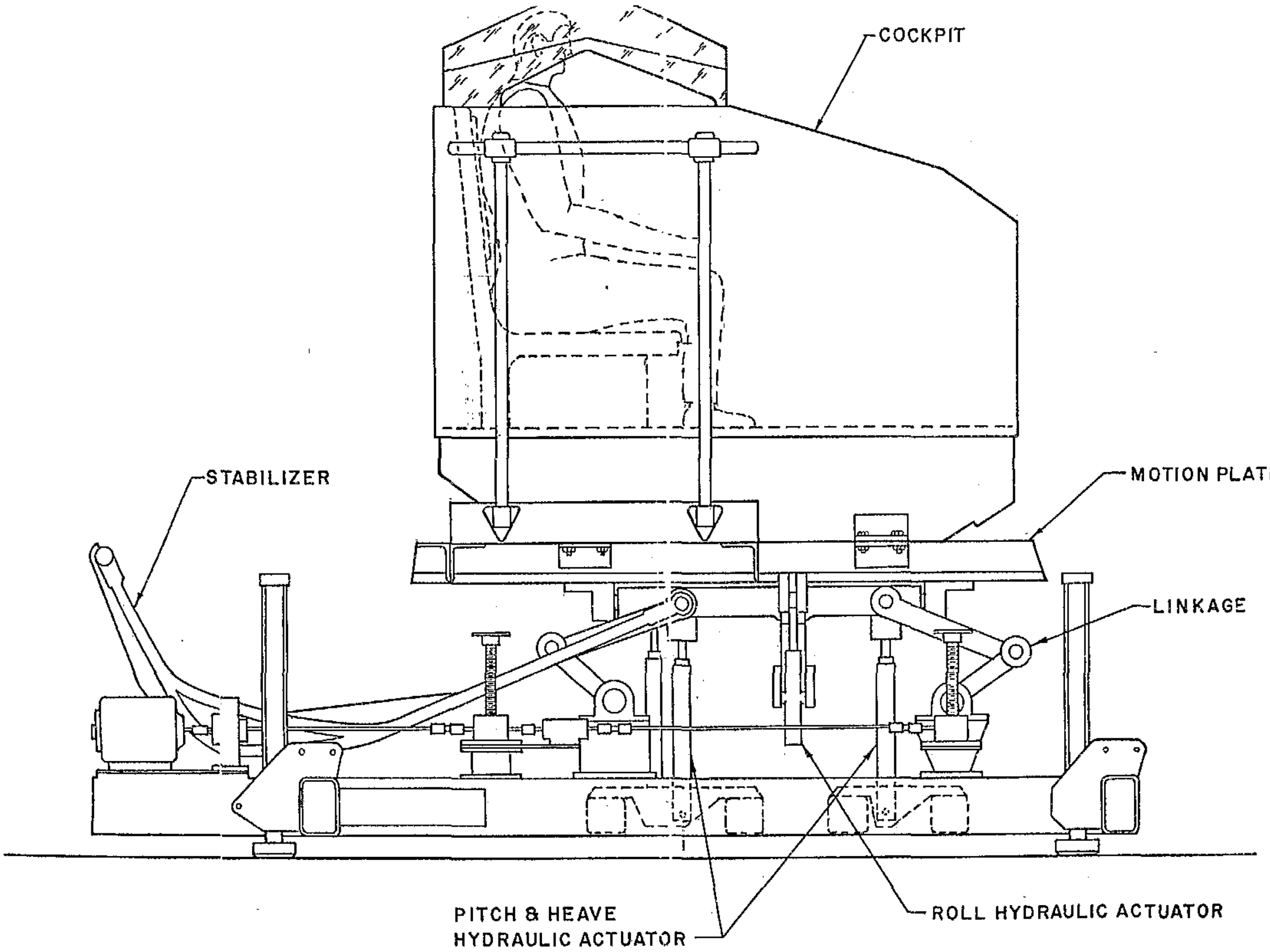
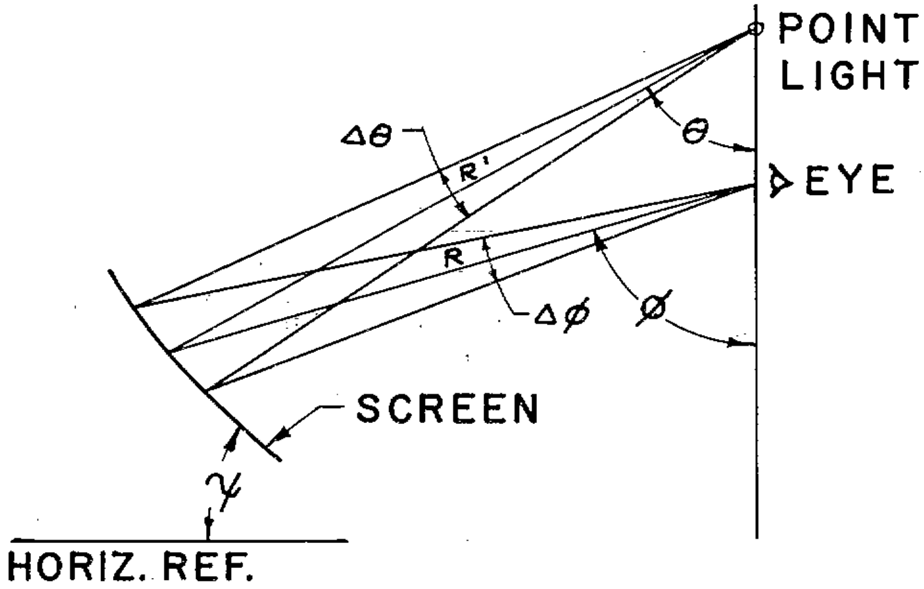


Figure 7. Motion Simulator

SIZE DISTORTION



$$S.D. = 100\left(\frac{\Delta\phi - \Delta\theta}{\Delta\theta}\right) = 100\left[\frac{R'\cos(\phi-\theta)}{R\cos(\theta-\psi)} - 1\right]$$

