

IMPROVEMENTS IN VISUAL FLIGHT SIMULATION

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Introduction

Before describing improved forms of closed circuit television visual simulation, it will be as well to refer briefly to the type which has become almost a standard for CCTV landing and takeoff simulation.

This uses a terrain model about 40 ft long by 15 ft high, and at a scale of 2000:1 covers an area of terrain 14 x 5 nautical miles, allowing circling approaches to a runway 1½ nm long. A 625-line broadcast type colour television camera generates a picture for display to the pilot using Duoview or Monoview displays over a field of view of approximately 50° wide by 38° high. The view of the runway with the simulated aircraft on the ground gives good training value, but is not sharply focussed in the foreground due to the limited depth of field of the optical probe.

The minimum pilot's eye height above the runway is determined by how closely the centre of the entrance pupil of the optical probe connected to the camera can approach to the model runway surface without a danger of making contact and so causing damage; a figure of 12½ ft at the 2000:1 scale has been specified as giving an adequate factor of safety.

The minimum eye height is the key factor which determines the minimum model scale that can be used if a view from the correct height is to be achieved on the ground. If the minimum eye height could be halved, the model scale could be doubled, allowing either a) four times the area of terrain to be modelled for the same size model, or b) the same area of terrain to be modelled on a model of one quarter the size.

Vertical Image Compression (VIC)

Figure 1(a) shows a pilot's eye view of the actual runway together with a vertical object standing beside it, and Figure 1(b) shows the identical view in the simulator with a 2000:1 scale model and the probe at the minimum eye height position.

Figure 1(c) shows the view obtained if a 4000:1 model is substituted; the eye height is now twice too large, although the vertical object is correctly represented.

Figure 1(d) shows the view at 1(e) subjected to 50% VIC; i.e., an anamorphic distortion in the vertical direction of 2:1, centered on the horizon. The view of the ground plane, including the runway, is exactly the same as the view produced by the 2000:1 model; however, the vertical object is compressed to half its correct height.

This principle can be used to reduce the effective eye height and so reduce the model scale if the right conditions are observed, as will be described.

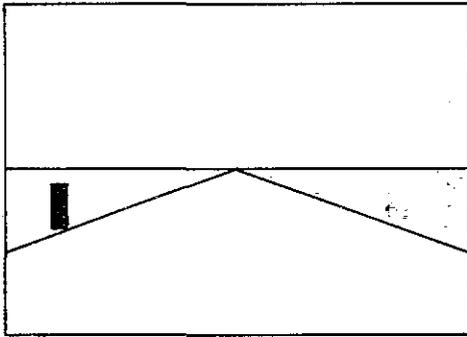
The anamorphic compression can be produced either electronically or optically; i.e., either by increasing the frame scan amplitude in the camera (to give compression in the display) or by optical prisms (compensated for chromatic aberration) in the probe.

Electronic VIC has been used in the Undergraduate Pilot Trainer (UPT) visual systems being built by Redifon for the USAF to reduce effective eye height and enable a 2000:1 model to be used rather than a 1000:1 model, with an eye height as small as 5 ft.

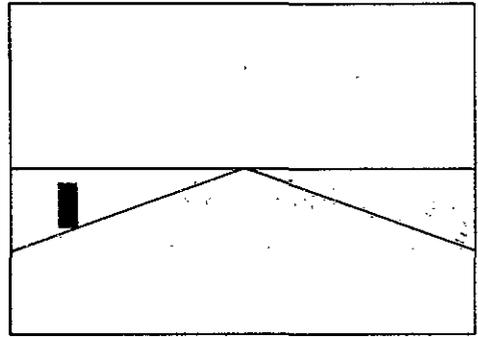
The standard optical probe has first of all been slightly modified by reducing a) the pitch mirror and mounting to the absolute minimum size necessary and b) the clearance between mirror and model by adjustments of the model/camera supporting structure to a smaller tolerance than previously. This has allowed the T38 aircraft eye height of 7½ ft to be simulated without VIC.

To achieve the 5 ft eye height of the T37 aircraft, approximately 30% VIC has been added by overscanning the camera frame scan. Vertical Image Compression is brought in smoothly under computer control prior to landing.

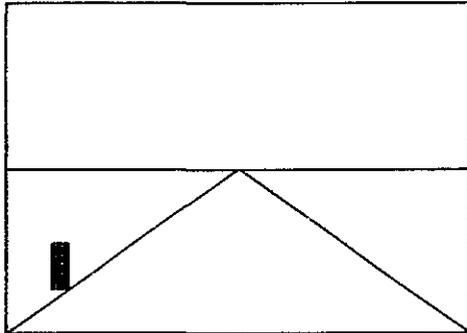
Tests have shown that if VIC is brought in only below 50 ft, vertical features such as nearby buildings are not visible in the field of view and the spurious compression of vertical objects shown in Figure 1(d) is not apparent.



