SYSTEMS TECHNOLOGY, INC

13666 SOUTH HAWTHORNE BOULEVARD, HAWTHORNE, CALIFORNIA 90250-7083
Email: jeffhogue@systemstech.com PHONE (310) 679-2281, ext. 52 · FAX (310) 644-3887

Paper No. 606

IMPROVING AIRCREW EMERGENCY SAFETY TRAINING THROUGH ENHANCED VIRTUAL REALITY PARACHUTE SIMULATION

March 28, 2003

Jeffrey R. Hogue
Systems Technology, Inc.
13766 S. Hawthorne Blvd.
Hawthorne, CA, 90250 USA
Tel :(310) 679-2281, ext. 52
FAX (310) 644-3887

Steve Markham
Valentine Technologies Ltd
Colt Hill, Odiham
Hampshire, RG29 1AN United Kingdom
Tel: +44 1256-701102
Fax:+44 1256-701104

Arvid and Cris Harmsen
Automatisering en Adviesbureau
1276 CP Huizen
Stuurboord 57
The Netherlands
Tel : +31-35-6232629
Fax : +31-35-6247218

Presented at:
SAFE Europe Symposium 2003
1-2 April 2003
Hilton Hotel, Munich, Germany

IMPROVING AIRCREW EMERGENCY SAFETY TRAINING THROUGH ENHANCED VIRTUAL REALITY PARACHUTE SIMULATION

Jeffrey R. Hogue
Systems Technology, Inc.,
13766 Hawthorne Blvd.,
Hawthorne, CA 90250 USA

Steve Markham
Valentine Technologies Ltd.,
Colt Hill, Odiham
Hampshire RG29 IAN, UK

Arvid and Cris Harmsen
Automatisering en Adviesbureau, 1276 CP Huizen
Stuurboord 57, The Netherlands

ABSTRACT

Ejection or egress from a non-flyable military aircraft is a rapid, highly stressful, and dangerous event, requiring quick but orderly, virtually automatic decision making and physical reactions. Virtual Reality (VR) parachute simulation training was developed and has been evolving as an answer to this critical need as it has become a widespread and accepted standard in U.S. and allied Navy and Air Force Aviation Physiology, Survival, and Life Support installations. Originally developed as a simple, low-cost, part-task canopy control trainer, this paper explains how the simulator now provides a complete and immersive emergency learning experience starting with manual or automatic canopy deployment, parachute malfunctions flight and correction dynamics, canopy collision avoidance, equipment procedures, and flight control and landing. This training includes automatic and instructor controlled performance assessment during and after the experience, and has been documented, specified, and incorporated into military lesson plans. Recent enhancements have been made in simulation equipment, user interface and rapid real world location-specific, highly detailed scene graphics. VR training has resulted in dramatic improvements in aircrew emergency performance.

BACKGROUND

Even in peace time, the US has roughly 25 Air Force and 50 Navy aircrew under canopy each year. In almost all of these incidents, the aircrew are uninjured when the parachute has opened successfully. When training relied only on classroom lectures and simple harness suspended procedures demonstrations (they were required to pretend that they were under a canopy, and exhibit actions without seeing timely correct results), more than half of aircraft mishaps resulted in significant landing injuries, usually due to incorrect emergency procedures. As an example, 4-line releases were seldom deployed. However, real-life parachute training is far too costly and dangerous to be required for aircrew personnel.

The solution lies in a simulator-based training system originally developed for USDA Forest Service (FS) smokejumpers [1] (civilian fire fighters operating round parachutes) to establish smooth basic parachute flight (canopy control) skills in extremely difficult conditions. They were faced with a similar problem, reducing training jumps to reduce injuries leads to more on-the-job injuries and poorer performance. The simulator provided training reduced injuries and improved skills. Similar results were obtained when simulator based training was adopted by military operational units [2].