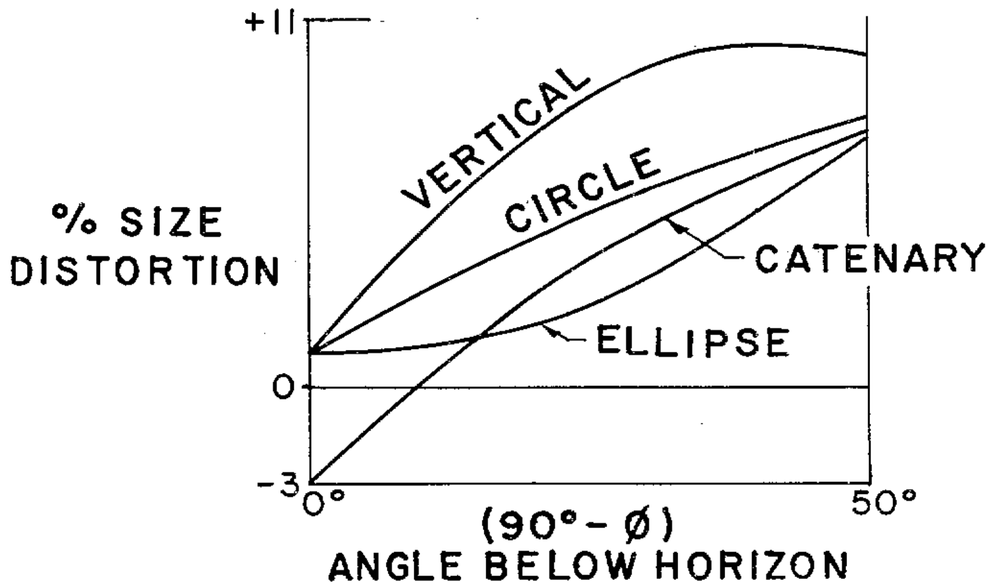


Figure 8. Image Quality Parameters, Size Distortion

as a function of the screen radius. This distortion is expressed as the ratio of the difference of the subtended angles and $\Delta\dot{\theta}$. From the curves for this expression, the catenary and the ellipse screen contours show the least size error. It will be shown later, however, that the ellipse has other disadvantages due to dynamic distortions. In general, the distortion in size of the projected image is primarily dependent on the slope angle of the screen surface and in most cases less dependent on the eye positions.

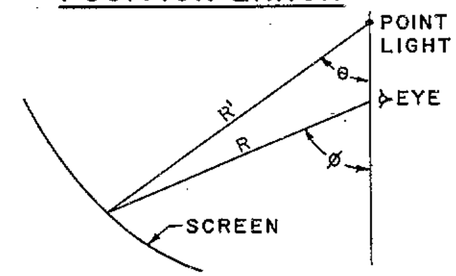
The error in the projected position, on the other hand, is a critical function of both the eye position and the screen shape as shown in figure 9. If the screen shape is such that the error in position varies across the screen, undesirable velocity and acceleration errors will occur. Since the eye is located below the point light, the image appears at a higher elevation than the true elevation. The horizon then appears to be above the observer resulting in the effect of traversing the inside of a bowl. The expression for position error can be obtained from simple geometry and is expressed as the difference between the angles ϕ and θ. We find the error is a maximum at 90° from the vertical and minimum of zero error at 0° from the vertical. This bowl effect is minimized by placing the projected horizon at eye level and using a separate sky projector.

A more serious error is the rate of change of the previous position error indicated in figure 10. This is the velocity error across the screen causing projected straight lines to bend or flex as the scene moves. The equation for the percent velocity error is obtained by taking the derivative of the position error and is shown as a function of the angle θ, the radius R and the rate of change of R with respect to θ and thus is a function of the shape of the screen.

The graph of velocity error is shown for circle, ellipse, vertical, and catinary cross section. The catinary curve appears the most attractive, since it doesn't show a rapid rate of change in velocity error across the field. In addition, the catinary was a very simple shape to construct by using sections of appropriate lengths of flexible sections of material whose distributed weight would generate the catinary curve. For these reasons this screen shape was selected for the Visual Simulation Laboratory.

With the imaging errors minimized to a satisfactory degree, the main problems remain with scene resolution and screen luminance. As shown in figure 11, only a portion of the light from the point light penetrates the transparency and the supporting plexiglass. The amount transmitted depends on the angle of incidence. Thus, the brightness varies across the screen with the highest brightness below about 40° incident angle and then decreasing with partial light reflection until the light is totally reflected at about 85° incident angle. This blackout occurs near the horizon and thus illumination for the sky and horizon is required through a separate sky projector. As will be shown later, this decrease in brightness is compensated by the increase in resolution due to the increase in range distance. Due to the variation of brightness across the screen a high gain specular screen such as aluminous paint could not be used. The screen used in the Visual Simulation Laboratory is a retro-reflective glass bead with a cloth backing, having a gain of about 2.6; the use of a retro-reflective screen tends to reflect more light back to the viewer in the cockpit and thus minimizes the detrimental effects of the off normal illumination. Screen brightness measurement from .1 to .3 foot lamberts were obtained with the

POSITION ERROR



$$\text{POSITION ERROR; } \phi - \theta = \tan^{-1} \frac{d \sin \phi}{R + d \cos \phi}$$

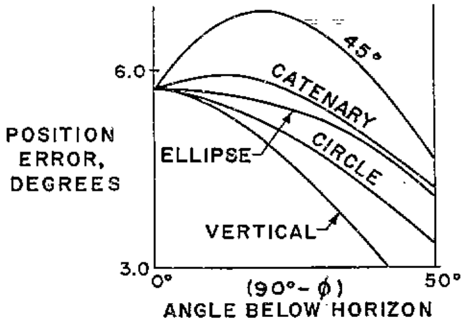
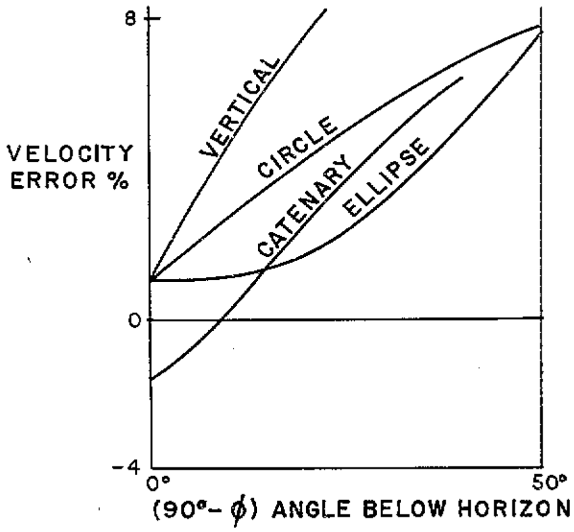


Figure 9. Image Quality Parameter
Position Error

VELOCITY ERROR



VELOCITY ERROR;

$$100\left(\frac{\dot{\phi}}{\dot{\theta}} - 1\right) = 100\left[\cos\theta - \frac{dR}{d\theta}\frac{\sin\theta}{R}\right]\frac{1}{(R^2 - \sin^2\theta)^{1/2}}$$

