# THE FARRAND GROUND EFFECTS PROJECTOR*

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## INTRODUCTION

The Farrand Ground Effects Projector is an outgrowth of the Mission Effects Projector which we designed and built for the Apollo Mission Simulators. Mission Effects Projectors were used to provide full color visual simulation for the NASA Apollo Simulators from the launch pad out to and including earth orbit, translunar trajectory and lunar orbit through the use of strip film. From lunar orbit to lunar touchdown a LEM Visual Simulator was used which the Farrand Optical Co., Inc. also designed and manufactured for NASA. The Ground Effects Projector, however, is specifically designed to provide real world views for aircraft flight simulation.

The Mission Effects Projector and the new Ground Effects Projector have very much in common in that they both utilize very wide full color strip film in multiple cassettes and their optical systems,as well as their functioning,bear a close resemblance to each other. The basic difference between the two systems lies in the fact that the Mission Effects Projector, in simulating orbital flights utilizes two-dimensional orthographic color strip film and distorts the imagery to provide a spherical earth view whereas the Ground Effects Projector utilizes continuous full color strip film to provide a full color presentation of simulated aircraft flight and rather than the generation of a spherical earth's view we now provide a perspective generation with vanishing points at the horizon.

One might ask why use strip film when one can utilize either cine-motion film or closed circuit television systems and map models. In the first place, film systems will always supply an inherently better view of the real world than any closed circuit television device can possibly achieve from the standpoint of color, resolution,and realism because films are actual photographs of the real world. Secondly, all film systems are far more compact than any model can ever be and aside from the increased realism, strip films in particular do provide wider operating margins. This last remark should be qualified. Visual simulators utilizing cine-motion projection systems are decidedly limited in translational excursions that can be provided to the simulator. It is the strip film system that provides latitudes and flight corridors far in excess of any model capability. Limits of a typical strip film are shown in figure 5. It is reasonable to ask at this point if film systems are so much better than television then why are closed circuit television systems still used? This question must be answered in several steps. First of all let us consider the cine-motion system. Cine-motion systems provide exceptional realism but there are certain compromises that one must accept.

*Patents Pending

For example,

a. The variation in aircraft velocity cannot safely exceed a ratio of 2:1 with respect to the filming velocity.

b. Cine-motion systems cannot come to a complete stop or cannot make a standing start at any place other than the vicinity where starts and stops were actually filmed.

c. Even with 70mm film the full frame cannot be used for the instantaneous view since a residue surrounding that portion of the frame projected for the instantaneous view is necessary in order to allow for lateral and vertical translations as well as the angular degrees of freedom. These two parameters of instantaneous film projection size versus maneuvering freedom are interchangeable so that available resolution with respect to field of view must be traded against the maneuvering envelope.

d. Since the maneuvering volume is inherently limited by the frame size it is obvious that all maneuvers must be contained well within the filmed view of each frame and so fly-arounds and wide approaches cannot be simulated.

Alternatively, the full color strip film system not only provides all of the advantages of better resolution and realism to a greater degree than the cine-motion film system but it also avoids all of the disadvantages mentioned above.

OPERATING PRINCIPLES

Before we explain the overall system and its advantages, as well as some of its minor disadvantages, it is best to illustrate what we mean by a full color strip film image generator and the difficulties that had to be overcome in order to make such a system functional. In figure 1 it is evident that an aircraft flying a course at constant altitude may photograph a very thin lateral slice of the earth below continously with a strip film camera. At the end of such a mission the "frameless" strip film photography would represent a two-dimensional scale model in full color of the terrain that was flown over. Additionally, if the thin slice photographed were well ahead of the aircraft say at 20° to 30° below the horizon, the two-dimensional rectilinear map model would include the aspect of three-dimensional objects. The right half of figure 2 is a portion of a full color film strip just described which is completely devoid of perspective but which includes aspect. The left half of figure 2 shows the same view but with perspective regenerated. This particular view is confined to include an angle from 30 to 50 degrees below the horizon. At this point, we should say that the method described herein for making a strip film is purely descriptive and far too complex and therefore does not represent the manner in which such a film would be actually evolved.