Aircrew may be in a far more trying situation than operational jumpers, since emergencies can occur without regard to the daylight, weather, altitude, terrain, etc. (all simulation-available) restrictions. Moreover, emergency parachute openings are much more likely to malfunction due to opening at severe speeds and adverse jumper body positions. A quick and accurate response is essential; there is no reserve parachute. Fig. 1 shows a typical parachute simulator in use for egress training.

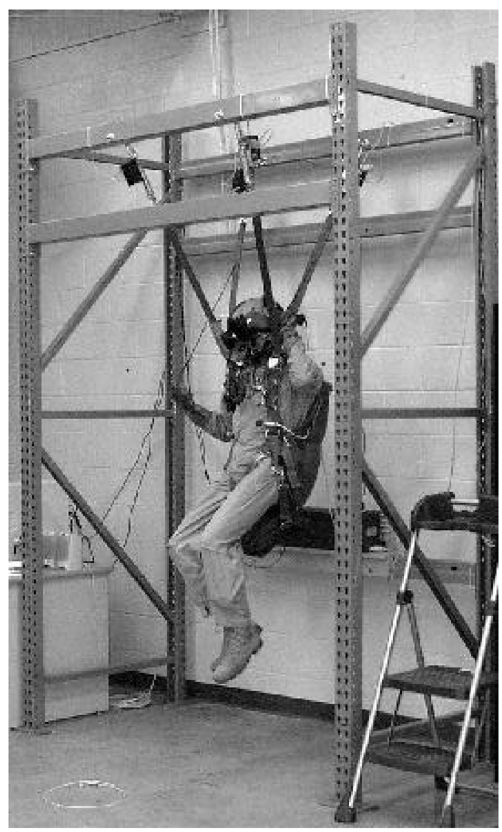

Figure 1. Simulator-Based Aircrew Parachute Training

LESSON PLAN TRAINING GOALS

Widespread adoption of emergency parachute simulator training has led to the development of procedures manuals, instructor guides, and lesson plans [3]. These plans vary depending on the particular emergency circumstances foreseen, but all share the goal of providing the capability to present as complete as possible a sequence of challenges that employ as much equipment and encounter as many of the events as can be expected in a real mishap; that is, a goal of minimizing the part task aspects of this training. These plans incorporate the extensive sequence of operations required for success in emergency parachuting.

SYLLABUS SCOPE

Suspended in the appropriate parachute harness, the trainee can and should be fully equipped with helmet, visor, oxygen mask and communications equipment, flight gloves, LPUs, ripcords if applicable, and seat kit. Training starts in free fall, with canopy deployment automatically by ejection seat (and should cover automatic seat deployment failures), by pulling manual ripcord at lower altitudes, or by pulling Automatic Activation Device (AAD) and oxygen ripcords at higher altitudes. Fig. 2 shows an aircrew trainee fully equipped for simulator egress training.

Figure 2. Aircrew Equipped for Simulator Egress Training

Once canopy deployment has occurred, the aircrew should check overhead and identify possible malfunctions, and decide and employ appropriate correction procedures which will mitigate a malfunction. Next it is time to assess the situation: is riser steering needed to avoid danger of canopy collisions, where is an attainable safe landing area, and what are the winds? This is followed by equipment procedures involving visor, oxygen mask and communications equipment, LPU's, and seat kit. Finally it is time to make the parachute steerable (or use the risers for steering, all parachutes can be steered this way) and fly to a safe upwind landing, Near the ground, attention changes to looking ahead and positioning for a PLF (Parachute Landing Fall), or tree or power line impact body configuration. If included, a PLD (Personnel Lowering Device) may be demonstrated to deal with tree entanglements.

Simulator enhancements allow the inclusion of all these aspects in a single continuous dynamic VR experience that produces many of the same sensory and procedural demands as might be experienced in a real emergency. Results of correct or incorrect actions are automatically displayed and scored, and a number of other program features are provided to facilitate instructor to student critique.