Figure 10. Image Quality Parameter
Velocity Error

TRANSMISSIVITY

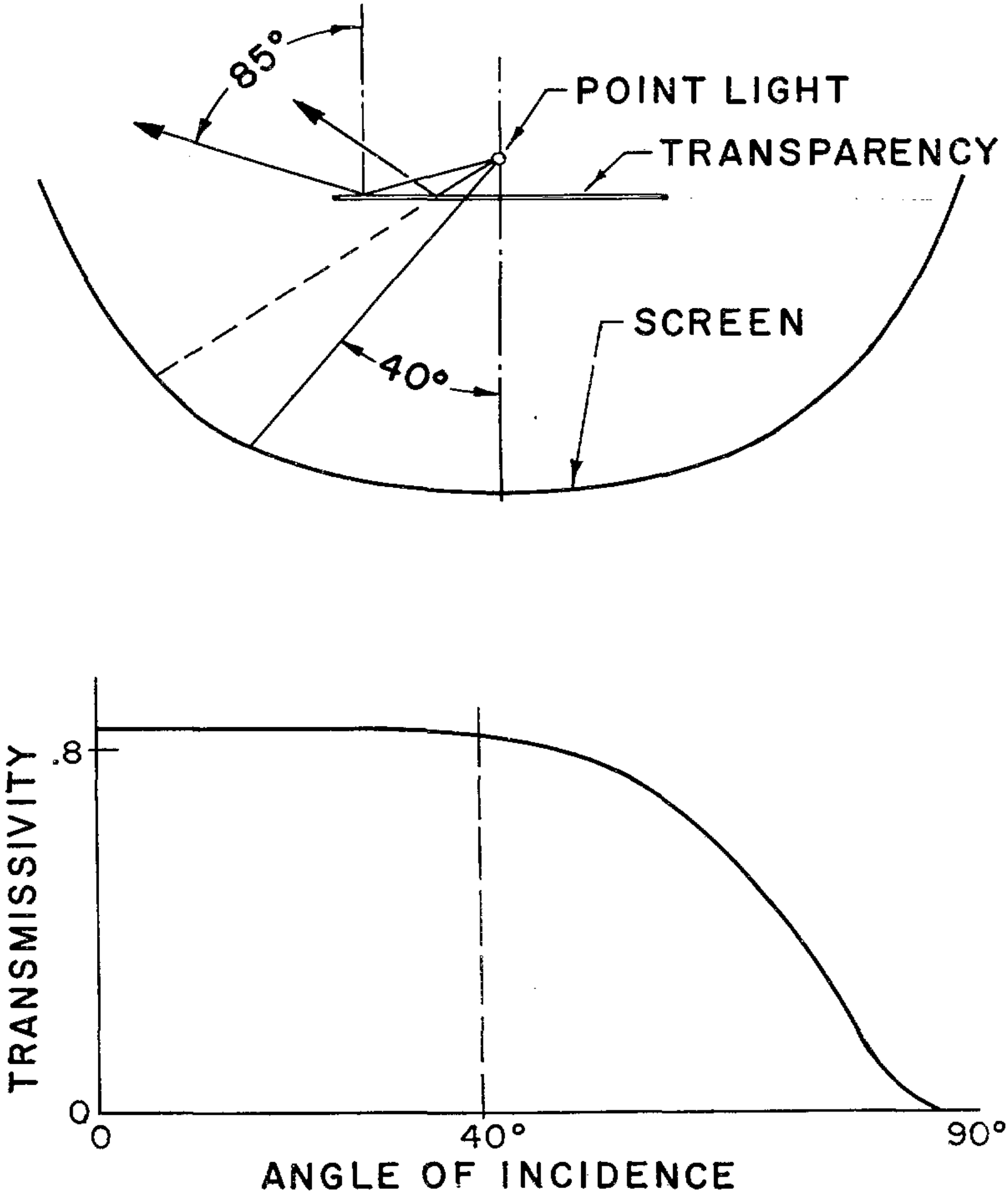


Figure 11. Image Quality Parameter
Transmissivity

laboratory equipment which is expected to be sufficient for the dark adapted eye for intended experimental purposes. The resolution of the point light source has been recently measured. It is shown in figure 12 to compare favorably to a television system at higher slant ranges. It can be seen that angular resolution for the point light system increases with a decreasing slant range. That is, the resolution deteriorates rapidly when the point light approaches the transparency or the slant range decreases below about 1/4 of its maximum. This is attributed to the effect of the size of the point light source on resolution. This also means that, when the transparency images are further away from the point light, the improvement in resolution compensates or offsets the previously mentioned loss of brightness with angle of incidence with the transparency. It is also noted that changing the transparency scale factor will shift the resolution curve. Thus, comparisons with other systems may require that these curves must be normalized to a common scale factor. It should be pointed out that the resolution indicated in figure 12 is available for the point light system with a greater wide angle capability than the television system.

MOTION PLATFORM REQUIREMENTS

Motion platforms in general, as stated earlier, cannot duplicate the translational motion of the aircraft exactly because of its limited motion capabilities. Thus, after an acceleration cue is sensed the motion must be washed out, that is it must be decelerated below the threshold of the operator's motion sensor before the platform reaches its limiting stops. If we consider the velocity of the Visual Simulation Laboratory motion platform during a uniform deceleration we see from figure 13 that it forms a parabolic envelope which is the limiting displacement of the motion platform cues. This envelope determines when the washout is to occur in accordance with what the velocity of the platform is at a certain position. The constant K would be selected so that the deceleration would be below the threshold that a person can detect. We can see from the curves for displacement, velocity and acceleration that the washout takes a considerable portion of the available distance. The washout is accomplished by using a switching circuit which is analogous to the platform motion equation. In this equation the constants K_1 equals 1 or zero so that when the platform is tracking the motion signals from the computer, $K1 = 0$ and only the tracking terms remain. When the velocity reaches a value which corresponds to the position as determined by the washout envelope, K_1 then equals 1, and the first tracking term is cancelled leaving the washout term.

In the case of the pitch and roll for the normal landing type problems the attitude or angular cues could be represented fairly closely. For this reason the present Visual Simulation Laboratory configuration includes washout only for the heave or vertical translation direction. The roll cockpit motion will include provisions for side force cues and return to neutral during a coordinated turn. The visual display will provide all the remaining apparent translational motions including the vertical motion independent of the cockpit heave. The visual display will be stationary during the pitch mode with the cockpit providing the pitching cue. In the roll direction, the visual display will move relative to the cockpit to give a true apparent roll cue.