In order to use this rectilinear two-dimensional model as an image source for flight simulation, one must be able to effectively locate the observer's eye at any altitude h above the film strip as shown in figure 3. The observer must be made to view this film strip out to a tremendous distance such that the angle of no detail below the horizon is minimal, say on the order of 20 minutes of arc. This means that a tremendous expanse of strip film must be used and it must be projected or viewed at such an acute angle that the perspective in the strip film is regenerated. Needless to say, use of any film in this manner is optically impossible and perhaps this is one of the reasons that such a system had not been devised up until the present time. We have been able to provide exactly the required view by the use of optical systems employed in the Apollo Visual Simulator together with a new optical device that regenerates perspective from a perspectiveless film strip.

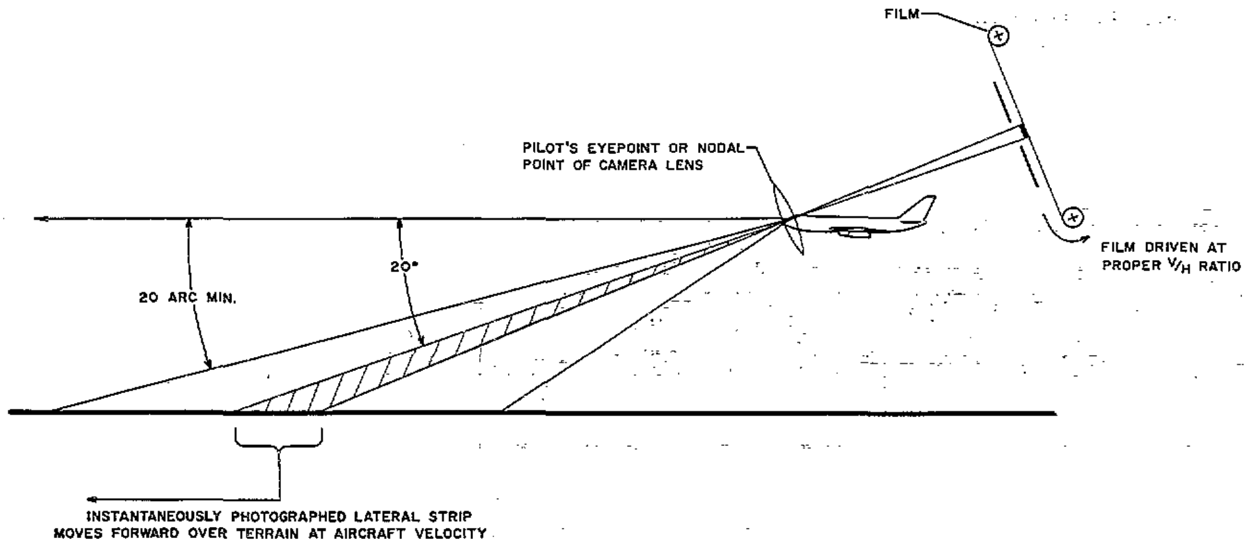