HARNESS SUSPENSION FRAMES

Suspended harness training is well accepted as an essential component of all initial and recurrent parachute instructional programs. The trainee hangs in an actual harness, suspended from above by riser straps. Lacking a simulator, trainees were required to pretend that they were under a canopy, and display actions without seeing timely and correct results. Some of these rigs were suspended from a ring-attached overhead to a single point (often attached to an electric winch). Some systems had elastic control lines attached to fixed points. When the jumper pulled on the lines, he was physically rotated in the direction he pulled. This was seen as advantageous in systems without a simulator, even though the control-motion-to-visual correlation was poor.

Early VR simulator installations were made by attaching control sensors to existing suspended harness configurations [4]. It quickly became obvious that undesirable motions occurred during the simulated jump. Major safety concerns were raised by military unit safety officers particularly during riser force inputs for malfunctions clearing and steering control, together with the shock loads when a Personnel Lowering Device (PLD) is used, as shown in Fig. 3.

The challenge was to provide extremely robust, rigid, and yet economical systems [5] which can be readily customized to widely differing training room setups. This was met by a number of designs based on industrial shelving (shown in Fig. 4), extremely sturdy commercial scaffolding, or balcony railing components capable of loads of several tons. These systems carry very conservative duty ratings of 300 lb. but actually vastly exceed applicable OHSA Standards 29 CFR 1296.451 and 1910.28 requirements, and do not need to be fastened to the floor, wall, or ceiling.

Figure 3. Personnel Lowering Device

In response to user requests, a lift platform has been developed to raise the instructor and trainee to accommodate widely varying personnel heights and more readily fit the harness, helmet, HMD, etc. to the trainee as shown in Fig. 5.

Figure 4. Industrial Shelving Based Frame

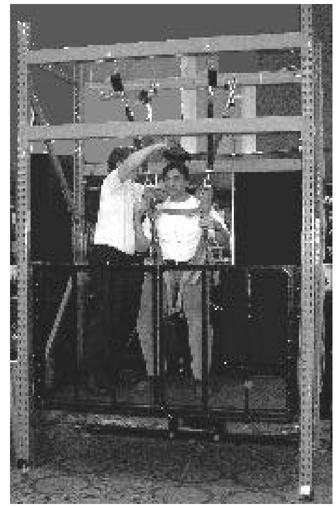

Figure 5. Lift for Frame

Figure 6. Transportable Frame

Upon discovery that users so valued their simulator based training that they were taking it with them when deployed on military missions, a more transportable 2X2X3 meter version, shown in Fig.6, was developed that stores in a 2 meter long by 10 cm diameter tube. The controller box has been reduced to one third of standard size, and the system can be operated from modern laptop computers with advanced NVidia or ATI graphics capability and auxiliary PCMCIA graphics and signal interface cards. This capability allows aircrew to maintain proficiency while located near tactical operations.

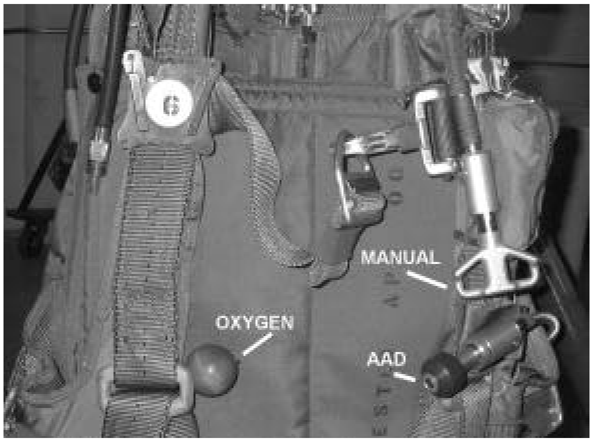

Figure 7. BA18 Manual, AAD, and O_2 Emergency Ripcords

Figure 8.Optical Ripcord Sensor on BA22 Harness

Figure 9. Instrumented CA12 Parachute

EQUIPMENT PROCEDURES

Some aircrew ride in aircraft with ejection seats; others get parachutes but must bailout (egress) in emergencies. As shown in Fig.7, these parachutes are typically equipped with emergency manual ripcords (metal handle), a ripcord to arm an Automatic Activation Device (AAD) with a red knob which then opens the parachute container when the jumper is below a preset altitude after a specified time delay. 14,000' and 4 second delays are typical. Some aircrew AADs also require that descent rate exceed a specified value. During egress, aircrew also can pull a ripcord with a green round knob to release oxygen.