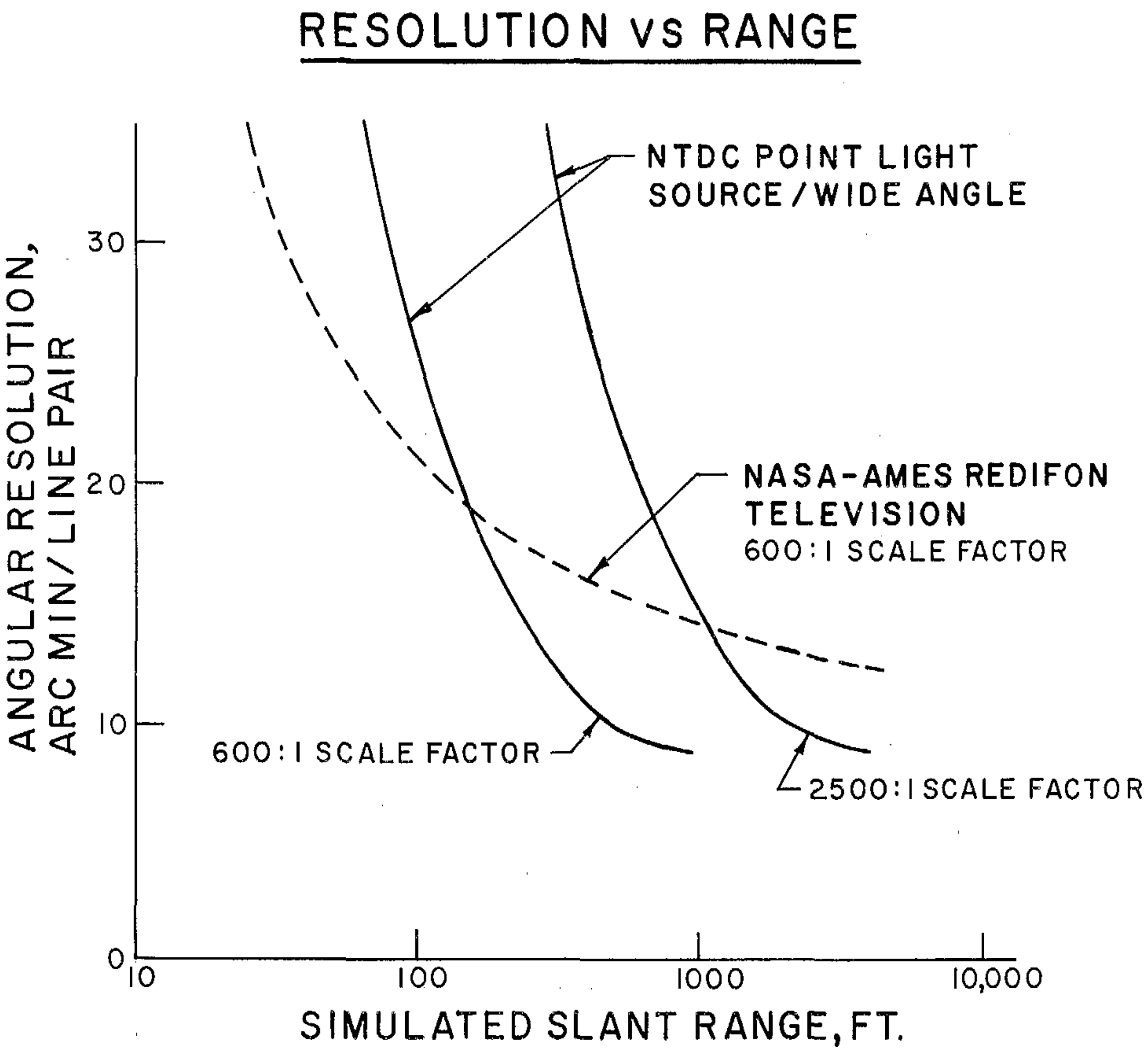
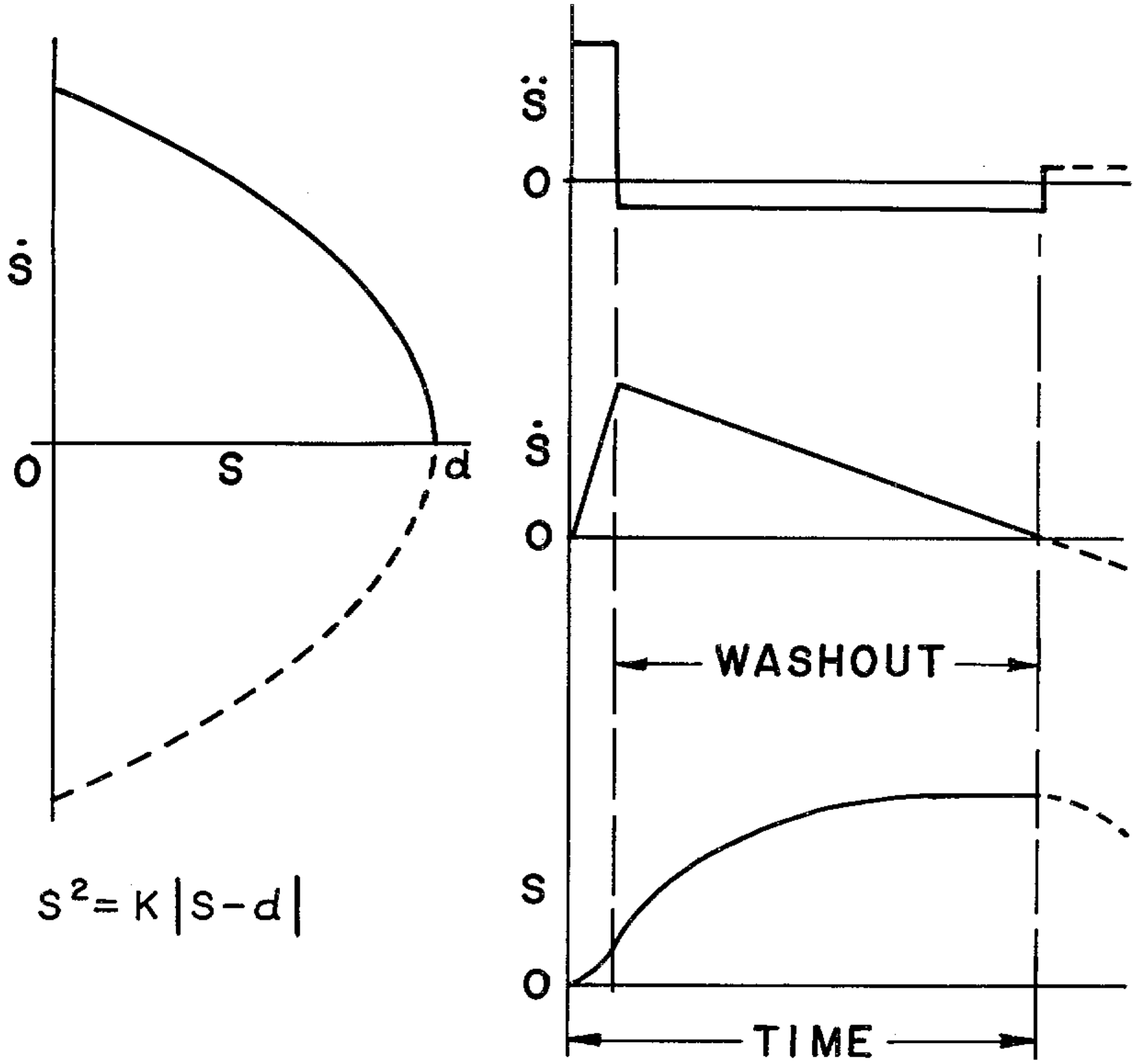


Figure 12. Image Quality Parameter Resolution VS Range

MOTION CUES



$$S^2 = K\,|S - d|$$

$$\ddot{S} = K_1 \dot{q} - \dot{W}_G$$

$$S = \int \left[\dot{S}\, K_{sn} + K_1 \left(-\dot{S}_n + K_2 \sqrt{S'_n - d} \right) \right] dt$$

Figure 13. Motion Platform Requirements, Motion Cues

The roll displacement will be made to rotate as a function of roll rate. This is a satisfactory method to provide a quicker motion response to compensate for the lag of the equipment using only computer signals which represent the true motion. This also means that the platform will return to neutral position when the roll rate is zero and when the displacement signal gradually decays to zero by the roll circuitry. The separate visual system meanwhile continues the illusion of a roll attitude.

