AIRCREW INFORMATION REQUIREMENTS IN SIMULATOR DISPLAY DESIGN: THE INTEGRATED CUING REQUIREMENTS STUDY

Kenneth R. Boff, Ph.D.
Engineering Research Psychologist
Human Engineering Division
Air Force Aerospace Medical Research Laboratory
Wright-Patterson Air Force Base, Ohio 45433
(513) 255-4820

- and -

Edward A. Martin
Technical Advisor
Simulator Engineering Division
Aeronautical Systems Division
Wright-Patterson Air Force Base, Ohio 45433
(513) 255-4408

ABSTRACT

Problems involved in the design of flight simulator displays have received insufficient attention. Simulator utilization and training problems have a basis in the design process. It is generally left to the simulator designer to use 'best judgement' in translating training requirements to display software/hardware specifications. At present, human factors data needed to accomplish this are either not available or simply not accessible in a form useful to the designer. Basic sensory and perceptual data, principles, and models exist or can be derived which could serve as a valuable resource for the designer in the specification of display requirements. The Integrated Cuing Requirements Study is a current Air Force sponsored effort to consolidate and publish these data in a format which will enable designers to rapidly access and apply this information.

INTRODUCTION

"Psychologists should be able to say what needs to be simulated and engineers should be able to say what can be simulated."

"In the absence of guidance from psychologists, engineers can hardly do more than strive for realism limited by technical consideration and cost." (1)

In the past few years, the importance of simulation to aircrew training has greatly accelerated as have the engineering state of the art and relative procurement costs. However, relatively little advancement has been made in providing an objective basis for translating training requirements into aircrew training device specifications. Much of the process as it currently exists is dependent upon the subjective judgement of experienced simulator engineers in the absence of sufficient behavioral (i.e., sensory and perceptual) resource data. In fact, the driving considerations are frequently the most advanced equipment features that can readily be produced.

The Air Force Human Resources Laboratory, Aerospace Medical Research Laboratory, and Aeronautical Systems Division's Deputy for Simulators and Engineering Directorate have jointly sponsored a study directed at the exploitation of sensory and perceptual characteristics in the design of visual displays for aircrew training devices. Based upon this research, it is clear that sensory/perceptual data, principles and models do exist (or can be derived) which could assist simulator engineers in the design of cost and training effective simulators.

DESIGN PHILOSOPHY AND PROCESS

Systems Complexity

The primary purpose of a flight simulator is to synthesize information, relevant to the training and performance of piloting activities, that is normally available to the aircrew in the operational aircraft environment. This information is typically imparted to the aircrew member at the flight station via a synchronized array of visual, motion, and aural displays. These displays interface, in turn, with a variety of non-display components.

The basic components of a flight simulator typically include a flight station, visual display subsystem, acceleration and motion subsystem, control simulation subsystem, sensor simulation subsystem, instructional/experimental control subsystem, and computational subsystem. Each of these system components is further reducible to subsystems, assemblies, subassemblies, etc. (Figure 1). The Flight Station includes status lamps and indicators, radar/sensor displays, and flight instruments. The Visual Display Subsystem is interfaced with the Flight Station to provide a through the windscreen view of the external flight environment (2). The Acceleration and Motion Subsystem simulates the non-visual environmental forces which act upon the aircrew member in operational aircraft. The feel of the controls, mimicking environmental forces such as aerodynamic loading of the control surfaces, is displayed via the Control Simulation or 'Control Loading' Subsystem.

Interactions occur among components and/or levels of a given subsystem as well as between individual subsystems (Figure 1). These interactions must be anticipated and specified in the design process prior to the actual integration of these components into a functional simulation.

Design Process

It is the critical task of the simulator designer to translate training (or research) requirements into display system/subsystem specifications. Training requirements are identified and reduced by task and cue analyses into simpler behavioral elements. This task/cue analysis results in the specification of aircrew information requirements which, in turn, is expected to lead to a specification of what must be displayed (i.e., content), and the necessary characteristics of the display (i.e., quality and format). These must then be translated, by the designer, into simulator system/subsystem specifications.