Figure 1. Forward Oblique Film Strip Fotography

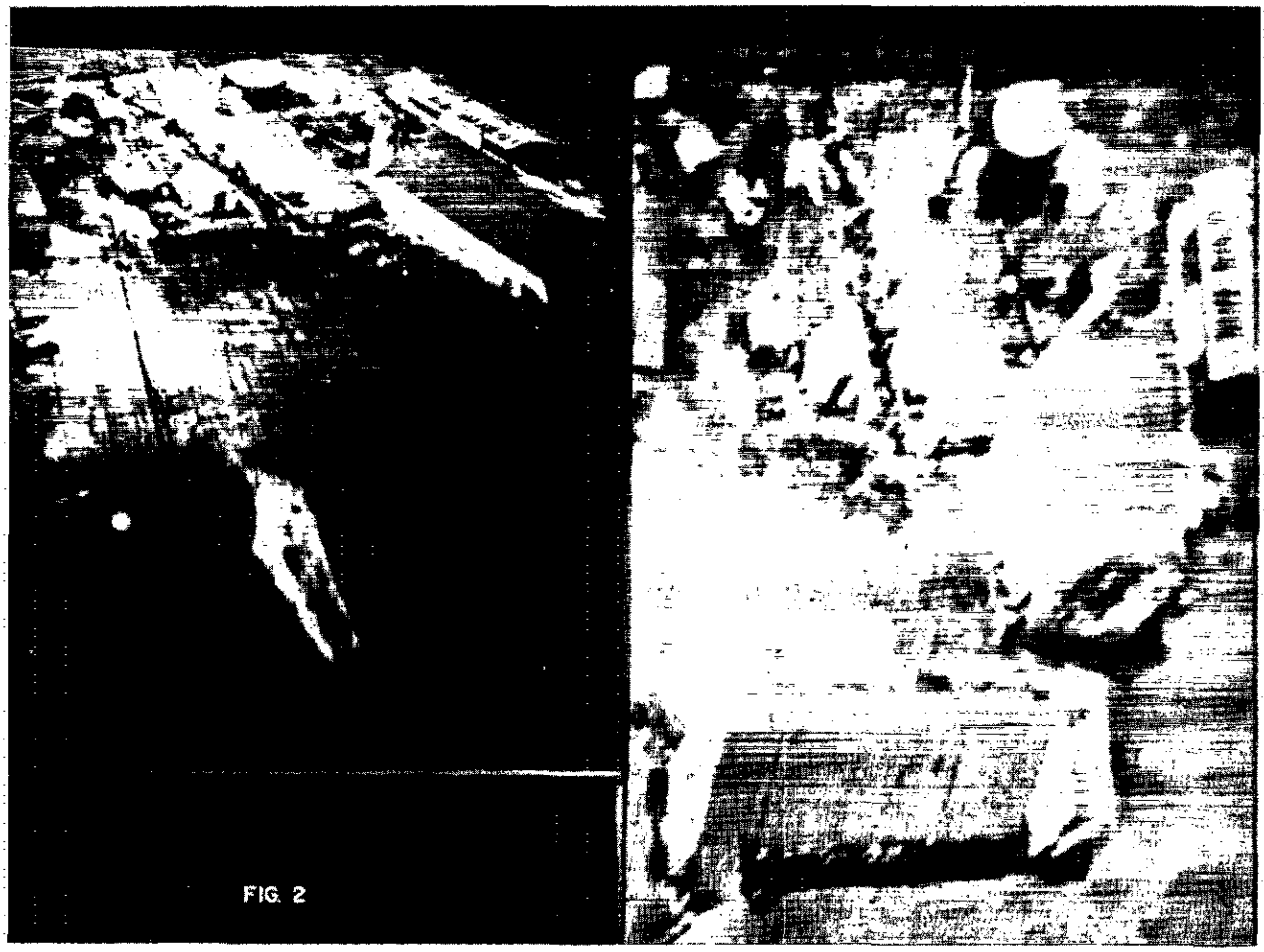


Figure 2. An Orthographic Strip Film View with Aspect is shown to the Right and the same View after Processing by the Perspective Regeneration System is shown to the left

Figure 3 illustrates the strip film principle used in achieving a reconstituted external world view. The system provides an instantaneous terrain view from 1.7h or 1.7 times the eye height forward of the nadir point to 150 h forward of the nadir point, an included vertical angle of approximately 54°. The Farrand Perspective Regeneration System permits the optical system to view the film in an orthogonal manner as shown, thereby avoiding illumination problems as well as shallow angle viewing problems. Note from figure 3 the angle at which the film would have to be viewed from an equivalent eyepoint in order to regenerate the proper perspective if the Perspective Regeneration System were not available -- an absolute impossibility!

