THE FORMATION FLIGHT TRAINER:

AN APPLICATION OF SIMULATED TEHCNIQUES

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This paper describes the development of the first jet formation flight trainer. This trainer, which utilizes a digital computer, a low-cost wide-angle visual scene generator, and a TV system including raster-shrinking techniques for ranging, simulates the Air Force T-38 jet trainer aircraft. The concept of the formation flight trainer (FFT), which originated at AFHRL/FT, Williams AFB, Ariz., is traced from its inception through its evolution to a practical form by means of an R&D contract to Goodyear Aerospace Corporation, Akron, Ohio. Further development, fabrication, and installation under a subsequent contract to Goodyear Aerospace are presented. In conclusion, the AFHRL/FT training effectiveness testing using actual pilot trainees is described along with resultant data and conclusions.

1. INTRODUCTION

This paper describes the concept and design of the formation flight trainer now installed at the Human Research Laboratory (HRL) at Williams AFB, Ariz. The FFT was conceived as a low-cost part-task training device; its purpose is to assist in training pilots to fly their aircraft in close formation. The FFT combines TV, visual display, and digital technologies to produce an integrated package that fulfills the training requirements.

Since a visual simulation of the position and appearance of the lead aircraft is essential to performance of the task, many visual cues had to be considered and evaluated. Due to the emphasis on cost, the simulation was restricted to only that related in positive transfer of training.

The FFT hardware is described in sufficient detail to show how each major simulation problem was solved.

After installation, AFHRL/FT planned, performed, and evaluated the results of a training effectiveness test program. The program and its results are briefly described in Items 4 and 5.

2. FORMATION FLYING TASK

a. Task Description

Formation flying is one of the more difficult tasks taught during the Air Force undergraduate pilot training (UPT) program. No other task requires the pilot to maintain so precise control of his aircraft. The student is taught to forget his former instinctive caution and to fly his aircraft very close to another aircraft. Further, he must maintain this relative position throughout a variety of maneuvers. The nature of close-in formation flying imposes new demands upon the student's skills as a result of the increased stress, use of another aircraft rather than instruments or horizon for flight reference, and absolute reliance upon another aircraft for all control cues.

The UPT formation flying task is taught as a series of subtasks, each representing a maneuver or condition that can be encountered during formation flying as experienced in a real-world tactical mission. The subtasks are:

1. Level flight in fingertip position
2. Crossunders
3. Pitchout
4. Turning rejoin
5. Straight-ahead rejoin

Each maneuver requires learning a technique not familiar to the student-pilot. A description of each subtask, given below, will serve to clarify the terms and attendant techniques.

b. Fingertip Flight

The basic fingertip position is one of the fundamental formations for much of the wingman's airwork and also is the starting point of the crossunder and the pitchout. The basic fingertip-flight formation is shown in Figure 1.

During fingertip flight, relative pitch angles between the wingman and the lead aircraft are small, but there is still some vertical translation. In addition, there is a minimal amount of both longitudinal and lateral motion.