Figure 14 indicates the possible forces resulting from a turn. For a coordinated turn which would not have a skid or side slip, the gravity vector side component is balanced by the centrifugal force during the turn which accompanies roll. Hence, the platform displacement would be zero and the visual system would continue the illusion of roll. However, should the pilot maneuver result in a net side force as in an uncoordinated turn, then an additional motion cue for a prolonged steady state force is required. The technique here, as mentioned earlier, is to use the gravity vector to produce the side force by rolling the simulator to the appropriate side depending on whether the force is outward or inward and then depend on the dominance of a strong visual cue to overcome the angular sensing mechanism of the canals of the inner ear.

Thus, we see that the motion platform does not provide an exact duplication of the aircraft orientation as well as the motion due to inherent limitations of the motion platform. However, accurate cues are required and the combination of the cockpit motion and visual display must indicate an accurate orientation of the aircraft. For the roll direction, as shown in figure 15, the visual display must therefore move in such a way that the relative motion between the motion platform and the visual display motion system produces an apparent aircraft motion, as viewed by the operator in the cockpit. On this basis the platform equation of motion, as previously shown, combines with the true motion signals from the computer to determine the drive signals to be provided to the visual display.

RECENT VISUAL/MOTION TECHNIQUES

A relatively new technique[4] which is currently used on other point light visual and cockpit motion systems, and under consideration by the NTDC Visual Simulation Laboratory for future modification is illustrated on the block diagram of figure 16 for the roll and simulated lateral directions. This system uses a high pass filter as indicated by the transfer function to introduce the high frequency components to the motion platform. The low frequency components to the visual system are obtained by taking the difference between the computer displacement signals and the filtered high frequency signals. This is in accordance with the human factor requirements mentioned earlier where the frequencies below the motion sensor threshold is avoided for the motion platform. Thus, the time constant used in the transfer function is selected experimentally to match the human motion sensor. The filters also provide the required washout of the motion cue. Phase lead compensation is introduced to the motion and the visual system by adding the velocity signals to the displacement signals. As with the displacement signals the high frequency components of velocity signal are directed to the motion platform and the low frequencies to the visual system. The true apparent motion, as discussed previously, is obtained by maintaining the current relative motion between the visual system and the cockpit. The lateral accelerations are introduced through a low pass filter. This provides

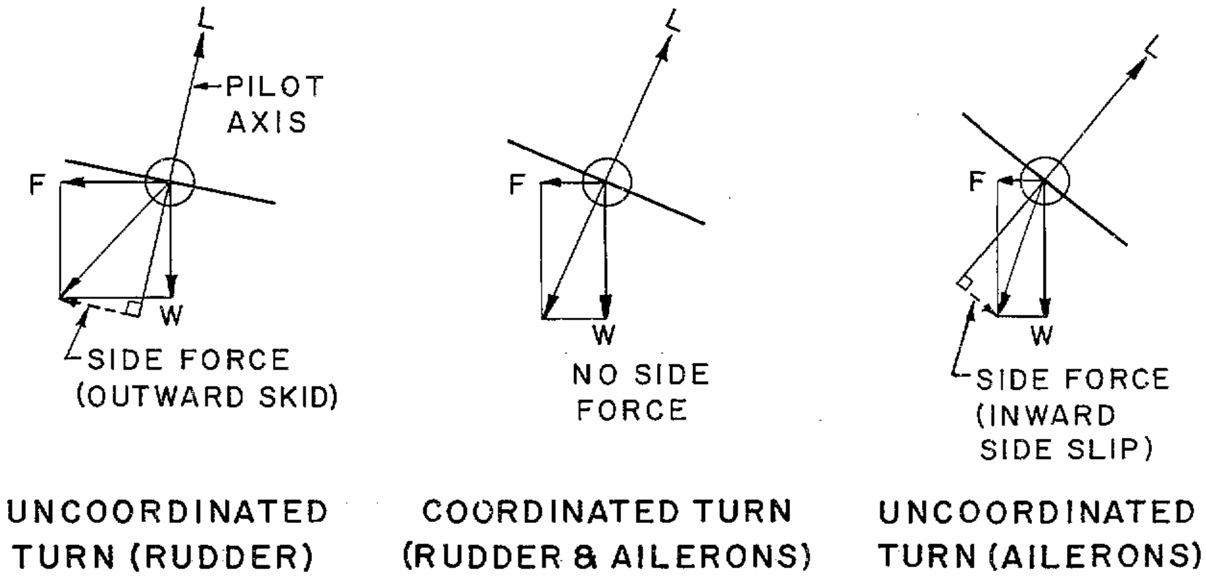
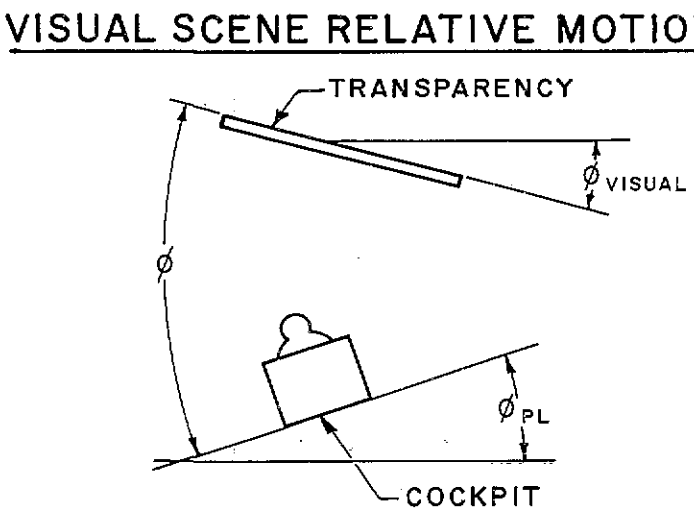


Figure 14. Pilot Turning Forces



$$\phi_{PL} = \dot{\phi} + \theta + \lambda$$

$$\phi_{VISUAL} = -\phi_{PL} + \phi_{VISUAL/PL}$$

WHERE $\phi_{VISUAL/PL} = \phi$

ϕ = COMPUTER SIGNAL (APPARENT DISPLACEMENT)