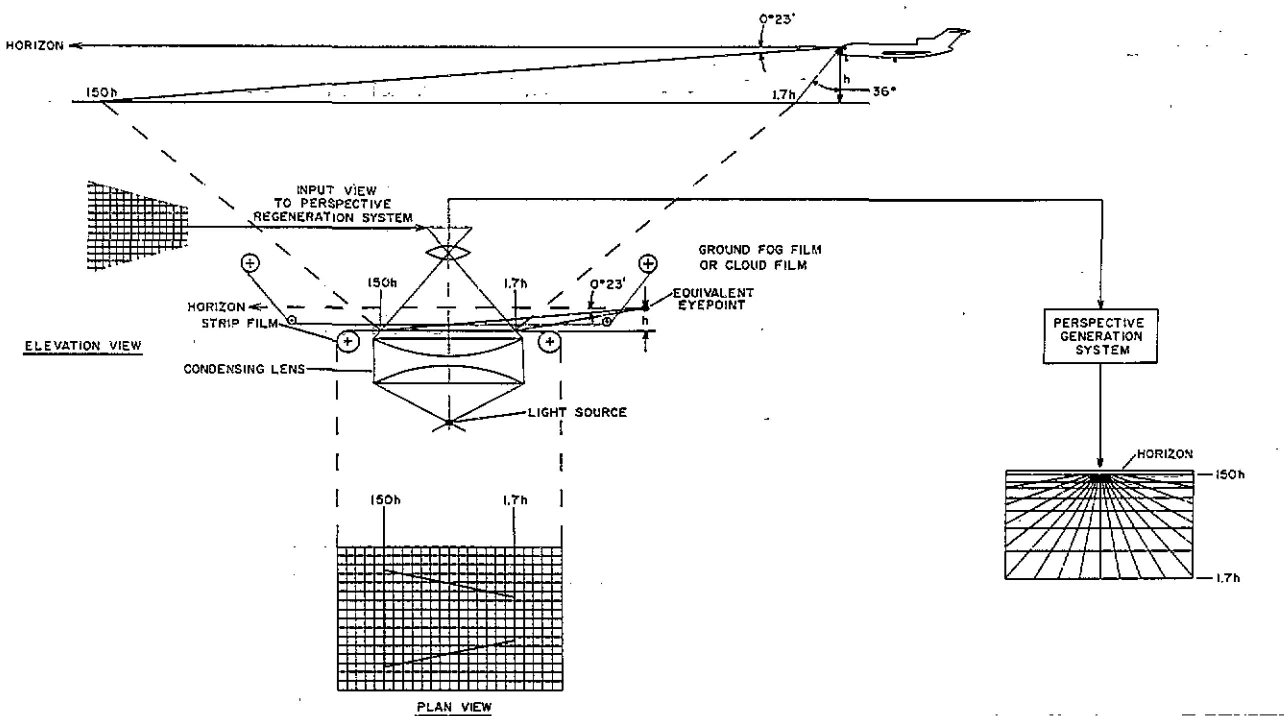


Figure 3. System Diagram

The rectilinear strip film is viewed in an orthogonal manner by a conventional optical system and the image is then processed by the Perspective Regeneration System, reconstituting the perspective out to 150 h or to within 23 arc minutes of the horizon.

Another noteworthy advantage of the strip film system employing a Perspective Regeneration System is the ease with which clouds or ground fog can be realistically simulated. The cloud or fog strip film shown in figure 3 is of linear density but becomes exactly analogous to the real world condition when the Perspective Regeneration System compresses the view vertically and laterally in accordance with elevation angle. This compression parallels true fog or clouds in the real world where the attenuation of visibility is a function of the angle of view through the fog. Because the fog source is of linear density, it is relatively simple to provide accurately repeatable RVR's (Runway Visual Ranges).

Resolution capability of any film system is directly related to the resolution capability of the film and the film patch size used to provide a given field of view. Considering a 136° field of view to provide 95° fields to both pilot and co-pilot with a 54° central overlap angle, the instantaneous patch size required of 5-inch and 9-inch strip films is shown in figure 4. The patches for both strip film sizes are compared to the instantaneous patch size of a 70 mm cine-motion system. When one considers the relative film areas used for projection, it is obvious that the resolution of either strip film system far exceeds the resolution that can be expected from the 70 mm cine-motion system. Additionally, the resolution increases as the angle of view approaches the horizon because of the compression or minification of the film area.

