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A VISUALLY-COUPLED AIRBORNE SYSTEMS SIMULATOR (VCASS) - AN APPROACH TO VISUAL SIMULATION

DEAN F. KOCIAN
6570 Aerospace Medical Research Laboratory

In recent years Air Force operational units have experienced a continuing trend downward in the number of flight hours in aircraft that can be provided to each individual pilot for training and maintaining proficiency. This comes at a time when aircraft systems are becoming ever more complex and sophisticated requiring comparatively more hours for training to maintain the same relative flying proficiency. With increasing costs for fuel and aircraft and the failure of DoD funding to keep pace with these costs, the trend is almost sure to continue. In adjusting to the realities of keeping overall experience at a satisfactory level and reducing costs, procurement of aircraft simulators has become a necessity.

The rapid proliferation of simulators with no standard technical criteria as a guide has resulted in the evolution of several different design approaches. Most existing visual scene simulators utilize electro-optical devices which project video imagery (generated from a sensor scan of a terrain board or a computer generated imagery capability) onto a hemispherical dome or set of large adjacent CRT displays arranged in optical mosaics with the weapon, vehicle, and threat dynamics being provided by additional computer capabilities.

These large fixed-base simulators suffer from the following drawbacks. The majority of the visual projection techniques used in these simulators do not incorporate infinity optics which provide collimated visual scenes to the operator. Those which do are large and expensive and incorporate large CRT displays. The luminance levels and resolution of these displays are usually low and do not represent true ambient conditions in the real environment. Additionally, hemispherical infinity optics are difficult to implement and this technique requires excessive computer capacity to generate imagery due to the need for refreshing an entire hemisphere instantaneously, regardless of where the crew member is looking. In this regard, existing computer capability is not used effectively to match the channel capacity of the human visual system. There are also generally no stereoscopic depth cues provided for outside-of-cockpit scenes. Another important drawback to these simulators is that the visual simulation is not transferrable to the actual flight environment, i.e., the ground-based system cannot be transferred to an actual aircraft to determine simulation validity. Finally, most existing techniques are very expensive and do not allow the flexibility of incorporating other display design factors such as different head-up display image formats, fields-of-view (FOV), representative cockpit visibilities, and optional control and display interfaces.

This paper describes a new

A quite different approach to solving the visual presentation problems of aircraft simulators ~~is to employ the use of~~ visually coupled systems (VCS). For many years it has been the mission of ~~the~~ This Aerospace Medical Research Laboratory to optimize the visual interface of crew members to advanced weapon systems. This mission has been primarily pursued in two areas: (1) the establishment of control/display engineering criteria; and (2) the prototyping of advanced concepts for control and display interface. An important part of fulfilling this mission has been the development of VCS components which includes head position sensing systems or helmet mounted sights (HMS), eye position sensing systems (EPS) and helmet mounted displays (HMD). The author believes

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In the process of accomplishing this work, it has been ascertained that many of the current Air Force air-to-air and air-to-ground weapon systems problems can be related to deficiencies in the configurations of control and display components which interface the crew member to aircraft fire control, navigation, flight control and weapon delivery subsystems. These interfaces tend to either overly task load the crew member or prevent optimum utilization of innate visual, perceptual and motor capabilities. These limitations are especially apparent in fire control and weapon delivery applications where visual target acquisition and weapon aiming are required along with primary piloting tasks. Under high threat conditions, the flight profiles necessary for survivability, as well as mission success, dictate that all essential tasks be performed effectively, accurately and most important expediently. With the recent advent of advanced digital avionics systems, the control and display design issue is further complicated. The proliferation of dedicated control and display subsystems in current aircraft cockpits has necessitated the development of multi-mode displays and control input devices. In addition, more exotic virtual image display devices (head-up display/helmet-mounted display) and unique control devices such as the multi-function keyboard, helmet-mounted sight and fly-by-wire subsystems have appeared. In this regard, the design options open to the avionics as well as control and display designer are great, thereby generating a real need for human engineering design criteria to elucidate the image quality characteristics, information formatting and interface dynamics which optimize the operator interface with these advanced systems.

The process of establishing practical design criteria with the number of options that are available is a laborious and time consuming task, especially if validation in flight environments becomes necessary. Typically, flight testing is very expensive and does not allow flexibility as well as consistent replication of experimental conditions.