The problem is that in actual practice there is insufficient information available to the designer to enable this logical and orderly design process to work. It is left up to the designer to use his 'best judgement' in those areas where data are lacking. Typically, design decisions are made on the basis of a phenomenological integration of a set of variables that are not necessarily optimal in terms of satisfying training requirements (Figure 2). These include the state-of-the-art technology, past approaches, cost/performance trade-offs, management constraints, and human factors guidelines to the extent that they are available in a useful format.

Design Philosophy

As can be seen from Figure 2, critical decisions made in the design process are based on the subjective integration of a range of variables by the system or subsystem designer. In the absence of sufficient hard data, the designer must make some basic assumptions about what information is necessary to satisfy training requirements, the approach to portraying that information (i.e., display content) and the necessary quality and format of the display.

Typically, the approach to simulator design has been to provide as much of a linear equivalent of the real world (i.e., realism) as the state-of-the-art technology will permit (3). This of course is done with the expectation that satisfactory compliance with training requirements is positively correlated with apparent realism (4). In other words, if a simulation looks, feels and sounds like the real aircraft, then the basic requirements for training should likewise be present. The design engineer can hardly be faulted here since he gets his direction from a customer (the operational user) whose criteria for acceptability is based upon the degree to which the ground based simulated environment approximates his perception of the 'real' flight environment (5).

Implementation of this maximum realism approach has fallen considerably short of its ideal (i.e., an objective simulation of the flight environment). As evidence of this, the most advanced computer generated visual displays are, at best, low fidelity representations of the real world. These typically appear cartoonish and deficient in fine detail. In motion simulation, platforms are pushed to their maximum excursion (within facility constraints) so as to display the aircraft motion environment with as much realism as possible before commencing washout. Regardless of these attempts, motion displays are beset with false motion information which is inconsistent with the aircraft motion environment. Additionally, there are numerous instances of spatial/temporal asynchrony between the visual and motion display modes. In sum, there exist many examples of what we call errors of omission, inclusion, and synchronization that detract from the realism of the display.

Errors of omission generally refer to those spatial/temporal details that may be lacking in a display which detract from apparent realism. Visual errors of omission include limitations in texture, density of scene content, size and continuity of the visual field, aerial perspective, resolution and directional illumination (shadows). In motion simulation, these include high-G loading and sustained motion.

Errors of inclusion are those artificial features or details unique to the simulation that are not commonly found in the 'real world'. Errors of inclusion for visual displays include saturated colors, level of detail switching, visible raster patterns, and stylized scene components that tend to be uniform in shape or distribution throughout the display. Similarly, in motion displays there are anomalies related to motion washout and to equipment limitations (e.g., 'hydraulic bump').

Errors of synchronization refer to spatial and/or temporal phase lags within or across display modes. These include delays and/or conflicting information among control interface, visual, and motion systems.

It is important to emphasize that these errors are errors only in that they depart from the intended realism of the display. The actual effects that these have on performance vary widely and are in need of further study. However, negative effects have been documented ranging from temporary distractions to which a pilot quickly adapts (6) to incidents of severe psychophysiological distress (7). On the other hand, planned distortions or manipulations of the visual scene have been shown to enhance performance in the flight simulator (8,9). Several studies have reported positive effects on training or performance by systematically augmenting the information available to the pilot in the simulated visual scene in order to facilitate the acquisition of task critical information (10,11).

Another more recent approach has been to tailor display specifications to the information requirements of the aircrew member. Presumably this would enable the optimal allocation and prioritization of technology constrained display resources. A major problem is that at present there are no reliable or comprehensive procedures for determining information requirements for the training or performance of specific aircrew activities. While it is possible through task/cue analyses (including geometrical analyses of the task environment) to define the information available to the aircrew to support the realism approach, it is not well understood which information is in fact relevant given the aircraft system, environment, mission, and a host of individual variables relating to the aircrew member and his previous training. Hence, given the current state of knowledge, it remains for the designer to bridge the gap between training requirements and information requirements. In the absence of sufficient guidance from psychologists, the designer has no choice but to use reality as his metric.

Once the designer has made these decisions regarding display information requirements, he must decide how this information should be represented in the display. Unfortunately, there is no objective methodology for generating pictorial scene requirements from visual information requirements (11,12). Here, once again, the designer is called upon to use his best judgement based upon a subjective integration of variables (Figure 2) that are not optimal for satisfying the aircrew member's perceptual information requirements.