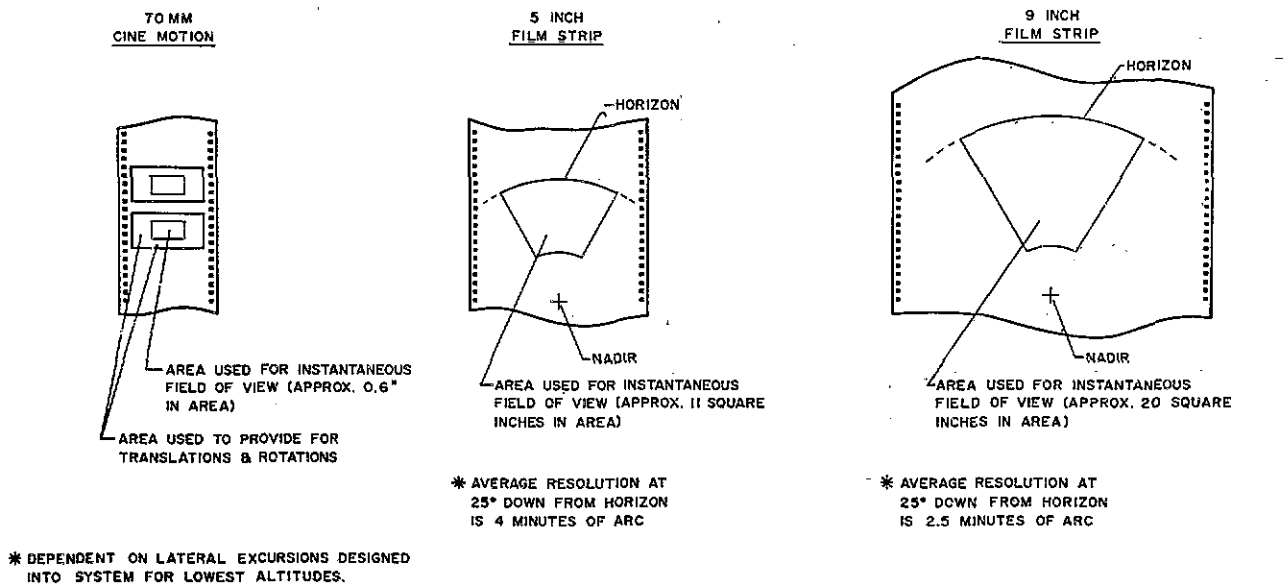


Figure 4. Comparative Sizes of Image Source

## PERFORMANCE CAPABILITY OF THE SYSTEM

Details of system operation will not be discussed at this point except for a few principles that will serve to explain the flexibility of the Ground Effects Projector. In order to achieve altitude variation, we employ a 2:1 varifocal lens system as well as a duplicate set of film cassettes. The reason for this duplication is so that when the varifocal lens in either cassette system approaches its limit of operation the adjoining varifocal lens and adjoining cassette system can be gradually brought into operation to replace the original system. In this manner one can leap-frog from one system to the other to almost any simulated altitude desired as long as different scale strip films are available. Switching from one set of cassettes to the other is accomplished by a cross dissolve system exactly in the same manner as was done in the Apollo Simulators. It must be noted at this point that the switching process from one system to the other is absolutely invisible to the observer.

The next point to be discussed concerns the lateral translational capability of a strip film system. Again referring to figure 4 it is seen that the patch sizes used for instantaneous projection do not extend to the edges of the film strip. To simulate lateral translation the film strip is merely translated laterally with respect to the optical system and when visual limits are reached, cloud banks and fog enter the scene so that no abrupt terminations are encountered. Translations are simply simulated because the perspective regeneration system is fixed with respect to the optical axis and, therefore, the horizon remains fixed with respect to the observer and only the film terrain input moves in accordance with the simulated motion of the observer.

Longitudinal translations or forward velocity can actually vary from rearward motion to zero velocity or hovering simulation on up through simulated supersonic and hypersonic velocity since velocity is a direct function of linear film speed -- quite unlike a cine-motion film system where frame rate determines apparent velocity.

The angular degrees of freedom are easily simulated by well-known optical techniques employing scanning mirrors for pitch, cassette rotations for yaw and a derotating prism for roll.

As an example of the maneuvering volume of the Ground Effects System we may refer to figure 5. Each of the rectangles shown in the length profile and in the width profile represent strip films photographed and reproduced in the laboratory to different scales to simulate different mean altitudes. Using a 2:1 varifocal system and using five film strips of different scale we can simulate flight anywhere from touchdown up to a 2287 foot altitude where the aircraft can cross the film strip boundaries anywhere at any time with complete freedom. Note also the extensive width profile which is 42,250 feet at 2287 feet of altitude, 16,800 feet at 925 feet of altitude, and 1350 feet wide at 75 feet of altitude. A final observation on the compactness of such a film model is contained in the note on figure 5 where the total film length for all of the scales shown is only 136 inches.

At this point it would be well to mention that the film strip system so far described is used to generate only terrain views. The sky is separately injected by another projection system. The Ground Effects Projector System not only provides unusual realism for ground fog with exact repeatability of RVR in the manner described previously, but strobe lights are also generated in a unique manner so that frequency can be varied and the strobe effect will never appear to separate from the lamps themselves as very often is the case with cine-motion simulations. A final point to be considered is that the visibility of this system as far as runway lights and runway detail is concerned is too good and must be attenuated to simulate the real world view. The reason for this surprising characteristic is that runway and terrain detail are photographed at a relatively low altitude and all objects are therefore photographed at relatively close distances. This detail appears in absolute clarity on the strip film and when it appears just over the horizon it is generated by large scale film detail which is compressed by the optical system so that such detail appears unrealistically sharp and unrealistically too visible. We might add, however, it is far better to purposely degrade a view than to try to upgrade a scene where the detail is not present.