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Due to these factors, high fidelity ground-based simulation is the only realistic alternative. However, it now becomes necessary to develop simulation methodology, techniques and apparatus which are subject to flight test validation. It is felt that the unique capabilities of a visually-coupled system (VCS - combination of a helmet-mounted sight and helmet-mounted display) can meet the simulation requirements stated above as well as improve upon existing ground based simulation techniques described earlier. It is out of this thinking that the VCASS concept evolved.

A more detailed analysis of the problem has produced a set of characteristics which a more ideal aircraft simulator might possess. Of primary importance is that it should be a flexible visual scene simulation providing synthesized out-of-the-cockpit visual scenes and targets, a representative vehicle whose type can be altered, threat and weapon dynamics, flexibility of control and display configurations, and inputs from sensor or real world imagery. It should be portable if possible and provide alternatives for crew station display options including number and configuration. This simulator should also be useable in both simulated air-to-ground weapon delivery and air-to-air engagement scenarios. Finally, it should be possible to use the same system in ground fixed base and motion base simulators as well as in aircraft.

As an approach to meeting these requirements the VCASS concept and program was initiated. Its objective is to develop and demonstrate a self-contained airborne and ground-based man-in-the-loop visual simulator for the engineering of advanced weapon systems. The approach that will be followed to obtain this objective will be to integrate VCS hardware with state-of-the-art computer image generators to provide a synthesized hemispherical visual space that will display target and environmental images. Included in this approach is the use of real and/or simulated plant dynamics.

The key components of VCASS will be VCS hardware which includes the HMS and HMD. These components are used to "visually-couple" the operator to the other system components he is using. AMRL has pioneered efforts in the research, development and testing of these hardware techniques.

Specifically, the concept of the VCASS is to utilize the HMS as a means of selecting information within a synthesized visual space and to use the helmet display as the visual input device for presenting that information to the operator as a collimated virtual image. This allows head-up display type symbology and/or imagery to be generated to represent a full hemisphere, out-of-the-cockpit view, a portion of which the operator perceives on the helmet display. The scale or size of this instantaneous portion of the total field is a function of the field-of-view of the HMD. The orientation of the instantaneous field-of-view is determined and selected in accordance with head orientation as measured by the HMS. In other words, if the field-of-view of the HMD is 30 degrees the observer sees a 30 degree instantaneous view of a hemispherical digital symbol set. This instantaneous view moves in a one-to-one correspondence with head movement. In essence, the total hemispherical scene is available to the operator a field-of-view at a time.

A system diagram and pictoral of the functional elements required to accomplish the VCASS are depicted in Figure 1. The operator utilizes conventional control devices (control stick, throttle, rudder pedals, etc.) to input a digital computer which provides the manipulation of the vehicle, weapon and threat states as a function of preprogrammed dynamic characteristics. This information is then used to manipulate synthesized symbology and imagery in terms of orientation, scale, target location, etc. as a function of the plant state. A representative visual scene generated by the graphics or sensor imagery generators is selected by the operator line-of-sight orientation as measured by the helmet-mounted sight. Again, the amount of information selected is governed by the instantaneous field-of-view of the helmet-mounted display (typically 30 degrees to 40 degrees). The helmet display electronics receives the selected portion of the symbology and sensor information and displays the video imagery to the operator through the helmet display optics in the proper orientation within three-dimensional space. For an airborne VCASS capability, it is only necessary to install the VCS components along with a small airborne general purpose computer in a suitable aircraft and interface a representative programmable symbol generator to an on-board attitude reference system in order to synthesize either airborne or ground targets. This approach has the ultimate flexibility of utilizing the same symbol set, threat dynamics, etc., in the air that were originally used in the ground simulation. In either case, the crew member will engage electronic targets (either air-to-air or air-to-ground) and launch electronic weapons. His performance in these tasks in turn will be recorded and assessed for performance or utilized as training aids for the crew member or operator.

Figure 2 depicts a more advanced configuration of the helmet-mounted sight and display that will be used in the VCASS installation. The helmet-mounted sight and display are integrated into one compact unit that allows a prealigned visually-coupled system package to be easily connected and disconnected from a standard flight helmet. The helmet-mounted sight transducers represented by the STA and SRAH are small and compact and allow a more or less benign mounting in the aircraft cockpit. The side mounted helmet-mounted display is capable of at least a sixty degree field-of-view in this configuration as compared to 30 to 40 degrees for a visor display with a reasonable form factor.