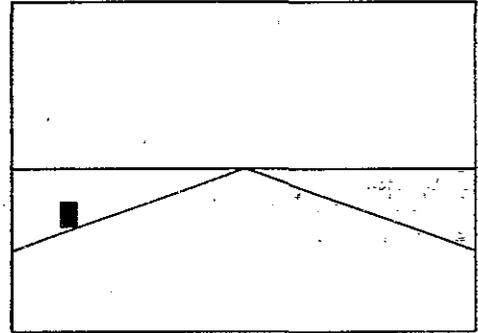
(a) ACTUAL VIEW OF
RUNWAY



(b) 2000:1 MODEL, PROBE AT
MINIMUM HEIGHT



(c) 4000:1 MODEL, PROBE AT
MINIMUM HEIGHT



(d) 4000:1 MODEL, PROBE AT
MINIMUM HEIGHT, 50% V.I.C.

Figure 1. Vertical Image Compression

It might be argued that two effects would impair the picture with this method of achieving VIC. First, roll causes a form of skew distortion because the scan expansion is applied to the optically rolled picture; however, roll must be at a minimum just prior to landing and no practical difficulty exists. Second, over-scanning the television camera causes the corners of the camera tubes to start showing in the displayed picture; again, this is a small effect and does not interfere with training.

Electronic VIC is a simple and cost-effective technique for dealing with an aircraft with a small minimum eye height.

Both the effects mentioned above may be overcome by using optical VIC in the probe. The anamorphic compression is applied before roll so that the skew distortion is eliminated. The vertical field of view picked up by the probe is increased as compared with the standard probe such that when this FOV is compressed back to the standard figure, no corner cutting occurs. Optical VIC is embodied in the new design of probe described below.

TCFE Probe

As stated in the introduction, the standard probe has a limited depth of field which somewhat impairs the sharpness of the view when the simulated aircraft is on the ground. Furthermore, both physical reduction in eye height by reducing probe/model clearance and the use of VIC (electronic or optical) bring nearer parts of the runway into view and so worsen this problem.

Probes operating on the Scheimpflug principle by which one or more lenses are tilted to improve the depth of field on the runway have been in use for some years. A new tilt lens principle, giving improved performances, has been described^{2,4}. This principle allows a small probe/model separation to be used with complete depth of field correction so that the whole model surface is in focus and is inherently free of loss of sharpness at the horizon with lens tilt. It has been designated the Tilt Compensation Field Element (TCFE) principle.

A prototype TCFE probe, designed and built for Redifon by the Sira Institute, England, is undergoing assessment at the time of writing. Final performance figures cannot yet be given but its main characteristics are:

Field of view : 50° horizontal, 38° vertical

Minimum separation of entrance pupil from model : $\approx 1\frac{1}{2}$ mm

Depth of field correction : complete down to $1\frac{1}{2}$ mm

Vertical image compression : optical, variable zero to 50%

Resolution : suitable for 1023 line TV system

Servos : high performance, suitable for military aircraft simulation

Roll and heading : continuous

Pitch : +120° to -120°

Wider field of view option : 67° horizontal if VIC removed

Applicability : new visual systems or retrofittable to existing

This new probe widens the scope of the CCTV visual system by allowing effectively very close approach to the model and providing enhanced image quality, particularly with the simulated aircraft on the ground.

Modelling Improvements

However the ability to see the model much more clearly at shorter distances makes heavier demands on the modelling, and if smaller model scales are used, these demands are accentuated. The TCFE probe development has accordingly included work on improved modelling.

The main problem area is the runway. Present runways are painted on a thin plastic sheet stretched on a frame, and have tiny acrylic prism inserts set in holes punched in the surface and illuminated from the back to represent runway and approach lights.

With the standard visual system, slight imperfections of the paint cannot be seen and it is uneconomic to improve the runway painting techniques. However, with the TCFE probe, the greatly increased resolution in the near part of the runway when the simulated aircraft is on the ground makes the use of printing or photographic techniques worthwhile.

Under day conditions, the form of the lighting inserts can be clearly seen with the TCFE probe, and it may be worthwhile using an improved more unobtrusive design.