An additional advantage of the strip film system arises from the fact that the film is practically indestructible. The wear and tear associated with cine-motion systems does not occur with strip film because it is not an intermittent drive, rather it is run through a gate at a simulated aircraft speed which is inversely proportional to the real world scale. Furthermore, the cassettes are so designed that the film itself never comes into sliding contact with any other material; it is in fact supported on layers of cooling air while in the film gate. In addition to this cooling air flow, the strip film is never subjected to excessive heat because of the relatively low flux density of illumination required as a result of the large patch size used for projection. Should a film eventually deteriorate, the cost for replacement is minimal since it involves reproduction of a film length of approximately 12 feet.

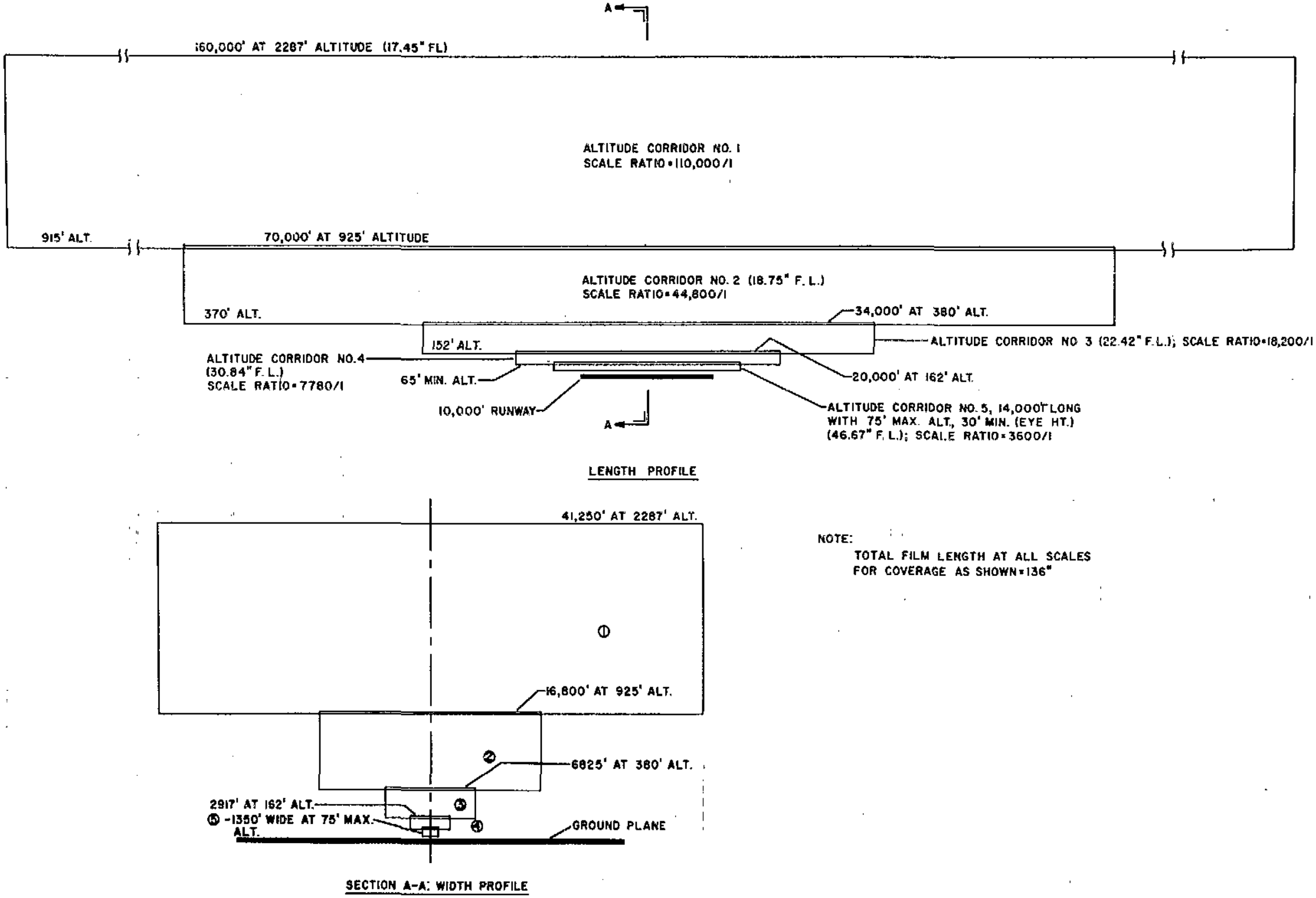


Figure 5. Composite Coverage of Terrain for Five-Inch Strip Film System

## LIMITATIONS OF STRIP FILM

Up to this point we have described the advantages of a film strip system without pointing out the limitations. So far as we know there are only three limitations associated with the Farrand Ground Effects Projector System. The primary limitation consists of an apparent lean of tall buildings, a defect which is introduced when regenerating perspective. Originally all detail is rectilinear, however, since buildings can only be represented in two-dimensions, when perspective is generated in the two-dimensional plane, the buildings are made to lean or point towards the vanishing point. For one or two-story buildings at reasonable simulated altitudes in excess of 500 feet the lean is not perceptible when flying at some forward velocity. This defect does not show up when landing on runways since runways are relatively flat with no vertical prominences visible.

The second minor defect concerns the appearance of buildings as we translate laterally in excessive amounts. Since building details are locked into the film we can never fly "around" them and so with large lateral displacements, buildings will always present the same face to the observer. Finally, the last limitation of a strip film system again derives from a two-dimensional film model where vertical prominences cannot be made to rise above the horizon. Fortunately, this limitation does not usually affect a commercial aircraft simulator.

## CONCLUSION

In conclusion, it would be well to illustrate not only the size of a film strip system such as we have described but also the fields of view currently available. Figure 6 illustrates the fields of view that can be provided to both pilot and co-pilot using an L-1011 aircraft as an example. Figure 7 shows the film strip image generation or Ground Effects Projector feeding an Infinity Display System where both units are mounted to an L-1011 simulator cab.