$$\phi_{VISUAL} = K_1\phi - \dot{\phi} - \lambda$$

Figure 15. Motion Platform Requirements
Roll Direction

LATERAL MOTION SYSTEM-VISUAL DISPLAY INTERFACE

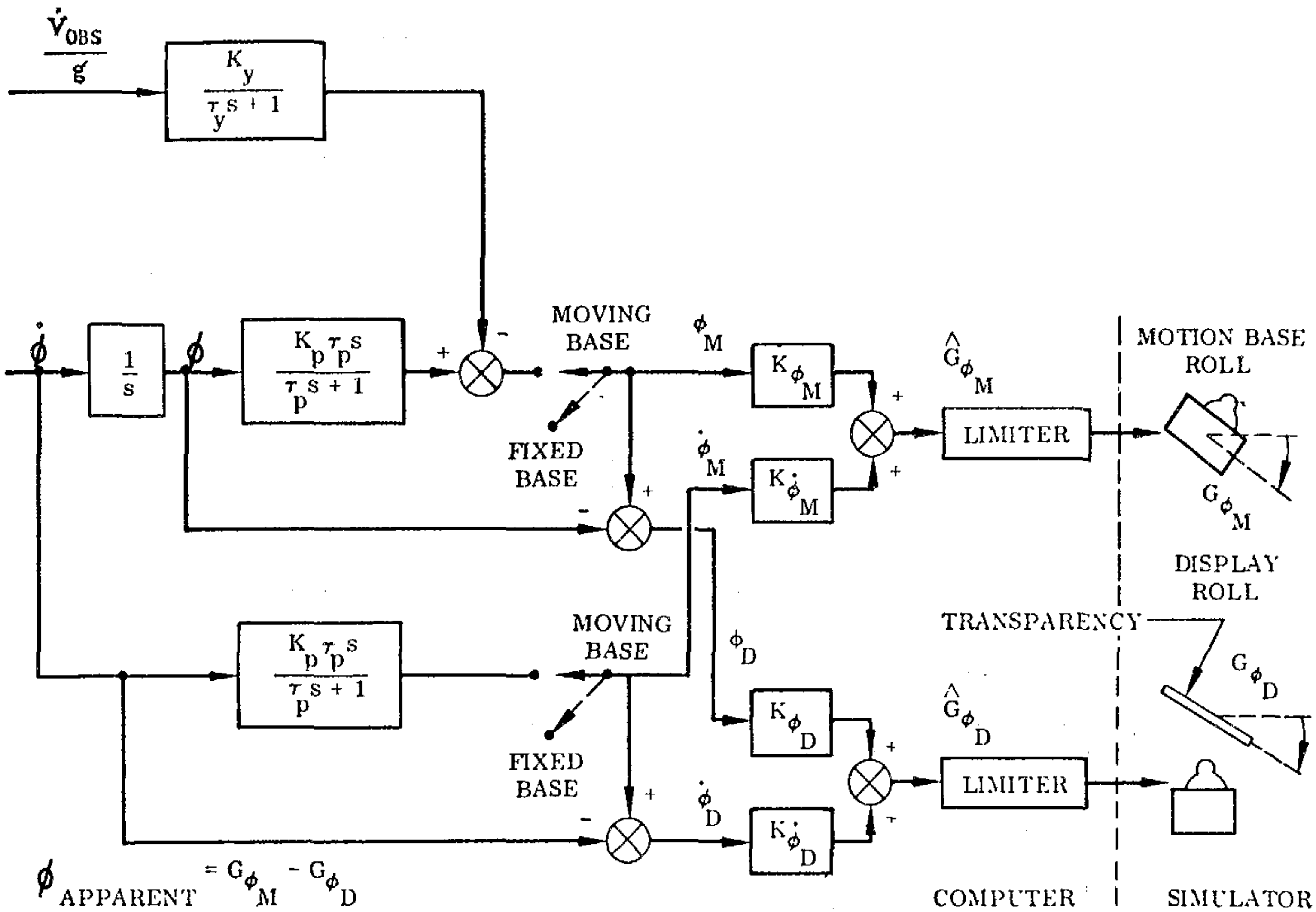


Figure 16. Block Diagram Recent Visual/Motion Techniques

a signal which will rotate the cockpit for a simulated side force by utilizing the gravity vector. In this case, the time constant is such that the high frequency components are filtered out so that the angular sensing ear canals are not affected, but the lower frequency linear utricle sensors will provide the prolonged acceleration effect during a side slip or a simulated uncoordinated aircraft turn.

COMBINING VISUAL AND MOTION SYSTEMS

In order to combine the motion and visual systems, the response characteristics of both the motion platform and the visual motion device must be matched to avoid visual distortions and false cues. Dynamic tests were performed on the NTDC Visual Simulation Laboratory equipment to determine the frequency response for both visual and motion systems. The results of these tests as shown in figure 17 indicated a drastic difference between the two systems for the pitch and roll directions. For example, as shown on the chart the 3 db cutoff for the visual basic motion device in roll was only .2 Hz while it is a respectable 1.1 Hz for the cockpit motion platform.

This unsatisfactory difference between the motion and visual system is shown again in figure 18 on the frequency response and phase lag curves for the roll direction. In an effort to make the two systems compatible, by making their phase lag vs frequency curves nearly identical, a study was made to determine the means to improve the roll and pitch visual system frequency response. This study indicated that the pressure drop in the 70 feet of pressure and return hydraulic lines from the hydraulic drive station to the transparency drive actuators were excessive and subsequent test data was obtained as shown on the next figure to verify the hypothesis.

If we compare the test data with slopes generated by the representative linear equation of motion as shown in figure 19, we see that the slope of $N = 1$ for the velocity exponent indicates that viscous portion of the curve dominates the loading. A slope of 2 for the inertia exponent is at a much higher frequency and therefore was not a dominant term. The hydraulic line size was subsequently increased which improved the frequency response by a factor of 4 from .2 Hz to .8 Hz. This would satisfy the requirement for the visual frequency bandwidth to match the bandwidth of the motion platform. Further electrical adjustments or compensation methods would be the next step to make a closer matching of the visual and motion drive systems.

An important point here is that the original specifications for the visual system would have been inadequate to meet the requirements for the present intended purpose of the equipment. That is, the maximum velocities and accelerations were specified and reported in the acceptance tests for the original equipment but the mechanical frequency considerations were neglected in the specifications.

As a recommendation, specifications for motion drive systems should include frequency response and phase lag information as well as a complete description of performance as shown on the nomograph in figure 20. The performance curve shown as an example is for the motion platform in the