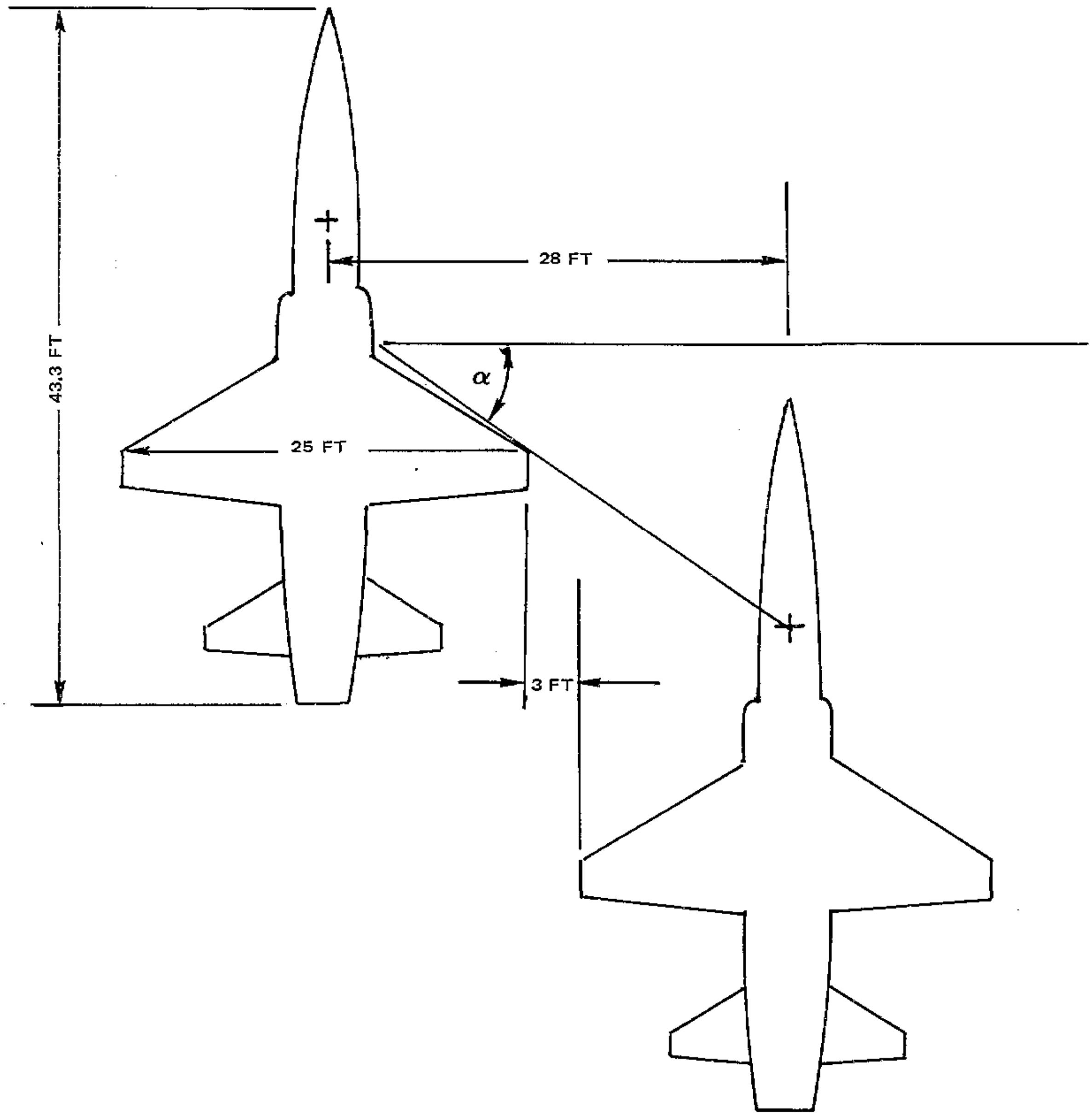

Figure 1 - Fingertip Formation

c. Crossunder

The crossunder maneuver is used by the wingman to change from one side of the lead aircraft to the other side during fingertip flight. It requires precise control of relative velocities on the part of the wingman since this maneuver is performed close to the lead aircraft. The student must demonstrate proficiency in this maneuver, which is accomplished by dropping back until longitudinal clearance is obtained, then losing about 10 to 15 feet of altitude, moving laterally to the opposite side of the lead aircraft, regaining altitude, and finally moving forward into fingertip position on the other wing.

d. Pitchout

The pitchout maneuver is used to establish an in-trail relationship between the lead aircraft and the wingman with approximately one mile separation. The maneuver is performed by a 60-degrees roll of the lead aircraft followed by a similar roll by the wingman after a fixed wait time. Since the wingman will have only the horizon and the lead aircraft as an altitude reference during the pitchout, he must concentrate on achieving precise control throughout the maneuver. As the maneuver progresses through 180 degrees of turn, the lead position moves angularly closed to the longitudinal axis of the wingman.

e. Turning Rejoin

The turning rejoin maneuver is the preferred method of joining on another aircraft. Since it is a joining maneuver, which involves initially high closure rates that must be reduced as the range decreases, the judgment of the range rate of change by the pilot is critical. The lead aircraft attains a constant 30-degree roll, which establishes a constant turn. The wingman then turns inside the predicted lead path and establishes an intercept course that is adjusted as necessary.

f. Straight-Ahead Rejoin

The straight-ahead rejoin maneuver is safer but in some ways is more difficult than the turning rejoin. The danger of a collision is not as great; however, the paucity of visual cues necessary for defining range and closure rates makes it difficult for the wingman to rejoin the lead aircraft.

3. TRAINING CONCEPT

a. Concept Description

A trainer capable of reproducing the formation-flight environment has a threefold significance. The first must be safety, since the trainer eliminates risk to human life. The second is economy, which becomes immediately apparent if the cost per hour of operating a minimum of two aircraft is compared with that of a single trainer. The third factor is time or, more properly, efficiency. With a trainer, students can begin training as soon as they are seated in the cockpit. There is no time lost in performing aircraft ground checks, taxiing, awaiting clearances, climbing to altitude, or weather.

The initial concept evolved by AFHRL/FT called for a single trainer capable of simulating the T-37 or T-38 aircraft flight characteristics over the ranges required for formation flight; the trainer was to use a rudimentary cockpit mockup, minimum cockpit instrumentation, and a computer. The overriding consideration was to be unit cost, on a production basis.

The first major task of the program was (1) to examine carefully all parameters of the formation flight student's task including aircraft performance, relative aspects and velocities of two-aircraft formation while performing desired maneuvers, and cue information available to the student and (2) to better define the trainer usage. The task examination was performed by Goodyear Aerospace Corporation, with AFHRL/FT aid, under a funded study program. During the study, it was decided that pitchout, turning rejoin, crossunder, and fingertip stationkeeping should be accorded maximum importance in developing training performance capability.

Since students receive only a very short formation flying experience in the T-37, it was decided that the trainer should be designed to simulate the T-38 aircraft, where formation flying is a major task in the training syllabus.

Training procedures are performed at a standardized altitude and airspeed. Thus, the corresponding trainer definitions are for a standard altitude of FL 300 (30,000 feet) and a nominal operating airspeed of 300 knots IAS.

b. Cue Evaluation

(1) Perception of Visual Space

(a) General

The stimulus conditions needed for space perception have been formalized under two subcategories: monocular and binocular (Stevens, 1951). The monocular cues - see Item (b) - relevant to formation flight are relative size, linear perspective, interposition, movement parallax, light and shade, accommodation, and aerial perspective. Binocular cues are discussed in Item (c).

(b) Monocular Cues

Relative Sizes - Distance discrimination is greatly dependent on the size of the retinal image representing the object and past learning associated with the object. In the design of a formation flight trainer, this variable can be manipulated by mechanical, optical, or electronic means. The FFT employs two of these techniques in an effort to optimize the size control inherent in each. To preserve linear perspective within a simulated distance of 300 feet from the lead aircraft, the TV camera is mechanically moved to vary image size. TV raster shrinkage is used to obtain the 20-to-1 range of image size required to simulate distances from 300 feet to one mile. Raster shrinkage is an important technique in this application because image resolution can be maintained as image size is reduced; this is possible because no fewer than approximately 20 retrace lines "paint" the object on the screen, regardless of image size. As a result, image cues (such as a vertical stabilizer) can be provided at simulated long-range distances during rejoin procedures.