In the simulator, these functions are provided by routing the ripcords and their conduits to an optical sensor pack mounted by Velcro on the parachute container, shown in Fig. 8 on a the back of a packed BA22 (Back style Automatic) and in Fig. 9 on the front of a CA12 (Chest style Automatic). If a BA18 or 22 aircrew sim ulation starts at 25,000 ft using ripcords, the trainee's display will gradually black out until the oxygen is deployed, at which point it will come back on. This blackout is somewhat accelerated for instructional effect.

Ripcord capability is also useful in ejection training where it can be used to cover the possibility of automatic seat deployment failures

PARACHUTE MALFUNCTIONS

Once a simulated parachute has deployed, the aircrew must look up and assess its condition. Malfunctions are much more likely in emergency parachute openings than in operational conditions due to opening at severe speeds and adverse jumper body positions, and the consequences are more severe since there is no reserve parachute.

The simulator programing has recently been migrated to Windows DirectX, providing greatly enhanced graphics depiction and user interface capability. One use of this improvement was to produce much more detailed parachute models which more accurately illustrate normal and malfunctioning canopy conditions and improve the aircrew's ability to provide quick and accurate corrective responses through the suspension risers.

Frequent riser manipulation to clear malfunctions, provide an alternative steering mechanism, and withstand PLD shock inputs led to the development of a more rugged design with a shock absorber inside a music wire suspension spring, as shown in Fig.10.

EQUIPMENT PROCEDURES

As shown in Fig. 2, it is possible to use a HMD worn under a single (or dual) visor helmet. A head orientation sensing tracker is attached to the back or the helmet and senses the direction that the jumper is looking. This information is then communicated to the simulation computer which uses this orientation vector, and the toggle and riser sensor inputs to the parachute dynamics model to compute a corresponding jumpers location and orientation within the graphics scene model. This model view is then displayed to the jumper on the dual screen HMD. The aircrew should be wearing flight gloves to replicate the difficulty that they create, and have an oxygen mask attached to his helmet and CRU fitting. It is even possible to wear the aircrew chemical defense ensemble (First Generation) and the Aircrew Eye Respiratory Protection System (AERPS), as shown in Fig.11. The aircrew can also be equipped with LPU's and a seat kit.

Figure 10. Damped Riser
Force Sensor

The instructor's training challenge is to see that the student proceeds rapidly but correctly through an extensive memorized specific sequence of actions:

Figure 11. AERPS Under HMD and
Dual Visor Helmet with
Attached Head Tracker

- if egress, - proper free fall position
  - activate/release parachute
  - decision about altitude
  - for T-38 AAD, normally use immediate/static line; for seat deployment and AAD failure use manual ripcord
- oxygen activation as necessary
- check canopy condition, correct malfunction
- check for canopy collisions
- lift visor, remove oxygen mask (and unplug communications) if low enough
- activate LPUs if over water
- release seat kit
- activate steering mechanism if canopy is intact (with 4-line,stopping oscillations)
- determine wind from turning and watching ground movement, and other indicators
- pick a target landing site, and fly to it using measured gradual control motions so as to be faced upwind below 200' altitude.
- avoid low altitude control inputs, particularly over-control
- be aware of possibility of landing in trees or power lines, opportunity to demonstrate correct body position.
- Verbalize awareness of situation and reasons for actions
- look up at horizon (avoid landing neck whiplash injury).
- hands on quick releases, assume PLF body position

SIMULATOR SITUATIONAL AWARENESS AIDS

Although the HMD-Tracker combination allows the VR simulation participant to see in any direction by turning his head, a real jumper has an extremely wide immersive view that he can rapidly scan to maintain a flight situational awareness. One consequence is that the simulator task requires a conscious scanning effort that is more difficult than the real task would require; a proficient simulator trained individual will find it easy to exercise situational awareness during a real parachute jump. This increased difficulty can be mitigated by a number of orientation indicators under instructor control. These indicators include a digital altimeter, wind line marker, control toggles, jumper's boots, and a jump partner highlight locator symbol, as shown in Fig.12.