VISUALLY-COUPLED AIRBORNE SYSTEMS SIMULATOR

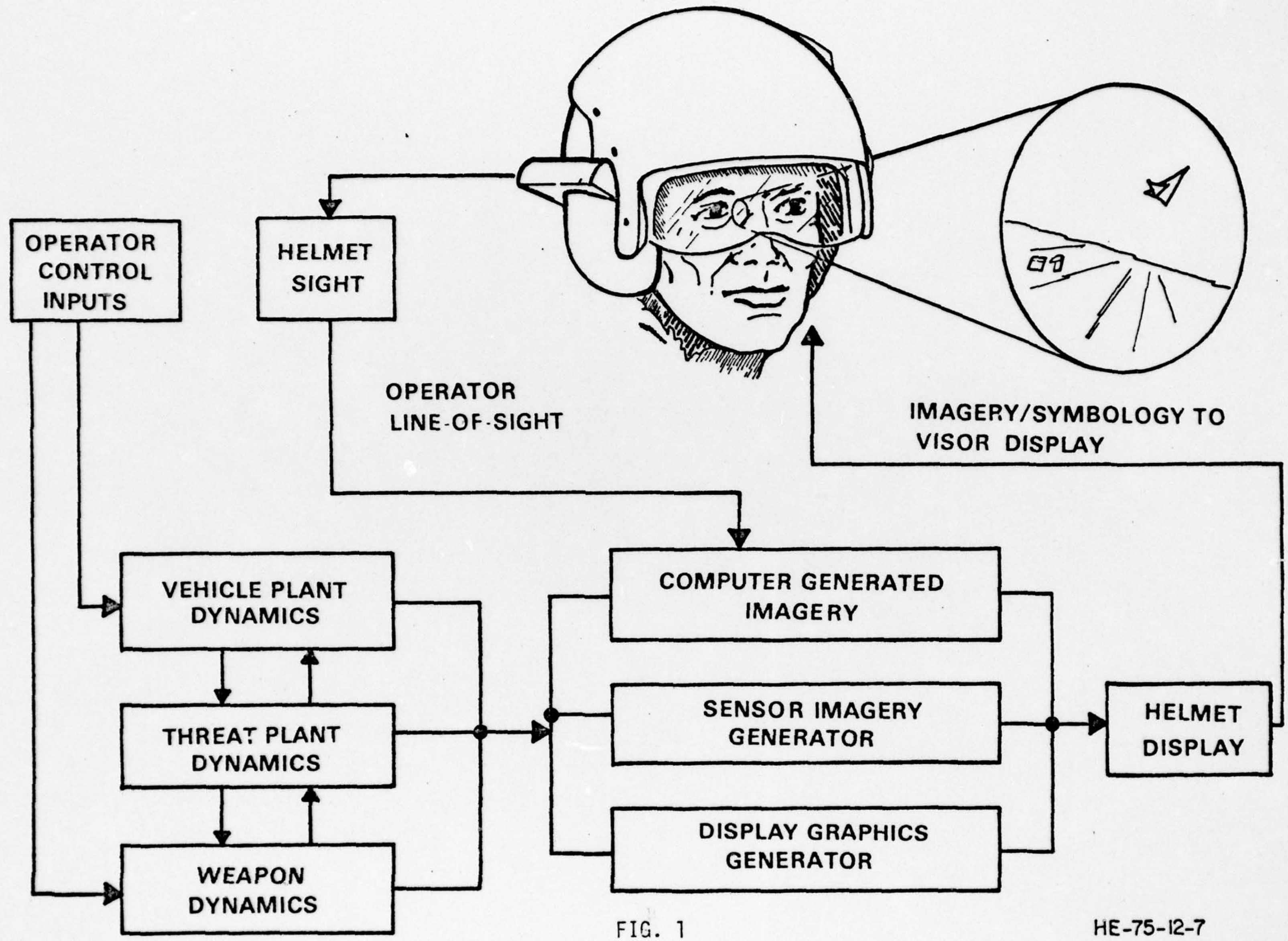

FIG. 1

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HELMET MOUNTED DISPLAY — HELMET MOUNTED SIGHT

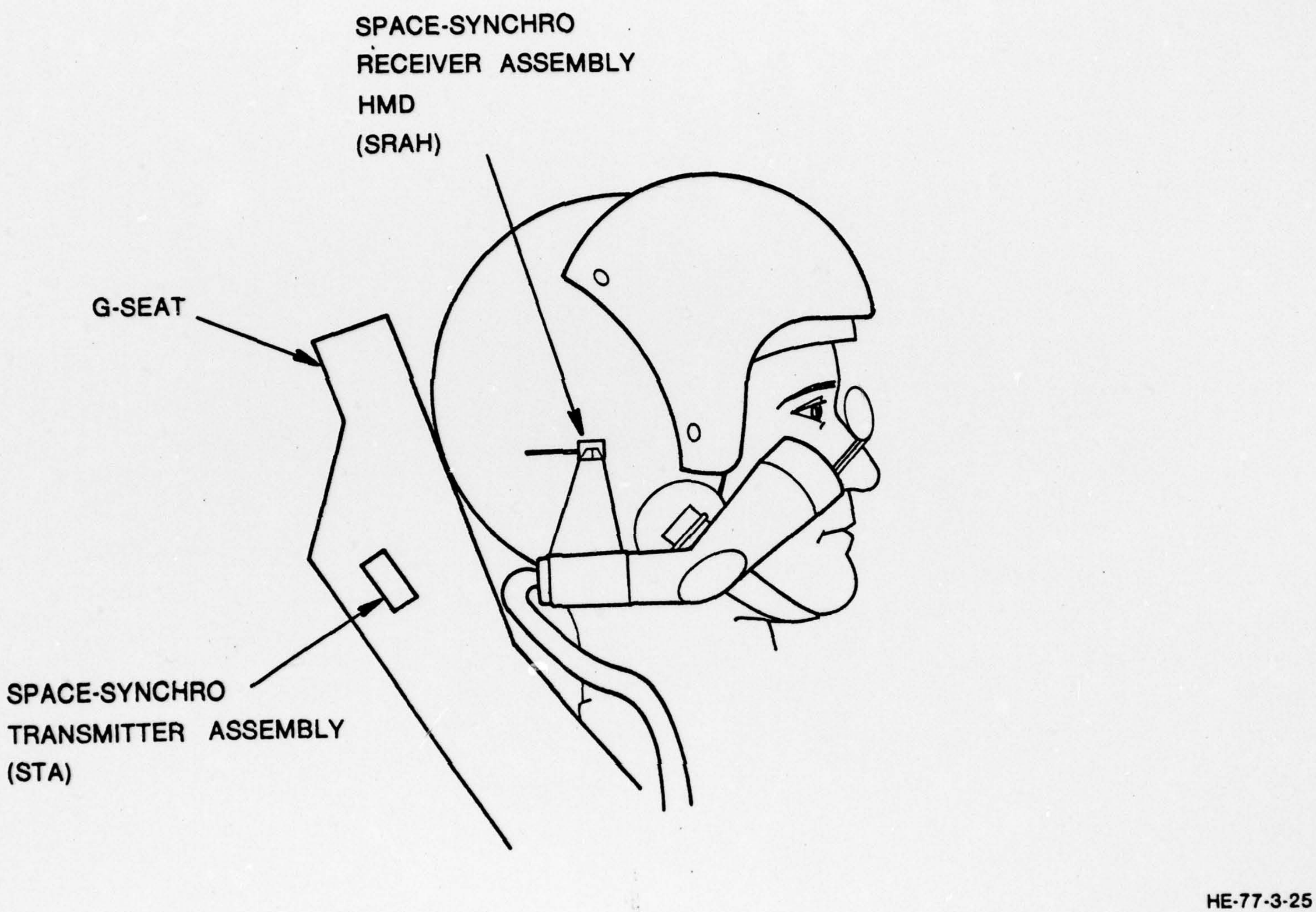

FIG. 2

Compared to other simulation systems this configuration permits a relatively easy transition from the ground to airborne environment for feasibility studies and demonstrations.

The VCASS concept of simulation provides a method of artificially duplicating all the standard scenarios that are provided by more conventional simulators plus more. For air-to-air formats the simulation can take the form of programmed maneuvers as a function of time, evasive maneuvers based on a set of computer algorithms that permit an adaptive strategy for the target, or a totally competitive simulation where the instructor maneuvers the target. For air-to-ground formats the target or threat can be stabilized at prestored ground coordinates, survivability against an active threat can be tested, and target size and vulnerability can be varied. Additionally, visual display design criteria can be developed for fixed base, moving base, and airborne type simulators to investigate and enhance techniques for simulation optimization. Finally, prototype visual display configurations in virtual space can be developed and altered by simply changing the related software.