Linear Perspective - The stimulus interrelationships defining this cue are determined by changes in visual angle subtended by various portions of a lead aircraft as the distances between it and ownship vary. One important consideration concerns the extent to which linear perspective must co-vary with simulated changes in range to provide efficient training. Some simulation techniques (such as mechanical adjustment of distance between a camera and a model) provide changes in image size with accompanying changes in linear perspective. Other simulations of range change (such as soom optics and electronic shrinkage circuits) provide size change with constant between-parts perspective. When a technique other than mechanical positioning of a camera relative to a three-dimensional object is used, special consideration must be given to manipulating linear perspective as a separate variable.

To obtain some indication of the linear perspective involved in the formation task, the ratio between the visual angles subtended by the horizontal tail and wing span of the lead aircraft (trail formation) have been examined. This ratio varies as a function of the distance between the two aircraft. The ratio is a maximum of 0.8641 at the 10-foot range (wing-nose to lead tailpipe) and diminishes as the distance between the two aircraft increases. The ratio decreases very little after approximately 100 feet and has a very small rate of change even as close as 45 feet. Thus, it is apparent that a visual presentation that accurately depicts (by mechanical motion) these ratios to a simulated 300-foot range is adequate to provide the perspective cues necessary.

Interposition - Interposition results when an object that overlaps another object is said to be nearer. In formation flight, the interposition of one aircraft part relative to another is important not only for depth perception but also as a parallax cue for determining a position in space for the ownship aircraft. Fortunately, a model-TV simulation system, which provides proper linear perspective at close range, provides proper interposition cues for formation flight without separate calculation.

Light and Shade - Various combinations of shadow and highlight can be interpreted in terms of varying dimension and distance. In the formation flight trainer, due to the use of a model-TV system, light and shade relationships automatically derive from illumination of the model. Because the model is programmed to provide apparent movement for both lead aircraft and ownship, it is necessary to utilize multiple light sources to prevent unrealistic shadow movement on the leadship during simulated level flight.

Aerial Perspective - As the surface detail of an object is obscured in terms of definition, contrast, or various other conditions, an individual reports the object as increasing in distance. Aerial perspective occurs in the FFT as the lead aircraft image is "painted" with fewer and fewer trace lines. The shrinkage circuitry of the TV system does, however, minimize this effect at far ranges.

(c) Binocular Cues

Convergence - Under approximately 20 yards (Stevens, 1951), the extent to which the individual's eyes are turned inward to fixate an object can be used as a distance cue. A large amount of convergence can lead to the response "nearby," while slight convergence can lead to a response "far off." The design of the FFT places a two-dimensional projection on a screen approximately 8 feet from the student. To observe the image, a constant convergence of 8 feet is required except when cockpit cues are fixated. Although fidelity of convergence would be ideally desired in a simulator, a mild convergence cue does not seriously affect the transfer capability of the trainer. A positive factor is that fingertip flight does not occur at infinity but at a distance not too far removed from the actual FFT screen distance (i.e., a screen distance of 8 feet compared to real-world close-in distances of 15 to 20 feet).

Stereoscopic Vision - When a student observes an object in three-dimensional space, the retinal image in the right eye is different from the retinal image in the left eye. This disparity of vision serves as a basis for many spatial discriminations. The FFT does not provide stereoscopic vision from a retinal disparity point of view. The wide-screen effect of the FFT display (with a 200-degree horizon and cloud-layer imagery) provides some peripheral imagery that enhances the three-dimensional illusion of the screen.

(2) Perception of Movement

(a) Field of Movement

The field of movement perception classically includes both real and apparent movement. Because the FFT simulates real movement by employing analogous servo movement, only real movement variables need be considered. In some instances of visual simulation, variables related to apparent motion become important simulation and training variables (e.g., the scintillation effect of rapid ground movement or of line edges in a computer image-generation system); such problems are not present in the FFT.

(b) Real Movement Thresholds

The earliest accepted reports on the visual threshold for lateral rate of motion across the visual field (Aubert, 1886) showed that the lower limit was 1 to 2 minutes of arc per second. Graham (1948) found a rate threshold of one-half minute of arc per second for low velocities and 100 seconds of arc per second for high velocities (in keeping with Aubert). In general, the rate thresholds of 1 to 2 minutes of arc per second have found general acceptance as design criteria.

Brown and Conklin (1954) found that with minimal detail in the comparison field the threshold is approximately 9 minutes of arc per second and that as the image in question moves toward the periphery of the retina the threshold increases. McColgin (1960) found that at a foveal angle of 9 degrees the lower limit of threshold is about 18 minutes of arc per second. In addition, if no comparison objects are available, the threshold is increased 10 to 20 times (Davson, 1962).

The exact influence of peripheral motion on the overall detection of motion in a real-world situation is difficult if not impossible to predict accurately. Since most formation flying situations allow the ownship pilot to maintain a foveal scan of the lead aircraft, use of foveal threshold figures for determining lower limits of relative motion cues between the two aircraft is a reasonable approach.

For the cue study, a threshold value of three minutes of arc per second was selected as the standard statistical reference. This figure was arrived at as a mean value between the one- to six-minute range in the literature.

c. Minimum Performance Requirements

(1) General

Defining the minimum performance requirements of an FFT required an analysis of the various maneuvers to be performed in the trainer. These maneuvers included flight in fingertip position (both left and right side), crossunders, pitchout, turning rejoin, and straight-ahead rejoin.