Jump Partners can be created by saving simulator runs for this purpose. This is useful in providing canopy collision avoidance for egress training, or for ejections from two seat aircraft ejections. When jumping with a jump partner, it is frequently difficult to locate the partner, particularly when the active jumper is at an appreciable distance from the partner. If Partner Highlight is enabled during the run, a colored ring will be displayed over the partner to aid in locating him as is also shown in Fig. 12.

If the jump partner is off-screen, out of the active jumper's current field of view, the colored ring will change to a filled-in color half-circle on the edge of the display closest to the jump partner's location. This indicator will move along the edge of the display as the jump partner and jumper move, indicating the jump partner's off-screen location

MULTIPLE JUMPER EGRESS TRAINING

The recorded jump partner is adequate for two seat aircraft ejections, but large aircraft egress situations may result in a number of jumpers in flight simultaneously. Training in this case can be provided by networked simulators originally developed for operational mission planning and rehearsal.

The networked system consists of a set of networked Jump Stations, a Master Controller, and a Scenario Developer consisting of a Visual Scene Generator and a Wind-Field Generator. A conceptual diagram of this network is shown in Fig 13. This system provides the ability to simulate group parachute jumps using networked simulators and multiple users. They can operate either independently in a stand-alone mode or in a networked mode for group jump simulations. In stand-alone mode, each Jump Station operates much like the basic training system, running and recording jumps independently of the other stations and the Master Controller. Each station stores its own copies of all data required for independent simulation operation.

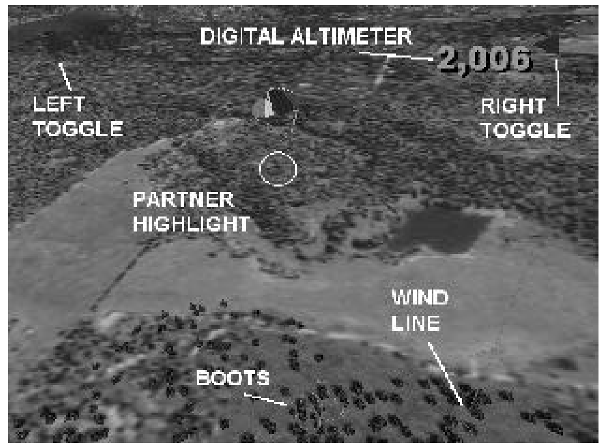

Figure 12. Simulator Orientation Aids

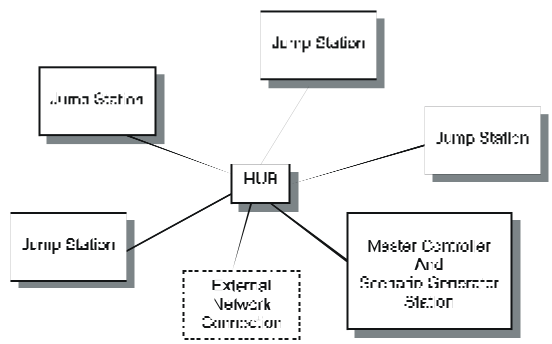

Figure 13. Networked System Diagram

In networked mode, each Jump Station is controlled by the Master Controller. It receives scenarios and information about other networked jumpers from the network and displays them in the HMD, permitting a jumper to interact with others in a live, networked jump. In this mode, the Jump Station does not require a simulation operator; all operator commands are made at the Master Controller and relayed to the individual stations.

Note that a simple variation for aircrew training can help minimize required instructor staffing. Only one instructor would be need to control large numbers of aircrew making completely independent training jumps.