USE OF SENSORY AND PERCEPTUAL DATA AS A DESIGN RESOURCE

Once the designer has established what is required and how it should be portrayed, it still remains for him to specify the parameters of display quality, format, and configuration relative to the total system. The issues of display quality are essentially information management issues. One approach to effective display management of aircrew information requirements is to capitalize on human sensory and perceptual capabilities and limitations.

The sensory and perceptual data are specifically germane to the needs of the simulator engineer or designer. These data provide functional relationships for the variables that influence the acquisition and processing of information as well as perceptual motor control output (13,14). For example, in determining the information requirements for an 'out the window' target interception task:

a. The information acquisition or sensory data describe the variables which influence target detection (e.g., luminance, contrast, target size).

b. The information processing or perceptual data describe those variables which impact identification of the target (e.g., perception of size, distance, motion).

c. The perceptual motor control data define the variables which influence the manual control of the aircraft while tracking the target.

When used appropriately, these data can be a valuable resource for:

1. Developing specifications based on sensory or perceptual characteristics (i.e., matching simulator display characteristics to human sensory capabilities). For example, it should not be necessary to simulate a specific force of 0.01 G since this is, under most conditions, below the threshold of detectability.

2. Evaluating specifications or prioritizing design options. Many existing specification requirements and industrial standards do not have an empirical basis for their existence. The sensory and perceptual data can be a valuable resource for their evaluation. In addition, past attempts to achieve realism have resulted in spatial/temporal distortions which could have negative impact on the acquisition or processing of cue information. The sensory and perceptual data can provide a basis for evaluating this impact. More importantly, capitalizing on the information processing data might provide a basis for alternatives to realism.

3. Generating new design or training alternatives. Data from Regan, Beverley, and Cynader (1979;15), Regan (1980;16), Ginsberg (1980;17,18) and others suggest that specific sensory capabilities may be enhanced through special training procedures. This portends a new approach to pilot training as well as a new generation of training devices which are geared toward improving the pilot's 'natural' ability to acquire and process information.

When used appropriately, the sensory or perceptual data can be an effective resource to the experienced engineer and designer. However, there are limiting factors to the value of these data. Specifications suggested by these data may not be practical in terms of technology or cost. In fact, in many instances current technology cannot match the limitations of human perception. As an example, consider the situation in Computer Generated Imagery wherein the displayed image of a light source is decreased in area as the square of the calculated viewing distance so as to provide a change in retinal image size that conforms with normal visual experience. The displayed image cannot be reduced below one pixel which, for most displays, subtends an angle two to four times larger than the optimal resolution limit (19).

Appropriate implementation of these data requires that they be integrated with other factors by the experienced engineer and designer (as shown in Figure 2) to yield final requirements or specifications.

Furthermore, much of the data regarding human sensory limitations and perceptual capability are either not yet known or have not been sufficiently well defined to enable their direct translation to engineering applications. Where data are known, they are usually not readily accessible in a form useful to simulator designers (20,21,22). It should be noted, however, that where visual sensitivity data have been accessible to designers (23, 24), they have been successfully exploited in the specification of visual displays (25).

The Integrated Cuing Requirements Study is a Research and Development program under contract to

The Boeing Aerospace Company (Seattle WA) to exploit sensory and perceptual characteristics, principles and models useful to the design and specification of simulator displays. The technical objectives of this study are:

1. To identify, collect and consolidate basic sensory/perceptual data germane to training and engineering requirements. This will be documented as a data base organized around principal areas of sensation and perception. It will contain a minimum of text but will instead concentrate on detailed illustrations, quantitative functions, characteristics and models.

2. To develop specialized information retrieval techniques to facilitate the accessibility and application of these data by design engineers. These will be documented as a User's Guide which will lend structure to the Data Base in accordance with the needs of simulator designers. It is also feasible to develop User's Guides to the Data Base for other user populations for whom these data could be a resource (e.g., human factor engineers).

In summary, the Integrated Cuing Requirements Study will, in itself, provide a valuable resource to design engineers. However, optimal implementation of this resource to training simulator displays is wholly dependent on also developing the ability to specify: (1) the *information necessary for effective training* of specific aircrew tasks, and (2) the optimal way of portraying this information (i.e., levels of abstraction or realism). A research effort which systematically responds to these basic questions is critical to the design of training effective flight simulators.