The cost/performance advantages of the VCASS concept as depicted above appear to be numerous and worthwhile. Of primary importance is the fact that a full hemisphere of collimated visual information can be provided which depends solely on the head orientation limits of the user. This hemisphere of synthesized visual target and environmental images can be accomplished without the need for costly domes or fixed mosaic infinity optics. Conservation of computer capacity is provided as a result of necessitating only the small instantaneous field-of-view of the HMD to be provided to the operator. This suggests that it should be possible to use conventional general purpose computers for computing and creating the environment, vehicle threat and weapon plant dynamics as well as to control a small special purpose symbology generator. The image quality should be very high at the greater luminance levels and color and stereo capabilities are also possible. Also, all threat aircraft and weapon dynamics are programmable providing an ultimate flexibility in design parameters and the cockpit display (HUD symbology sets) can be manipulated easily to determine the interaction between the symbol sets and the synthesized real world imagery. Finally, almost all components including the most critical ones can be utilized in either a ground-based or airborne simulator.

If all the critical components were in an ideal form for the VCASS application it would merely require that one perform the hardware interface, software development, and test the performance obtained out of the final system configuration. However, VCS hardware development and performance has lagged somewhat relative to the performance capabilities of other components that are to be used in the VCASS simulation.

Added to this is the fact that the VCASS simulation imposes certain psychophysical considerations on the entire system configuration. Among the most important of these is the required instantaneous field-of-view of the helmet-mounted display beyond which there will be relatively little improvement in operator performance when flying the VCASS system. The important decisions to be made here are the amount of area on the display that must have a high resolution format and how large the display field-of-view must be to provide necessary information cues in the peripheral vision. Another important requirement is to determine the required update rates and throughput delays to be allowed in the head position sensing information in order to minimize perceptable lags in the change of information on the helmet-mounted display. The symbology and environmental information presented on the display must also change realistically in relation to changes in observer look angle and aircraft parameters in a manner that appears natural with no confusing contradictions. The crew member must be able to relate to aircraft attitude and heading at any look angle. Experience already gained on an interim VCASS configuration has shown that these requirements will necessitate a major symbology and format design effort.

Some of the above mentioned areas of consideration must wait for further testing before a design approach can be formulated while others will not. To some extent the maximum obtainable performance of certain parameters of the most suitable VCS components is already known and must be accepted or its effects reduced by changes to other portions of the VCASS system. For the helmet-mounted sight the individual added requirements are both more easily defined and met than is the case for the helmet-mounted display.

Even though individual requirements for the helmet-mounted sight are straightforward in an engineering sense the total design change package represents a significant increase in performance over systems currently available. To minimize perceptual lags and prevent loss of head movement coverage, the update rate must be increased from the presently available 33Hz to 100Hz or more and the motion box must be enlarged from one to four cubic feet. In order to provide sufficient information to simulate the parallax of aircraft structures on the helmet-mounted display as the operator moves his head, a six-degree-of-freedom HMS is required that provides not only attitude information (azimuth, elevation and roll) but x, y, z position information as well. Another significant problem is the smallest change in head movement which can be measured by the HMS and therefore provide updated information for changing the video imagery on the helmet-mounted display. Preliminary studies have suggested that resolution must be increased from 0.097 to 0.03 degrees to eliminate noticeable step changes in the display presentation as perceived by the observer. Finally, some form of output stabilization must be provided to reduce head jitter noise from whatever source to an acceptable level that would not visibly degrade display resolution.

The design considerations involved in building a helmet-mounted display for the VCASS simulation present a more formidable and subjective set of problems whose solution is not entirely clear. It is certain that a larger display field-of-view is required but how large remains an unanswered question. The optical physics that are part of the display design imposed constraints which are difficult to resolve. Currently, an interim display possessing a 60 degree instantaneous field-of-view is planned for the VCASS; however, recent studies have shown that this may not be large enough especially when viewed with one eye. This leads naturally to biocular or binocular configurations. A whole host of human factors problems then becomes important including brightness disparity, display registration, and eye dominance. The decision whether or not to include color also becomes a major design decision not only because of the engineering development required but because user acceptance may weigh heavily on this factor.

If the design problems can be overcome it appears that the benefits of the VCASS for training are great. Experience for the crew member can be provided in many aircraft types against a wide variety of threats, armament, encounter dynamics, etc. Feedback in the training situation can be significant and rapid with optional instructor involvement, repetition and instant replay on all encounters, and the fact that an airborne vehicle can use VCASS components to correlate ground-based results. The cost effectiveness of this approach seems to be overwhelming. The cost of this system is assured of being significantly less than the costly ground visual simulators now in existance. One system can be used for the air and ground environment. In the airborne case no darts, drones, chase planes or bombing ranges are required and no aircraft armament installation or expenditure of munitions is needed.