IMPROVING TRAINING FACE-VALIDITY

Immediate face-validity is a key training simulator issue. It is possible to perform an engineering analysis and determine that a very sparse graphics scene display may contain the essential feedback cues to train a student for a particular task, but that may be rejected by an actual training population because they can not envision this experience as representative of the real world. The primary objection raised by the parachute simulators user population was the difficulty experienced by trainees in visualizing operating in the somewhat austere generic scenes as a real world experience. This has now been overcome in the parachute simulator by a US SOCOM-funded development of a capability to rapidly create real world location-specific, highly detailed simulator scene graphics.

This new capacity benefits from the development, acquisition, and open distribution of a large amount of digital terrain data, and aerial and satellite photographic imagery. As this data became available, a number of PC-based software tools have been developed by several companies which automate the rapid development of simulator scene databases. As the time and effort required to develop scenes to simulate specific geographical locations was reduced from man-years to man-hours following the process diagramed in Fig. 14, it became possible to transition the parachute simulator from simple generic training scene to elaborate models of real word sites. These remarkable graphics improvements have received enthusiastic user evaluations.

Fig. 12 shows a scene located based on a USDA FS training site west of Missoula Montana. As shown in Fig. 15, these scenes can contain terrain specific wind fields with data obtained from weather forecasts.

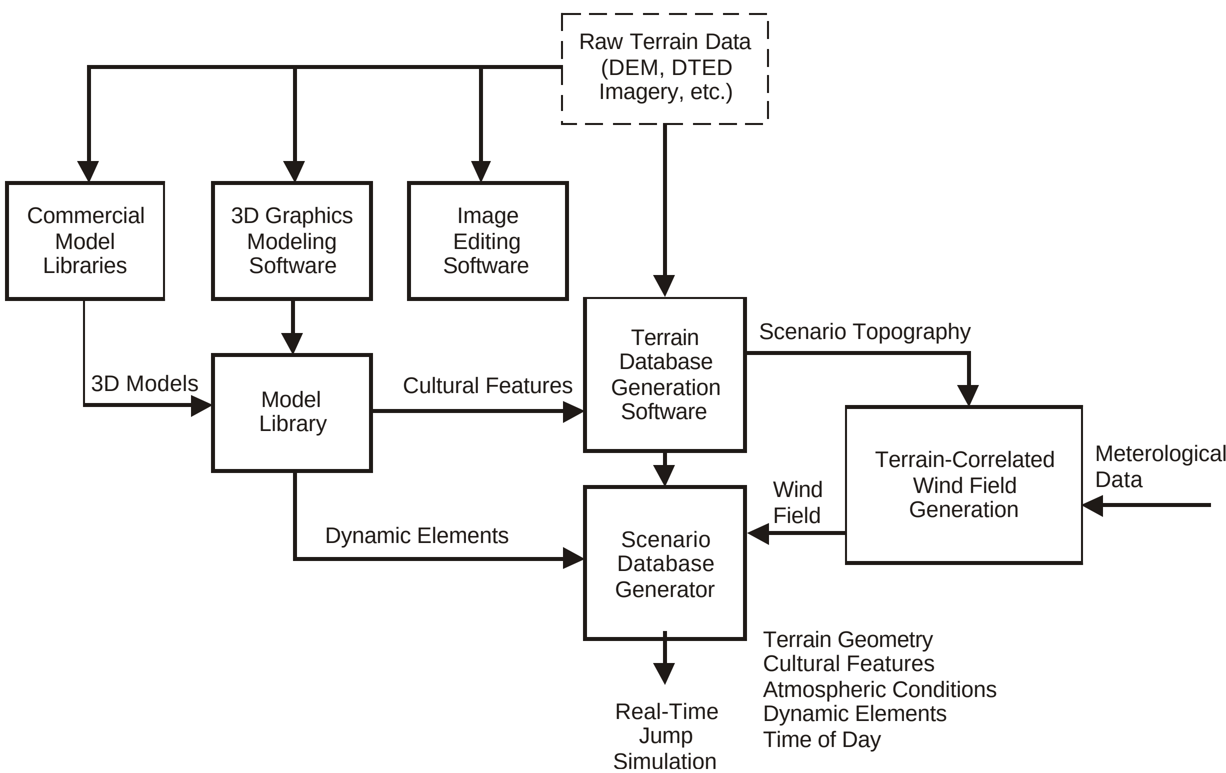

Figure 14. Process for Generating Mission Planning and Rehearsal Simulator Scenes