In establishing minimum requirements, the maneuvers were analyzed to determine worst case conditions for relative position in the ownship (student's) field of view, vertical and horizontal visual angles subtended, relative rates, and accelerations. Since positioning the lead aircraft image properly with respect to the wingman is a critical factor in trainer performance, the various maneuvers were investigated to determine both relative size and position of the lead aircraft as viewed by the wingman.

(2) Fingertip Flight

The fingertip position is the fundamental formation for much of the wingman's airwork; it also is the starting point of the crossunder and the pitchout maneuvers. Thus, it dictates a basic requirement of the display system. During fingertip flight, relative pitch angles between the wingman and the lead aircraft are small. There also is some vertical translation and some small lateral and longitudinal motion.

(3) Crossunder

The crossunder maneuver is used by the wingman to change from one side of the lead aircraft to the other side during fingertip flight. The wingman's view of the lead aircraft during a crossunder encompasses a left fingertip view, a rear view, a right fingertip view, and the visual movements associated with the entire transition. Almost the entire field of the display system (200-degree horizontal) is used during this maneuver.

(4) Pitchout

The pitchout maneuver is used to establish an in-trail relationship between the lead aircraft and the wingman with approximately one mile separation. Since the wingman has only the horizon and the lead aircraft as an altitude reference during the pitchout, the trainer must display the lead aircraft throughout all or at least most of the maneuver.

(5) Turning Rejoin

The turning rejoin maneuver is the preferred method of joining on another aircraft. The size and position of the lead aircraft in relation to the wingman's field of view during the turning rejoin do not test the display system as severely as the fingertip and crossunder maneuvers do.

(6) Straight-Ahead Rejoin

The lack of visual cues necessary for defining range and closure rates makes the straight-ahead rejoin maneuver difficult. The major trainer problem is maintaining lead aircraft cue visibility at range.

(7) Minimum and Maximum Relative Velocities

It was stated that three arc minutes per second of angular rate would be a reasonable statistical minimum threshold value for relative angular velocities between the lead aircraft and the wingman. During actual formation flight, minimum velocities occur during fingertip formation and crossunders, where the wingman is trying either to stop all relative motion and maintain a constant position relative to the lead aircraft, or to control the relative velocities precisely in order to fly a distinct path relative to the lead aircraft.

Figure 1 shows the positions of the two aircraft in fingertip formation. Assuming an angular rate of 3 minutes of arc per second, after 1 second the bearing angle, alpha, is now 34 degrees 57 minutes instead of 35 degrees (assuming the wingman is moving longitudinally forward relative to the lead). Resolving this angular rate to a lineal rate at fingertip ranges results in a relative velocity of 0.03 feet per second. At this rate, it would take the wingman 33-1/3 seconds to fly forward 1 foot relative to the lead aircraft.

The minimum angular perceptual rate translates into very small real-world linear velocities. All flight in fingertip formation and crossunders is in the gantry mode of operation. The minimum rate must be within the capabilities of the gantry servosystem. A good quality rate servo provides a 1000-to-1 performance range. If the minimum rate is 0.03 feet per second, the maximum rate capability of the servosystem will be 30 feet per second (17.8 knots TAS). Thus, by providing the minimum visual rate, the maximum rate within the gantry mode is restricted.

4. HARDWARE

a. General

The formation flying trainer is intended to provide, in a ground-based environment, the minimum sensory cues necessary to simulate successfully the formation flight environment. The student pilot, occupying the student station, is provided with a control stick, throttle quadrant, rudder pedals, and an airspeed indicator (ASI) to fly a simulated wingman's position in relation to a wide-angle view of a lead aircraft. An instructor pilot (IP) can operate the trainer from any desired position by means of a portable control.

The trainer basically is an unprogrammed simulation device in that both the lead and wingman's (student's) aircraft can continue to fly on any heading and with any relative separation - from collision range to a limit of one nautical mile - for an indefinite period. Thus, there are no artificial boundaries to be observed during a training mission. The background scene presented to the student consists of a distant horizon with occasionally resolvable cloud buildup, a light-toned low-altitude undercast, and a blue skyscape. When the student rolls or pitches his aircraft or changes heading, this background scene responds realistically.

The lead aircraft image, which is generated separately, will appear in any appropriate area of the background scene. The IP, by means of his portable control, can cause the lead aircraft to perform pitchout maneuvers in either direction, 30-degree turns for rejoin, and random altitude and bank variations during the turns or during level flight. He also can insert initial conditions corresponding to fingertip, one-mile in trail, or constant 30-degree turning rejoin. In addition to these basic capabilities, the student also can practice route, echelon, close trail, and extended trail formation during level flight, level flight with altitude and bank variations, turning maneuvers, or turning maneuvers with altitude and bank variations.

For demonstration and student familiarization, the instructor can command both aircraft to perform together either a crossunder or a standard turning rejoin in either direction.

If at any time during normal student control of the wingman's aircraft the combination of separation and closure rate becomes hazardous, the IP is notified by a warning light located on his portable panel. If the student allows the condition to deteriorate so that collision avoidance is impossible, the visual scene is immediately frozen and a red crash indicator on the IP's panel is illuminated. At the same time, the student is notified of his error by means of a red color display projected into his field of view.

b. Physical Description

(1) General

Major components of the FFT system (see Figure 2) are imagery presentation unit (IPU), student station (SS), computer/video unit (CVU), and imagery generation unit (IGU). These major components are described in Items (2) through (5), below.