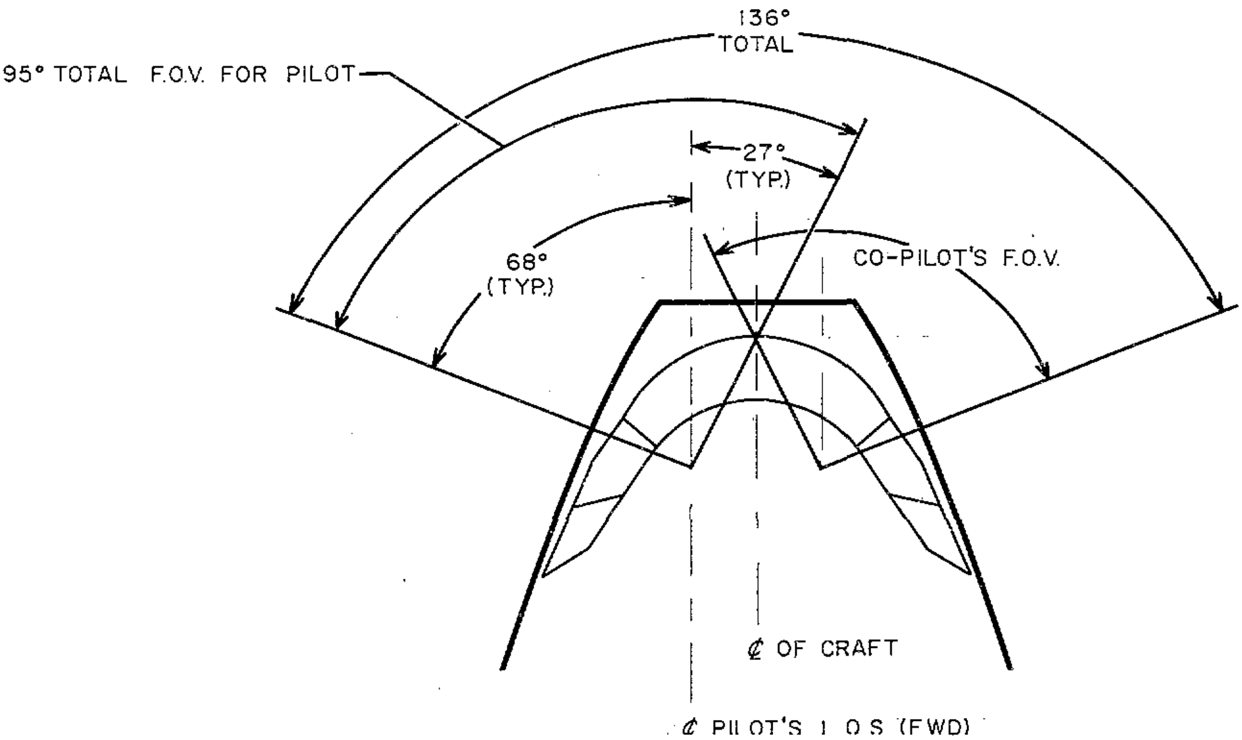


Figure 6. Fields of View, Pilot and Co-Pilot, L1011