In considering improvements in modelling to approach more and more clearly to real life,

cost can very easily escalate and make the whole visual system uneconomic. The important consideration is training value and satisfactory training is certainly given on standard systems. Enhancement of the picture presented to the pilot, as now becomes possible, should be shown to be related to enhanced training, and a collaborative research programme was set up last year between Redifon and Southampton University, England, to investigate the value of the various visual cues available from a CCTV terrain model in judging altitude.

Reduced size CCTV visual system

The use of the TCFE probe with its improved resolution, depth of field improvement and VIC features enables a better picture to be obtained from a 4000:1 model than can be obtained with the standard probe at 2000:1.

This makes a reduced size visual system possible covering the same area of terrain as the standard, but with a terrain model no more than 7½ ft high and 20 ft long. The lighting need only be one quarter the level used on the standard model and the ventilation can be correspondingly reduced.

Furthermore, such a high quality system can be fitted into a room of normal height and so building costs are saved. For military use containerisation of the system to allow easy resiting becomes feasible.

The cost of ownership over a ten year period of a visual system of this type could well make it an attractive proposition.

High resolution cameras and displays

It has been a firm policy in Redifon for many years to use 625-line broadcast-type television colour cameras, projectors and picture monitors for generating and displaying CCTV images for simulation. The great advantage has been that the equipment used has been very fully developed, has had extensive field service in the broadcasting industry, and spares and service are readily available throughout the world.

The 625-line television system together with the standard Redifon probe give a resolution at the pilot's eye in the simulator cockpit of about 10 arc mins., and for landing and takeoff this resolution is adequate. However, greater resolution would obviously be desirable and there are some training situations where it is necessary.

Black and white television equipment operating at around 1023-lines is well known and reliable, but colour equipment is not

generally available. Some interesting development work has been done on high resolution colour cameras³ but the problem of obtaining and maintaining registration between the primary colours at the higher definition standard is considerable.

Redifon has been responsible for development work in this area but at the time of writing it is premature to give results. The TCFE probe is capable of doing justice to television equipment working on 1023-lines.

Higher resolution can of course in principle be exchanged for larger field of view and the TCFE probe can deal with a 67° wide FOV if VIC is removed. Larger angles need a different design.

Inflight refuelling

Extension of Redifon CCTV techniques to inflight refuelling simulation has recently been achieved for use on a visual system being built for Boeing for the Advanced Warning Airbourne Control System (AWACS). Boeing is the prime contractor to USAF for the complete simulation equipment.

The requirement was to provide a view of the KC 135A tanker from a maximum range of about a mile and a maximum relative height of 1200 ft down to physical contact of the tanker's boom with the AWACS receptacle.

The boom was to be manoeuvrable (by the instructor acting as boom operator) and director lights were to be provided on the tanker, controlled by the instructor and (after boom/receptacle contact) by software to indicate elevation and telescopic status of the boom. Fuselage lights were also required.

The model of the tanker at 144:1 scale was added on an 8 ft x 15 ft blue (sea/sky) area at one end of the main 2000:1 landing and takeoff model.

The first problem was the relative height requirement of 1200 ft between the two aircraft, the maximum height of the probe above the ground being only 288 ft at 144:1 scale. This has been overcome by arranging to move the probe/camera away from the tanker model in the direction of the main axis of the terrain model to obtain the increased separation required and at the same time pitching the tanker model to maintain the correct aspect corresponding to a height change. Software ensures a smooth changeover from the normal height servo (used when the probe is close to the model) to the variable pitch regime.

The second problem is that at extreme range the small image of the tanker is surrounded by unwanted picture detail, in particular the terrain model at a different scale. The unwanted part of the picture is removed by generating electronically a rectangle surrounding the image of the tanker on the display and varying the position of the rectangle and its size under computer control to blank out all of the picture except the part inside the rectangle.

A standard electronic sky generator provides a horizon line with blue above it and white beneath it and the rectangle is inset into the blue part of this picture. This produces an image of the tanker against a blue sky above a cloud layer. To render the boundaries of the rectangle invisible it is generated with soft edges so that there is no hard transition between the two signal sources, and the luminance and chrominance of the blue part of the electronic sky generator is matched to the blue backing behind the tanker model.

The above techniques provide adequate simulation of the view of the tanker right up to contact. It will, however, be possible to achieve better performance with more elaborate visual systems if the requirement exists.

First, the scale chosen for the tanker of 144:1 is large enough to allow drives to be taken through the model to operate the boom, but improved smoothness would result from a larger scale. Second, the resolution of the television system/probe shows the tanker as a small spot at about one mile, whereas in real life considerable detail can be seen.

A scale of 50:1 is more suitable for the tanker to enable a really good model to be made, but at this scale one mile corresponds to 120 ft and this is an inconveniently large separation between model and probe and demands a large building.