REFERENCES

1. Gregory, R.L., The Display Problem of Flight Simulation. In 3rd Flight Simulation Symposium (Theory and Practice in Flight Simulation),April 1976.

2. Heintzman, R. J. and Shumway, D.A., A Systematic Approach to Visual System Requirements and Developments. Proceedings AIAA Visual and Motion Simulation Conference, Dayton OH, April 1976.

3. Bunker, M.W., Training Effectiveness Versus Simulation Realism. Proceedings of Society of Photo Optical Instrumentation Engineers, 162, August 1978, 76-82.

4. Harvey, J.F., Current Trends and Issues in Visual Simulation. Proceedings of the Society of Photo Optical Instrumentation Engineers, 162, 1978, 2-5.

5. Fulgham, D.D., Extending the Scope of Flight Simulation. Fourth Flight Simulation Symposium, April 1978.

6. Woodruff, R.R.; Smith, J.F.; Fuller, J.R.; and Weyer, D.C., Full Mission Simulation in Undergraduate Pilot Training: An Exploratory Study. Air Force Human Resources Laboratory, Flying Training Division, AFHRL-TR-76-84.

7. Coward, R.E.; Kellogg, R.S.; and Castore, C.H., Psychophysiological Effects of Training in a Full Vision Simulator. AFHRL-TR-80-XX in preparation.

8. Ritchie, M.L. and Shinn, S.B., Beyond Linear Perspective with Computer Generated Displays. Proceedings of the 17th Annual Meeting of the Human Factors Society. Human Factors Society, Santa Monica CA, 1973.

9. Ritchie, M.L., Object Illusion and Frame of Reference as Design Criteria for Computer-Generated Displays. Abstract from SPIE, Visual Simulation and Image Realism, Vol 162, 8-11, 1978.

10. Lintern, G., Transfer of Landing Skill After Training with Supplementary Visual Cues. AFOSR TR-78-2, July 1978.

11. Semple, C.A.; Hennessy, R.T.; Sanders, M.S.; Cross, B.K.; and Beith, B.H., Simulator Fidelity Features: Simulator Training Requirements and Effectiveness Study (STRES). AFHRL-TR-80-XX. (in Press)

12. Carel, W.L., Pictorial Displays for Flight. JANAIR TR 2732.01/40 Office of Naval Research, Arlington VA, 1965.

13. Kaufman, L., Perception: The World Transformed. New York, Oxford University Press, 1979.

14. Kaufman, L., Sight and Mind. New York, Oxford University Press, 1974.

15. Regan, D.; Beverley, K.; and Cynader, M., The Visual Perception of Motion in Depth. Scientific American, 1979, 241 (1), 136-151.

16. Regan, D., Assessment and Development of Visual Flying Skills by the Application of the Channel Theory of Vision. (Abstract) Review of Air Force Sponsored Research: Flight and Technical Training. USAF Academy, March 1980.

17. Ginsberg, A., The Measurement, Interpretation and Improvement of Spatial Vision for Target Acquisition in Terms of a Multi-channel Model of Vision. (Abstract) Review of Air Force Sponsored Research: Flight and Technical Training. USAF Academy, March 1980.

18. Ginsberg, A., Specifying Relevant Spatial Information for Image Evaluation and Display Design: An Explanation of How We See Certain Objects. SID: in Press.

19. Stenger, A.J.; Thomas, J.P.; Braunstein, M.; Zimmerman, T.A.; Advanced CIG Techniques Exploiting Perceptual Characteristics. AFHRL-TR-80-XX in preparation

20. Meister, D. and Farr, D.E., Development of Tests to Measure the Utilization of Human Factors Information by Designers. TR Office of Naval Research, NONR 4974-00, 1965.

21. Meister, D. and Farr, D.E., The Utilization of Human Factors Information by Designers.

TR for Engineering Psychology Branch, Office of Naval Research, NONR 4974-00 Amendment No. 1, 1966.

22. Meister, D. and Sullivan, D., A Further Study of the Use of Human Factors Information, By Engineering Psychology Branch, Office of Naval Designers Research, NONR 4974-00, Amendment No. 2, 1967.