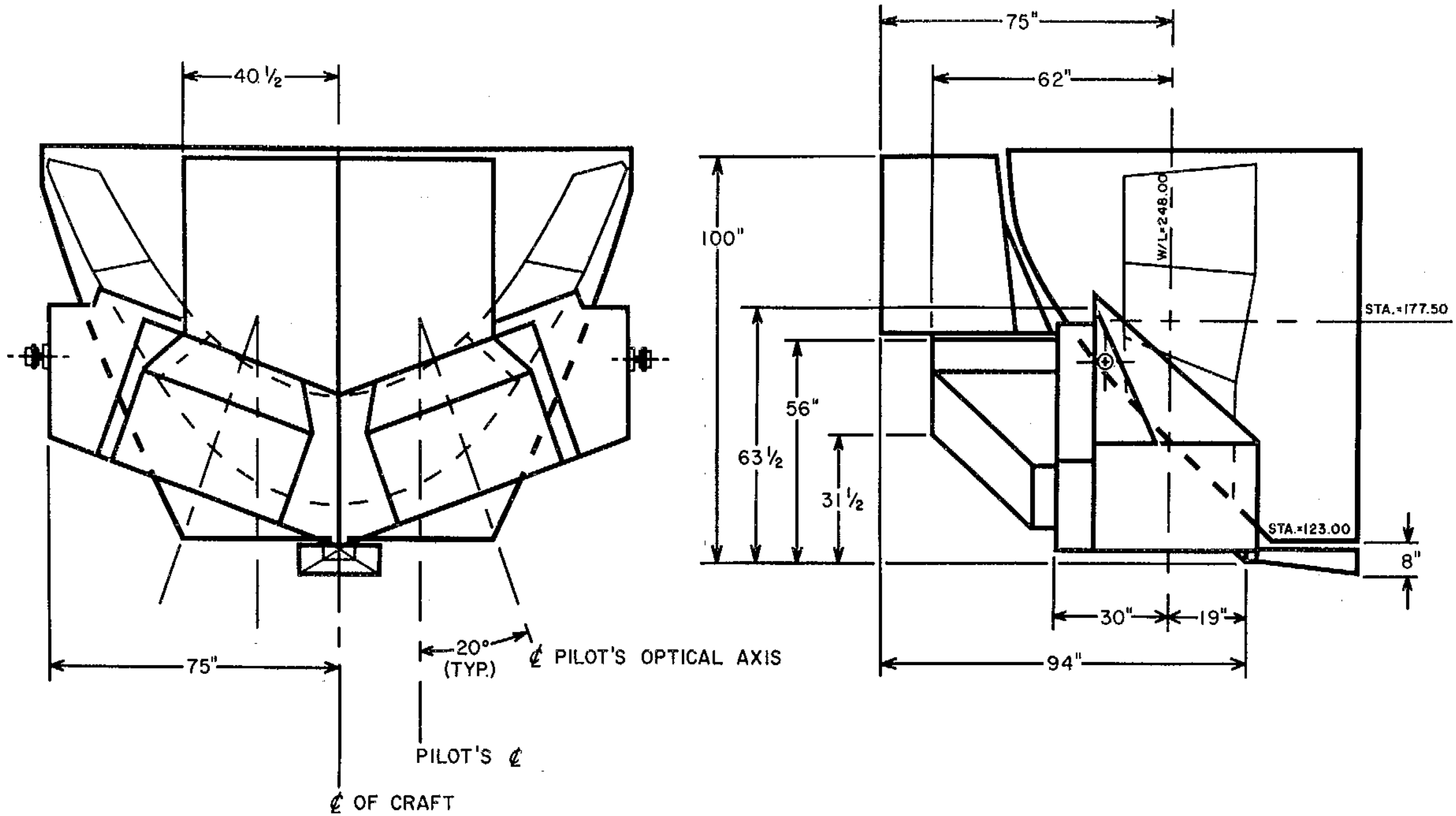


Figure 7. Visual Attachment Schematic, L1011