The IPU presents the complete dynamic scene to the student seated in the simulated cockpit (student station). The lead-aircraft television (TV) image of this scene is generated at the IGU; a horizon, sky, and undercast are generated optically at the IPU support structure above the SS. The entire system is controlled by a digital minicomputer located in the CVU. A portable control indicator is connected by a flexible cable to the CVU by which the IP or the student can control the system mode from any convenient location.

The IP can freeze the dynamic scene at any time. He can insert any of three initial flight conditions before starting the system and can select any of seven programmed lead aircraft maneuvers. Finally, he can command the system to perform either of two types of completely programmed demonstration exercises that control both the lead aircraft and the student's aircraft.

Figure 3 shows the system electrical interconnections. The CVU receives system input 60-Hertz power and distributes it to the rest of the system through appropriate controls and protective devices. Additional conductors route 60-Hertz power to the utility outlets. The total FFT electrical requirement is approximately 7 kilowatts of 120/208 volt, 60-Hertz, 3-phase power.

(2) Imagery Presentation Unit

(a) General

The IPU includes the screen assembly and the support structure assembly

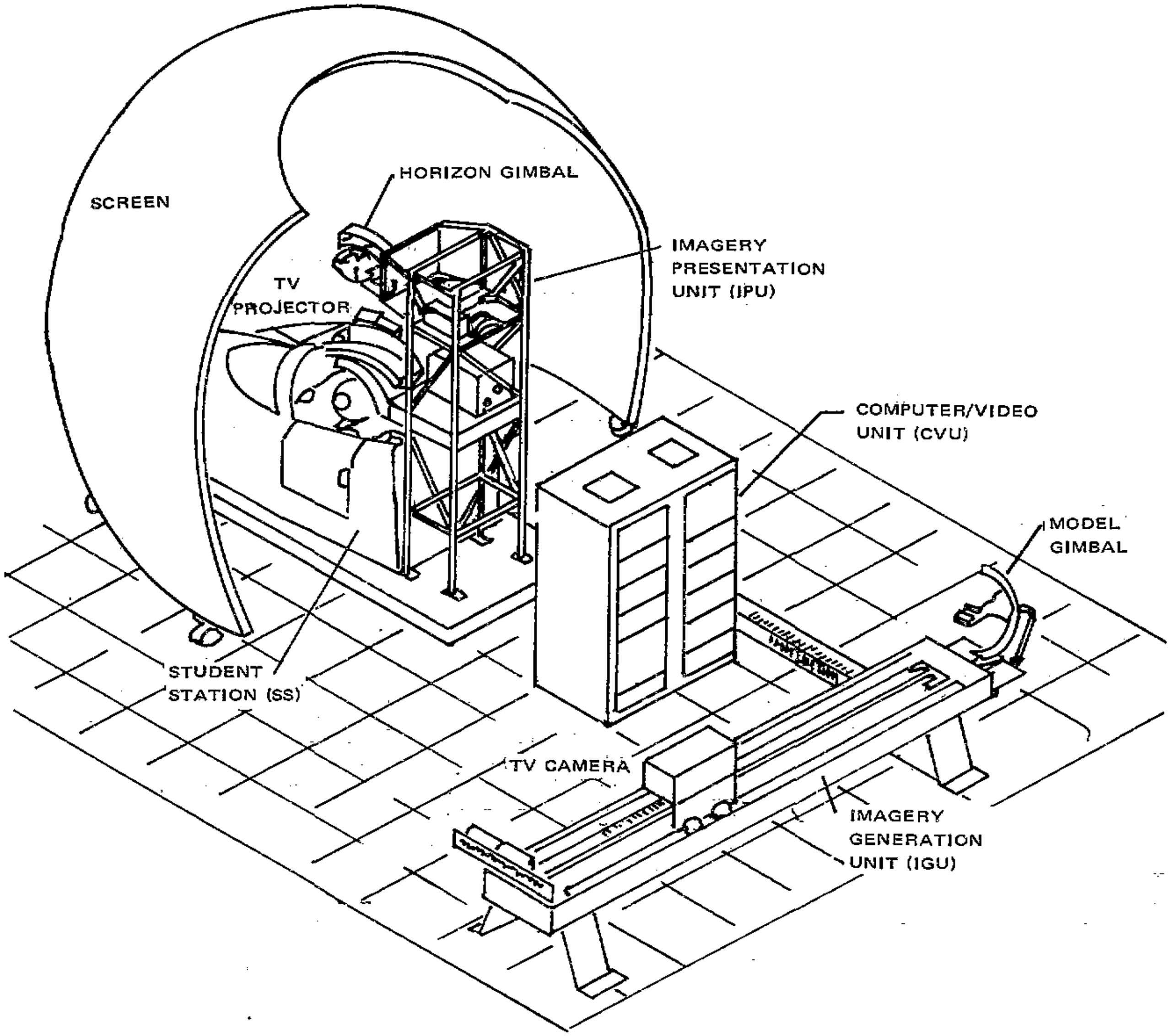

Figure 2 - FFT System

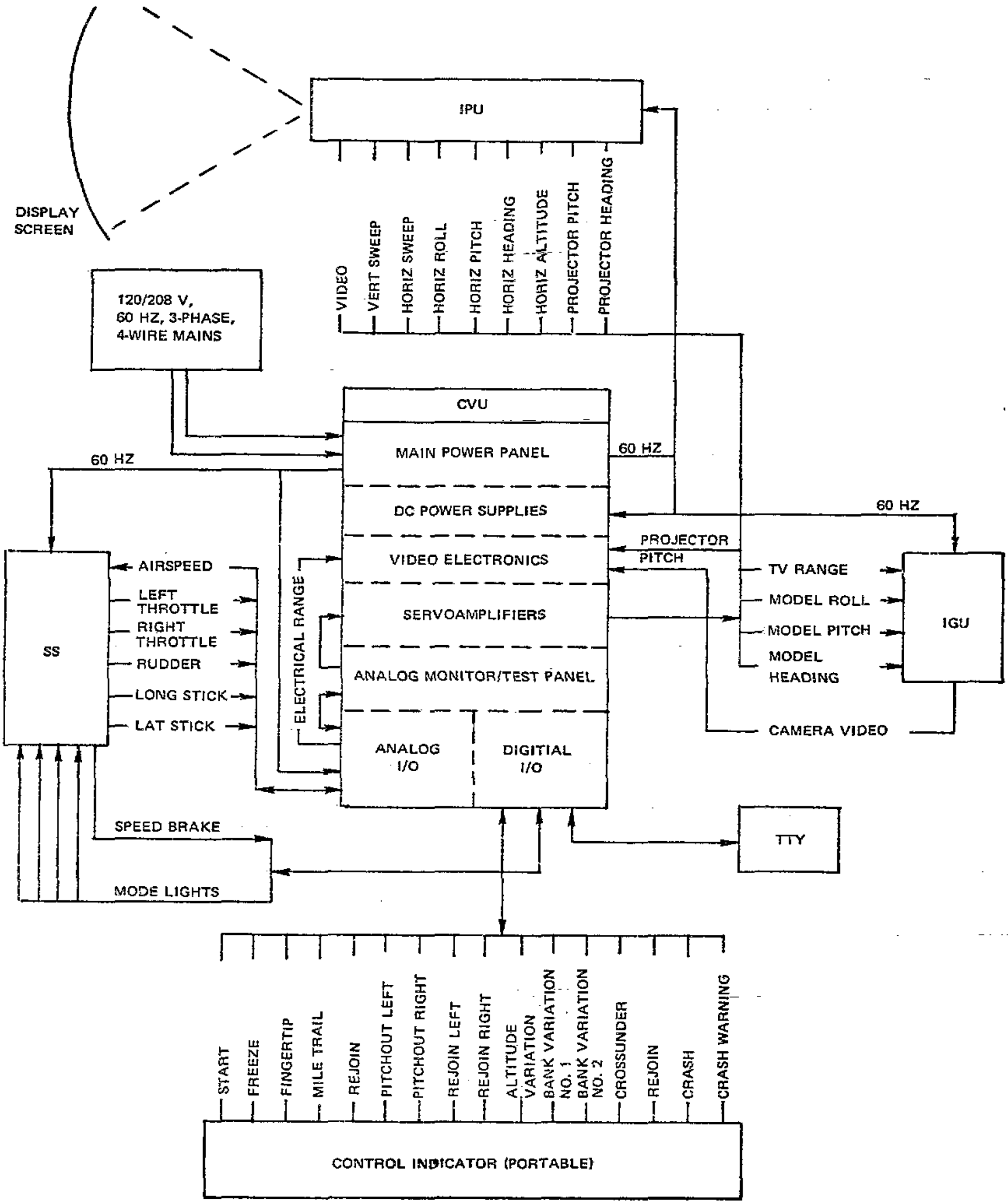

Figure 3 - System Electrical Interconnections

and subsystems mounted thereon. The screen consists of five vertically oriented 88-inch-radius spherical sections arranged side by side and fastened to subtend an aggregate 200-degree horizontal by 90-degree vertical field of view at the student's eyes. The support structure, together with the SS, is mounted on a base assembly. The horizon generator assembly, projector gimbal assembly, projector control unit, projector horizontal deflection amplifier, and horizon generator illumination controller are mounted on the support structure.