23. Farrell, R.J. and Booth, J.M., Design Handbook for Imagery Interpretation Equipment. Boeing Aerospace Company, Seattle WA, 1975.

24. Kraft, C.L.; Anderson, C.D.; and Elworth, C.L., Psychological Criteria for Visual Simulation Systems, AFHRL TR-79-30, 1980.

25. Kraft, C.L. and Shaffer, L.W., Visual Criteria for Out of the Cockpit Visual Scenes. AGARD Specialist Meeting on Piloted Aircraft Environment Simulation Techniques, Brussels, Belgium, 1978.

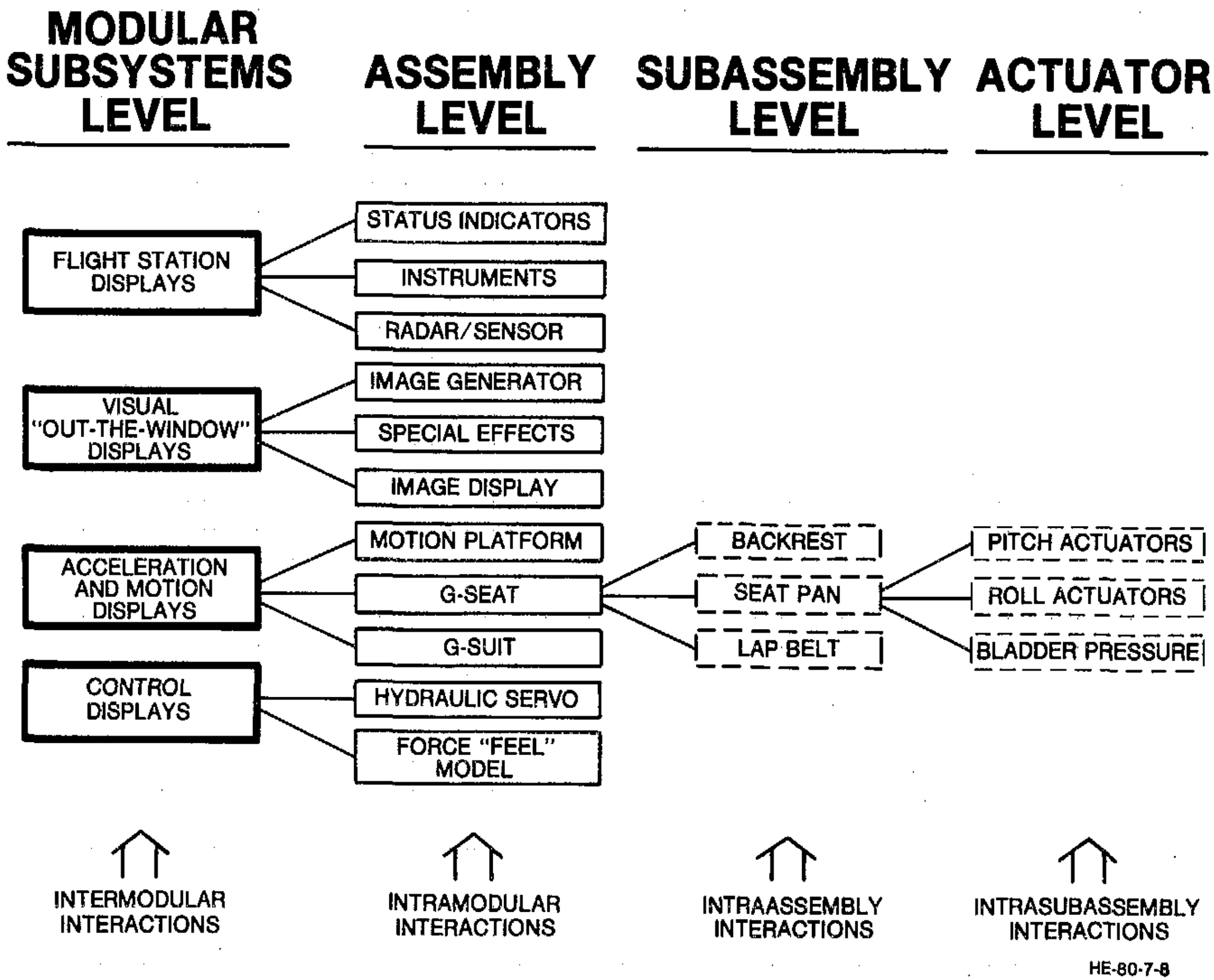

Figure 1. Simulator systems complexity. Each system is reducible to subsystem levels. Interactions may occur among components and/or levels of a given subsystem as well as between individual subsystems. Reduction of subsystem components below assembly level is shown for the G-seat only.