ROLL	± 15°
PITCH	± 15°
HEAVE	± 6 IN
ACCELERATION	± ½ G
HYDRAULIC PSI	800 OPERATIONAL
	3000 TEST

Figure 17. Motion Platform Characteristics

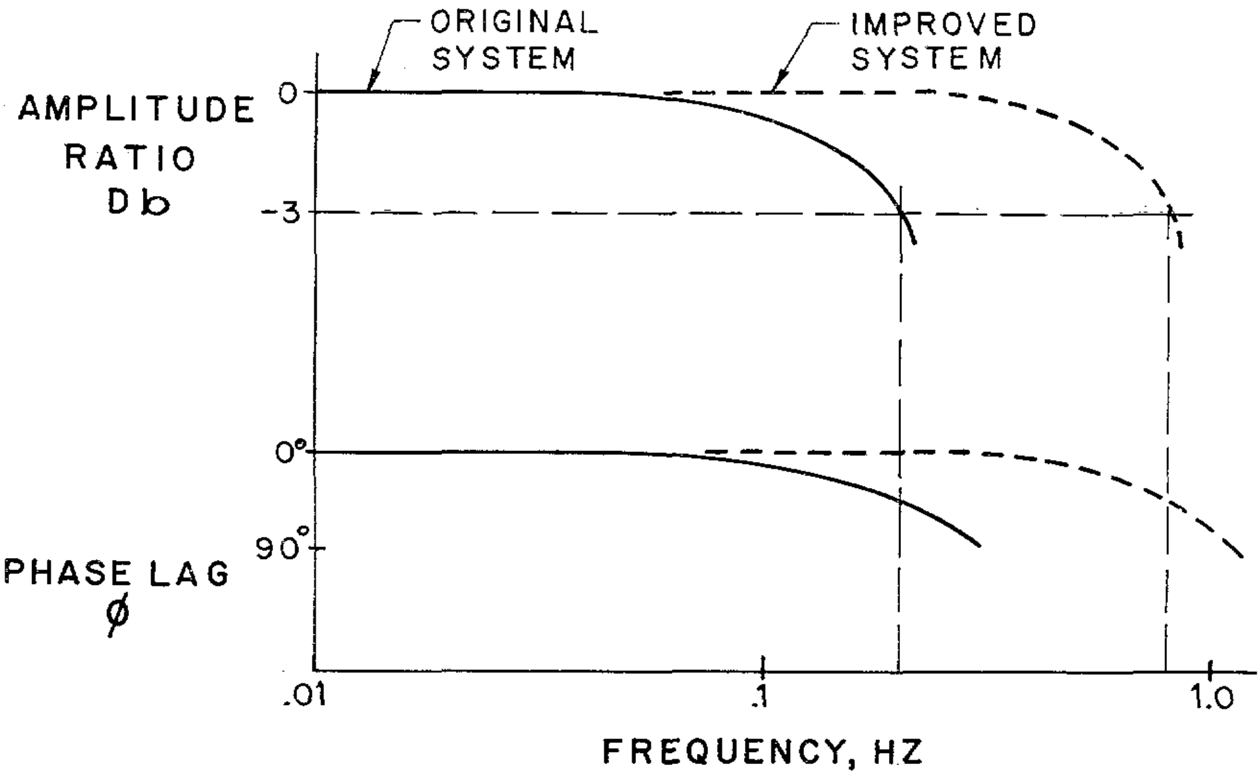
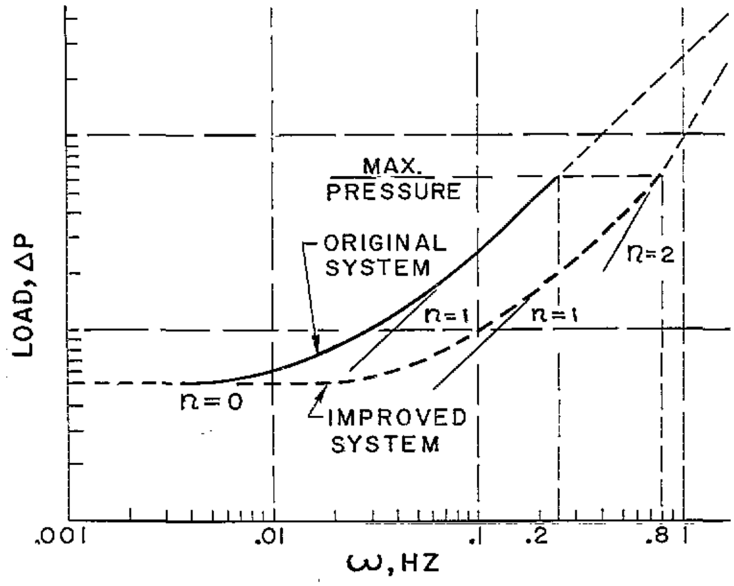


Figure 18. Roll Frequency Response



$$\Delta P = Ma + Bv + Kx$$
$$= M\ddot{x} + B\dot{x} + Kx$$
$$= (M\omega^2 + B\omega\angle 90^\circ + K)x_{MAX} \sin \omega t$$

Figure 19. Visual Display Mechanism Load

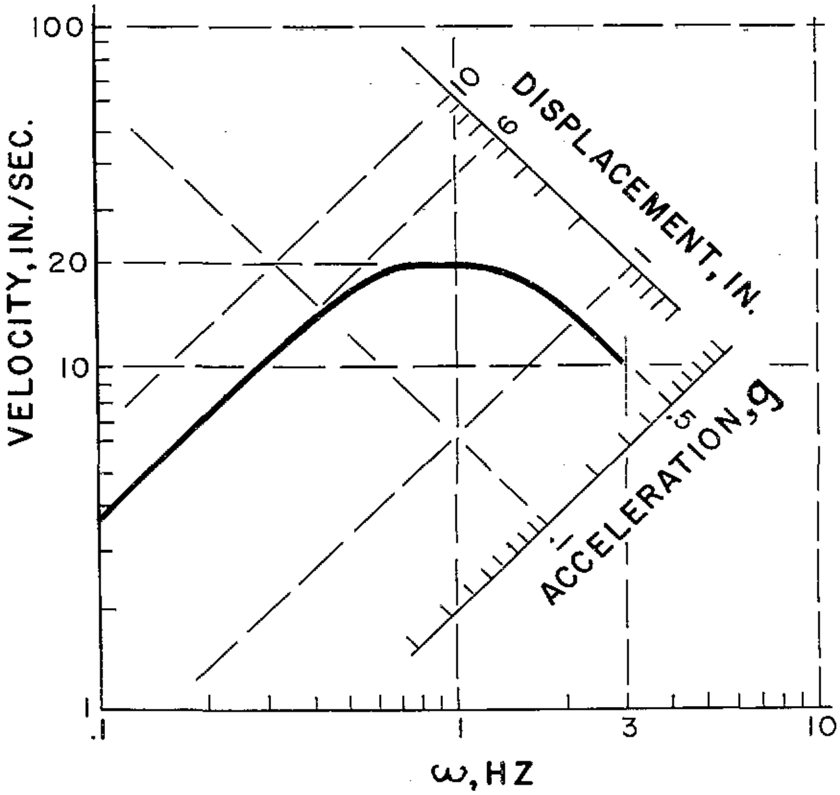


Figure 20. Motion Platform Performance

Visual Simulation Laboratory. This curve defines the limiting envelope of displacement, velocity and acceleration requirements at all points within its frequency bandwidth. This would be preferred to than just specifying maximum amplitude of displacements, velocities and accelerations without frequency considerations as has been apparently done in the past.

EXPERIMENTAL TEST PROGRAM

The present and future test and evaluation programs (except for platform motion) are based on recommendations from the various studies on NTDC Device 2FH4. The completion of the testing for the present task is scheduled for reporting in Dec of 1971. Validity tests of the T-28 Flight Simulator, will establish its perceptual fidelity to the aircraft it simulates less the display. Qualitative indications of the instruments response to cockpit control inputs have been completed. Quantitative tests of the instrument response for lateral and longitudinal stability have been started. The second item is Validity of Flight Simulator-Visual Display Characteristics. This includes dynamic testing of the visual mechanism for frequency response to meet the T-28 performance requirements which have been completed. The combination test will involve a pilot flying the aircraft to a contact flight landing. The criterion here will be pilot performance in making visual landings on a runway in accordance with rating techniques to be set forth in a report being prepared by Mr. Moe Aronson, Head of the NAVTRADEVCEN Visual Simulation Laboratory. The tests to determine design parameters for visual displays for specific missions would include experimental designs devised by the Human Factors Laboratory. The next item Validity of Motion Platform Characteristics include dynamic tests which have been completed. Further threshold acceleration measurements and threshold experiments are intended. And finally Specific Motion and Visual interactions will cover effects of visual distortion due to eye displacement to platform motion. This would also include effectiveness of math model of simulated motion cues.