(b) Horizon Generator Assembly

This assembly is a servocontrolled four-axis gimbal system whose load, on the inner gimbal, is an internally illuminated hemispherical blue transparency. Two inner gimbal drives simulate wingman (student) heading change and horizon altitude compensation; the middle gimbal drive simulates wingman pitch; and the outer gimbal simulates wingman roll. The point source (lamp) projects the transparency information directly onto the display screen in accordance with the student's instantaneous simulated attitude.

The altitude axis is used to compensate for an apparent altitude error that results from off-axis projection of the horizon. This error would occur, if uncompensated, with gimbal roll positions other than zero or near-zero degrees.

Table I gives the performance of the horizon generator gimbal axes.

TABLE I - HORIZON GENERATOR GIMBAL AXES PERFORMANCE

Item	Pitch	Roll	Heading	Altitude
Max travel	±20 deg	±80 deg	Continuous	0.3 in.
Max velocity	60 deg/sec	60 deg/sec	60 deg/sec	0.2 in./sec
Min velocity	0.25 deg/sec	0.25 deg/sec	0.25 deg/sec	0.001 in./sec
Velocity ratio	200 to 1	200 to 1	200 to 1	200 to 1
Resolution	0.01 deg	0.01 deg	0.01 deg	0.1% full scale
Linearity	±0.06 deg	±0.08 deg	±0.03 deg	0.1% full scale

(c) Projector Gimbal Assembly

The TV projector gimbal assembly uses a two-axis gimbal system to project optically and to position the lead aircraft TV image laterally and vertically within the student's field of view. The lead aircraft image range from less than fingertip formation range out to 304 real world feet is mechanically simulated by camera-model spacing. Over this distance, the apparent lead aircraft projected field of view decreases as the lead aircraft image size decreases. Beyond the 304-foot range, the projector TV raster is itself reduced in size to simulate greater ranges to a maximum of one nautical mile. The lead aircraft image is vertically positioned by a combination of the projector pitch servoaxis motion and vertical translation of the projector cathode ray tube (CRT) raster.