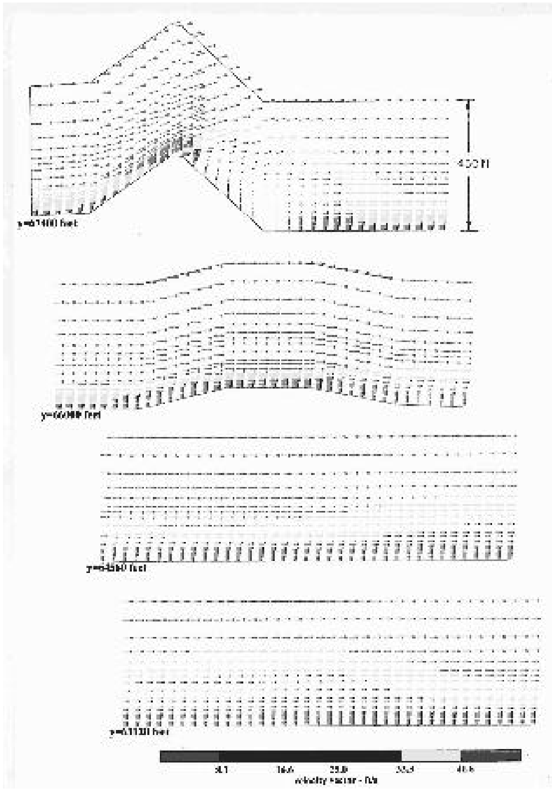

Figure 15 Wind Field Data Graphics from Weather Forecasts and Digital Terrain Database

CONCLUDING REMARKS

Optimal results require continuing to dedicate substantial trainee preparation in the classroom, as well as some at the simulator before starting a training run. Instructors need to learn to carefully select and pace training challenges, assess performance during the simulation, and use the simulator-provided post-run tools to provide a critique through a dialog with the trainee. The instructional goal is to optimally develop a useful positive transfer of skills training and self confidence within the tight time limits of aircrew training. The success of this approach can be judged from the wide-spread adoption of simulation as an essential training technique, as well as from the very positive assessments of this concept by instructors and students.

REFERENCES

1. Hogue, Jeffrey R., Johnson, Walter A., Allen, R. Wade, Pierce, Dave, *A Smokejumpers' Parachute Maneuvering Training Simulator,* AIAA-91-0829, American Institute of Aeronautics and Astronautics 11th Aerodynamic Decelerator Systems Technology Conference, San Diego, California, April 9-11, 1991

2. Hogue, Jeffrey R., Johnson, Walter A., Allen, R. Wade, Pierce, Dave, *Parachute Canopy Control and Guidance Training Requirements and Methodology*, AIAA-93-1255, RAes/AIAA 12th Aerodynamic Decelerator Systems Technology Conference, 10-13 May 1993, London UK

3. Hogue, Jeffrey R., R. Wade Allen, Marion K Hogue, Steve Markham, Arvid Harmsen, *Teaching Emergency Ejection and Egress Parachuting with Virtual Reality Simulation,* 39th Annual SAFE Association Symposium, 28 September 2002 to 3 October 2002, Jacksonville Florida.

4. Hogue, Jeffrey R., Frederick G. Anderson, Cecy A. Pelz, R. Wade Allen, Steve Markham, Arvid Harmsen, *Parachute Simulation Enhancements for Post-Ejection/Egress Training*, 36th Annual SAFE Symposium, September 14-16, 1998, Phoenix, AZ.

5. Hogue, Jeffrey R., Jerry MacDonald, Steve Markham, Arvid Harmsen, *Expanding the Role of Virtual Reality Simulation,* Parachute Industry Association Symposium 2003, 26-31 January 2003, Jacksonville Florida.