The proposed tests beyond the present task would continue with tests to determine design parameters and would involve effects of reducing the level of brightness, and effects of varying contrast ratios of selected targets. The tests to determine application of training of specific visual tasks would cover (1) resolution or recognition of checkpoints for low altitude navigation (2) effects of transparency scale on low altitude observation, and air to surface attack missions (3) adequacy of forward visible missions (4) effect of limitation on visual display displacements in pitch and roll, (5) scoring of surface attack mission (6) training techniques studies based on initial flight conditions and (7) visual display for creating illusions of aircraft spins. The Specific Motion and Visual Interactions would also be continued from the present task to include determinations of amount of motion necessary to prevent conflict between visual and motion cues and to determine the extent of improvement of pilot performance with addition of motion.

SUMMARY AND CONCLUSION

In summation we can state that the recent efforts for combining the visual and motion systems indicate the trend for considering the man and machine as a system unit.[5] This is shown by the block diagram of the pilot and the simulator in figure 21. It is seen that the pilot has three

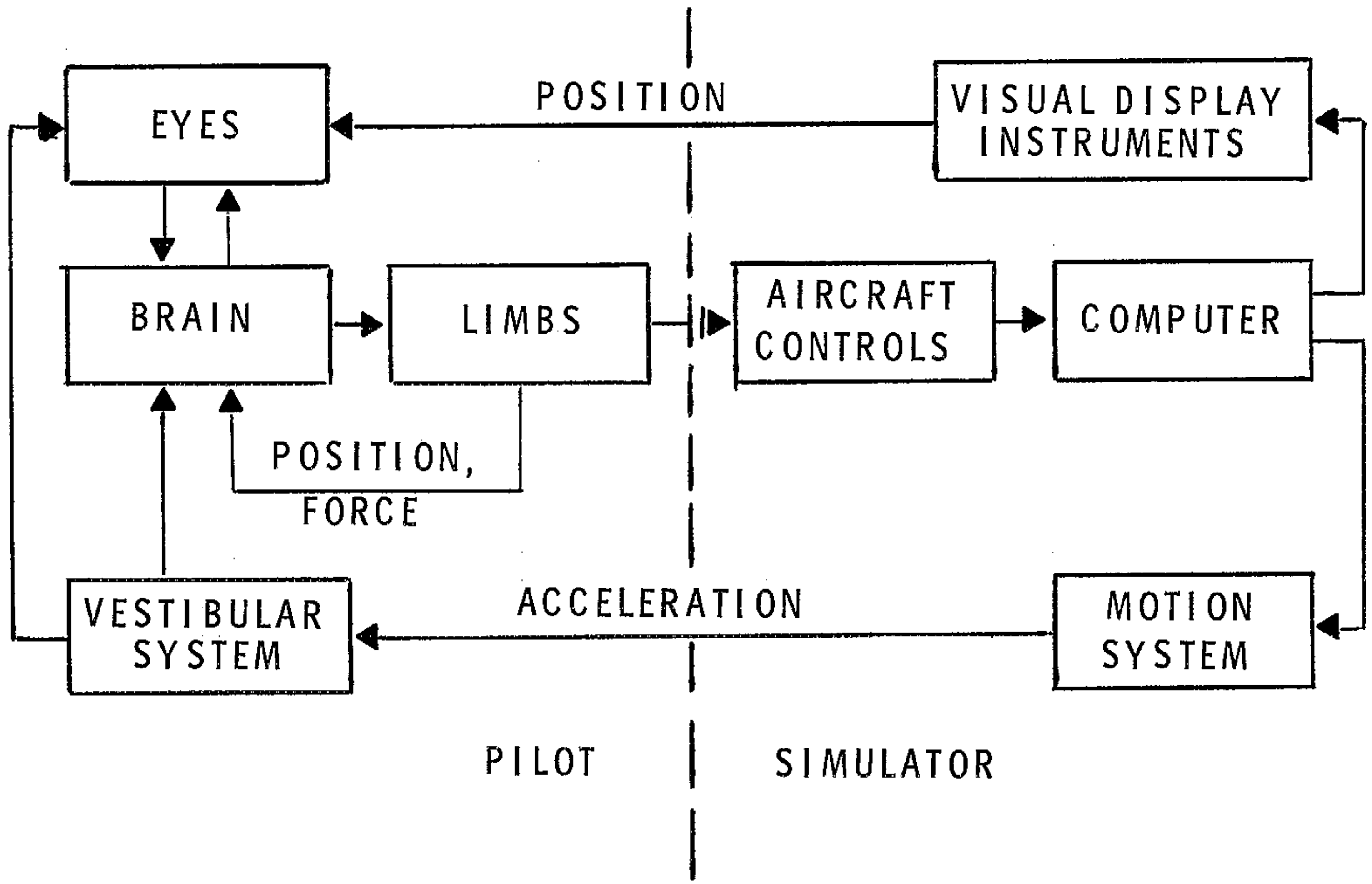


Figure 21. Block Diagram of Pilot and Simulator

main input sources for information: First, his eyes, which provide the main input. The information from his instruments and the visual scene tells him his attitude, position in space, and to a lesser extent, the rate of change of these variables. Second, his limbs, which tell him the position of the vehicle controls, the force he is exerting on them and the external forces on them. Third, the vestibular system which tells him when he is subjected to acceleration. And it also stabilizes the eyes during motion.

If a sudden disturbance is applied to the simulator he is immediately alerted through the vestibular system and is thus prepared to detect any visual or instrument changes. The visual indication will be delayed due to the inherent lag of the visual response, but the motion cue permits a faster pilot response for applying a correction to the pilot control. This brings another feedback loop into operation which tells the pilot how much he has moved the controls. An interaction occurs here since the aircraft acceleration generated by the controls displacement is sensed by the vestibular system and the pilot knows the correction is taking effect even though the instrument is indicating the result from the previous disturbance. In the case of the kinesthetic cues the pilot has even a quicker response to acceleration and has the added possible advantage, where the pilot can distinguish, between an aircraft response to outside disturbances and the aircraft response to his control movements. The pilot is thus able to predict what is going to happen to the simulator by means of these feedback loops, and build up pattern habits similar to those used in the aircraft. Whereas, in a simulator without motion, the pilot is deprived of the fast acceleration feedback and so he builds up an entirely different habit pattern.

In conclusion we may state that the point light source system is presently the only 360° non-programmed visual system in existence. Recent NAVTRADEVCEN reports have investigated multichannel TV systems as a potential technique for wide angle presentation but as yet no hardware has been built. The resolution and brightness is recognized to be the major drawbacks to the training utilization of the visual point light system, though not detrimental to the research tasks outlined. Plans have been underway for a new point light source optical system at the NAVTRADEVCEN Visual Simulation Laboratory which would provide improved uniformity of screen luminance and increased brightness by a factor of about four, and improved display resolution. In addition, laser technology has progressed so that laser light will be a possible light source in the near future. This could permit an extremely small spot with considerably more brightness than with conventional light sources. Finally, there appears to be a definite advantage for the addition of motion to visual systems, where the mission requires pilots to acquire habit patterns, similar to those obtained through actual aircraft training. However, considerably more basic knowledge is still required on the interactions of combined motion and visual cues for accurate representation of an operational situation.

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