The projector gimbals position the projector in heading and pitch in response to commands generated by the minicomputer. The entire assembly is bolted to a rigid box structure that is integral with the support structure of the IPU. Projector heading and pitch servo performance are given in Table II.

TABLE II - PROJECTOR HEADING AND PITCH SERVO PERFORMANCE

Item	Heading	Pitch
Max travel (deg)	±160	-25 to +42
Max velocity (deg/sec)	60	60
Min velocity (deg/sec)	0.1	0.1
Velocity ratio	600 to 1	600 to 1
Resolution (deg)	0.01	0.01
Linearity (deg)	±0.02	±0.02

(d) Support Structure

The support structure supports the projector gimbal assembly and the horizon generator assembly. This structure consists of welded square aluminum tubing of sufficient wall thickness to provide the required structural rigidity to act against any loads imparted by the accelerations of the various axes of the two gimbal assemblies.

The support structure is bolted to a base assembly that is common to the student station. The projector control unit, the projector horizontal deflection amplifier, and the horizon generator light control are mounted on the support structure. The support structure is provided with cabling that carries servocontrol signals, servomotor power, TV video, and horizon generator light power.

(e) Screen Assembly

The screen assembly is an 88-inch-radius concave spherical surface whose geometric center is located at the student's eye. The screen is a five-piece assembly of vertical concave sections that are bolted together at the rear and supported from below by five adjustable floor mounts. The screen proper consists of a fiberglass-reinforced structure whose surface has been treated to increase photometric gain. Overall thickness is approximately three-eighths of an inch. A 200 degree ring structure is bolted to the top of the screen assembly for rigidity.

(3) Student Station

The student station consists of a cockpit base, cockpit enclosure, seat, rudder pedal assembly, control stick assembly, throttle quadrant assembly, consoles, and instrument panel. The cockpit base is a single piece of BONDOLITE,[a] which consists of end-cut balsa wood sandwiched between one-sixteenth of an inch aluminum sheeting. The cockpit enclosure consists of a fiberglass shell that attaches to the base. The windscreen and canopy do not have glazing. A hinged door is located on the port side of the enclosure for student access. The seat simulates the general form of a T-38 ejection seat. To maximize the IP's view of the display, there is no headrest on the seat. The seat can be adjusted electrically in height to suit the individual student. The control stick and the rudder pedals act and feel like those in the T-38. Both the longitudinal and

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[a]TM, Goodyear Aerospace Corporation, Akron, Ohio.

lateral modes of the trim switch are activated, thus allowing repositioning of the stick null point to correct for nose-up, nose-down, wing-up, and wing-down trim changes. The throttle quadrant assembly consists of two throttle levers and a three-position speed brake switch, all of which are functional. The instrument panel has one active instrument attached, the airspeed indicator (ASI). The instrument panel is the same general shape as the panel in the actual aircraft.

(4) Computer/Video Unit

(a) General

The CVU includes the 16-bit digital minicomputer system, special video electronics, servoelectronics, main power panel, analog monitor/test panel, dc power supplies, model illumination control, teletype, and portable control indicator. The IP's control indicator is attached to the CVU cabinet through a flexible cable. The teletype is located on its own stand adjacent to the front of the CVU and also connects to the CVU cabinet.

(b) Computer

The basic minicomputer is contained in a single basket that includes an 8192-word memory and buffered input/output (I/O) controllers. The analog I/O system is contained in an additional basket. The minicomputer I/O signals include servodrive signals plus analog and digital signals for system control.

(c) Video Electronics

The video electronics circuitry is designed to fulfill raster and video control requirements of the FFT system. The video signal from the camera located in the IGU plus TV range and projector pitch information from the minicomputer are used as inputs. Raster shaping, magnification and intensity control, and position control are varied in proportion to these inputs to provide the appropriate lead aircraft image on the display screen.

(d) Servo Electronics

All electronics for the 10 servo axes are contained in the CVU. Only the servomotors, gear trains, tachometers, and feedback potentiometers are located at the gimbals.

(e) Control Indicator

The control indicator consists of a portable metal case with attached control panel and carrying handle. The panel contains 16 lights and 14 switches to control all normal training operations. Integral with each switch is an indicator light that illuminates under minicomputer control to indicate either an acknowledgment from the minicomputer of the input or to inform the IP of the present operating mode of the trainer. Five categories of switch/lights are used: CONTROL, RESET, LEADING AIRCRAFT CONTROL, DEMONSTRATIONS, and ERRORS.

The CONTROL switch group has two switches, START and FREEZE, that control mode. The RESET switch group controls the initial conditions: FINGERTIP, MILE TRAIL, and REJOIN.

The LEADING AIRCRAFT CONTROL switch group controls the flight of the leading aircraft only. This group consists of PITCHOUT LEFT and PITCHOUT RIGHT control switches; the REJOIN LEFT and REJOIN RIGHT switches; ALTITUDE VARIATION switch; and the BANK VARIATION #1 and #2 switches.

Two demonstrations are provided through the DEMONSTRATION switch group, CROSSUNDER and REJOIN.

Two ERROR lights are provided, the CRASH WARNING light and the CRASH light.

(5) Imagery Generation Unit

(a) General

The IGU consists of the camera assembly, model gimbal assembly, support legs, and model illumination system.