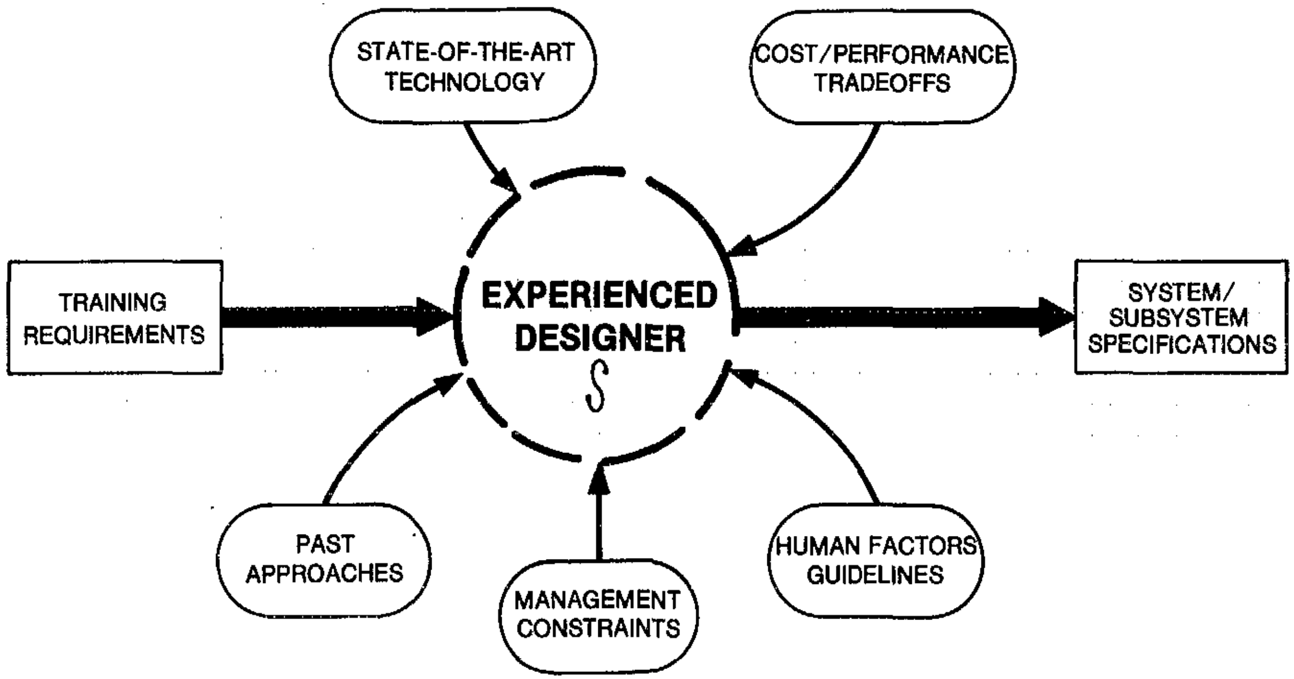

Figure 2. Design decision process. Design requirements and specifications are determined by the subjective integration of a range of variables.

ABOUT THE AUTHORS

Dr. Kenneth R. Boff, Engineering Research Psychologist with the Air Force Aerospace Medical Research Laboratory at Wright-Patterson Air Force Base, Ohio. Ph.D. in Experimental Psychology (Vision) from Columbia University.

Mr. Edward A. Martin, Technical Advisor in the Simulator Division, Directorate of Equipment Engineering, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio. B.S. in Electrical Engineering from Virginia Military Institute. M.S. in Electrical Engineering from Syracuse University. Ph.D. candidate in Biomedical Engineering at Ohio State University.