As an alternative to physical movement to achieve the required range, variable magnification must be considered, either electronic or optical, in either camera/probe or display. However, the full range cannot be achieved by this sort of technique due to perspective distortion, so physical movement is necessary for the near part of the range with variable magnification for the far part.

Variable magnification in the display has the advantage that the higher resolution required at the far end of the range is easily obtained without using more than 625 scanning lines, whereas variable magnification at the camera does not increase the display resolution

at the far end of the range and a higher definition television system becomes highly desirable. Colour is not necessary in the display, however (if the same camera is not used for landing and takeoff); a 1023-line black and white camera and projector are sufficient and are fully developed available components. The probe used requires a larger entrance pupil than the standard Redifon one to do justice to the higher resolution television system.

If, however, variable magnification is used in the projector, the sky/horizon must be added from a separate source, probably an optical projector, and must not be too bright or it will show through the tanker image.

If the view from the tanker of the aircraft being refuelled is to be simulated, the situation is complicated by the view of the boom which must remain in view throughout the exercise and a) must not of course change in magnification and b) must be seen to enter the receptacle of the aircraft being refuelled.

It can be seen that improvement in inflight refuelling visual simulation above the standard provided on AWACS is by no means straightforward and at the time of writing the various alternatives need further consideration.

Aircraft Carrier landing and takeoff

One of the special types of visual system of importance in the simulation field is the carrier landing and takeoff visual system. There are of course particular problems associated with this type of system, and it is proposed to examine these, describe how they were met in previous systems built by Redifon and indicate further improvements for future systems.

The carrier must be constructed to roll and pitch against a seascape background and to be illuminated to represent day or night conditions. It must be provided with flight deck lights and a deck landing projector sight (hilo and meatball) or fresnel lens optical landing system (FLOLS) appropriately illuminated under computer control in accordance with the aircraft position and attitude. The carrier speed and direction must be allowed for in the flight dynamics programme.

For the systems built at Redifon (in particular an F4K Phantom for the Royal Navy, landing on Carrier Victorious), the carrier model was scaled at 800:1 (e.g., about 15-in. long) and all the lights on deck and on the mast simulated using flexible fibre optic light guides receiving light from a fixed

framework behind the model. Simple electro-mechanical shutters and filters were used to operate the meatball and hilos. As an alternative, a separate FLOLS light projector has been proposed in some specifications.

Catapult takeoff and arrester wire landing must be simulated and were provided by software subject to aircraft position on the carrier and operation of the appropriate controls by pilot and instructor.

To achieve realistic landing, simulation of ground effect is necessary, as the drag falls and the lift increases as the aircraft passes over the end of the carrier on the approach, and this is an important cue to the pilot.

To simulate "ground" effect it is necessary to know the height of the aircraft above the rolling and pitching carrier, and this requires some form of height sensor. On the Phantom, a light, sprung, ball-ended lever was attached to the probe and operated a linear pickoff over a range of zero to 50 ft. This scheme satisfied the requirement and the equipment is still operational, but the physical contact of the ball on the carrier deck causes wear and requires renewal of the surface (a stick-on sheet) from time to time.

Protection of the optical probe from collision with the model poses a more serious problem with a carrier than with a normal runway on land.

The standard probe protection techniques used on normal Redifon landing and takeoff CCTV visual systems include a spring-loaded nose cone which, on being touched, closes a contact which retracts the probe rapidly from the model. However, with the carrier it is possible to approach too low and hit the end of the carrier

before this mechanism can operate.

On the Phantom a thin wire, projecting forward, was used to give advanced warning of an impending collision. This wire was out of focus and for practical purposes invisible.

It is apparent that the functions of height sensing and probe protection could with advantage be achieved in a better way. A development programme in progress at Redifon on height sensing using infrared light beams is expected to lead to an improved method of carrying out both these functions.

Finally, for a clear view of the carrier deck, the TCFE probe will give a substantial improvement over the standard probe.

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ABOUT THE AUTHOR

DR. ARCHER MICHAEL SPOONER is Chief Scientist for Redifon Flight Simulation Limited, England. He holds a B.S. degree in Electrical Engineering and a Ph.D. in Electron Path Plotting from London University. He joined the Redifon Group in 1968 and has been responsible for a number of technical advances in visual simulation. As Chief Scientist, he is responsible for the research activities of Redifon Flight Simulation Limited. Formerly, he worked as an electronic development engineer for several British companies. He has made significant contributions to the recording of television programs on film, and to electronic special effects for broadcast television.