(b) Camera Assembly

The camera assembly includes the TV camera and mechanical range system. It is used to simulate scaled physical range separations up to 304 real-world feet from the lead aircraft. The camera carriage assembly, which rides on roundways, is driven by the servomotor. Near the maximum range of travel, electronic ranging is initiated automatically by the minicomputer so that, as the carriage slows near the end of its travel, electronic ranging (TV raster minification) makes up the necessary rate difference and ultimately takes over the ranging simulation completely. Performance of the range servo is given below:

1. Full travel - 86.8 in.
2. Maximum velocity - 10 in./sec
3. Minimum velocity - 0.009 in./sec
4. Scale - 1 to 39.3
5. Velocity ratio - 1111 to 1
6. Resolution - 0.01 in.
7. Linearity - 0.05 in.

(c) Model Gimbal Assembly

This assembly is similar to the horizon generator assembly. Instead of a hemispherical transparency, the inner gimbal load is an accurately scaled model of the T-38 aircraft. All three axes of rotation pass through the aircraft center of gravity to simulate actual aircraft angular motions. Aircraft roll motion is attained by means of a shaft connected directly to the nose of the model; this is the inner gimbal. The middle gimbal is pitch, and the outer gimbal is heading. The required motions of these axes are computed relative to a constantly changing reference: the line-of-sight (LOS) vector from the student's eye to the lead aircraft in the real world.

Aircraft pitch motion is attained by means of a curved rack whose radius centers at the rotational center of the aircraft model. The pitch motor, located on the pitch carriage, drives it along the rack. The pitch rack and its load ride on the heading gimbal assembly.

The performance characteristics of the model gimbal assembly are given in Table III.

(d) Model Illumination System

The model illumination system consists of six 500-watt incandescent spotlamps on independent mounts. Each lamp is adjustable in height, direction, and elevation angle.

TABLE III - MODEL GIMBAL ASSEMBLY PERFORMANCE

Item	Roll	Pitch	Heading
Travel (deg)	±170	±65	±135
Max velocity (deg/sec)	80	60	60
Min velocity (deg/sec)	0.4	0.25	0.25
Velocity ratio	200 to 1	200 to 1	200 to 1
Resolution (deg)	0.01	0.01	0.01
Linearity (deg)	±0.02	±0.04	±0.06

5. TRAINING EFFECTIVENESS TEST PROGRAM

a. General

As of this writing, the data have been collected and analyzed from only the first experimental group of subjects (N=36). All the subjects (Ss) were student pilots randomly selected from Class 73-08 of the of the UPT program at Williams AFB, Ariz. An experimental second group from Class 73-09 has completed training, but analysis of these data is not yet complete.

b. Objective

In collaboration with Air Training Command (ATC), AFHRL/FT decided to perform the first experiment as a demonstration of the minimum cost effectiveness of the FFT in the UPT program. Based on projected unit costs of future FFT's, pilot production rates, and estimated training costs, it was determined that cost effectiveness would be achieved if the FFT could reduce formation flight training time by at least two hours.

A team comprised of AFHRL/FT researchers and experienced ATC instructor pilots analyzed the wingman formation flying tasks from the T-38 syllabus for those tasks that could be addressed in FFT. From this analysis and from pretests, the team determined that five 50-minute sorties in the FFT would have the equivalent training value of two 1.3-hour sorties in the aircraft. This hypothesis, then, dictated the objectives of the first experiment.

c. Experimental Design

Prior to entering the formation phase of T-38 training, the 36 students selected were divided into three equivalent groups of 12, designated Groups A, B, and C (see Table IV). Each group received different training and the results were compared, with Group A being the experimental group, Groups B and C the comparison groups. At the end of the experimental procedures, each group was tested using the performance measurement standards described below. Briefly, each group received an orientation ride in the aircraft, experimental rides in the FFT or the aircraft, and a final data collection ride in the aircraft except Group B, which received only the orientation ride and the data collection ride.

TABLE IV - EXPERIMENTAL PARADIGM

Experimental group	Training flight		
A	5 FFT	5101*	Data collection
B	5101	. . .	
C	5101	2 T-38	

*ATC syllabus designation for first formation orientation ride.

From this design, it can be seen that comparisons are made between Ss with ground training in the FFT (Group A), Ss with training in the aircraft (Group C), and Ss with no training (Group B).

d. Procedure

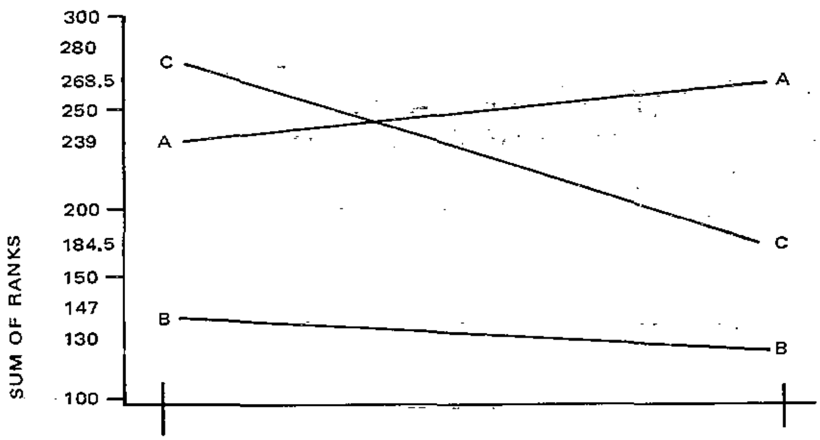
Following selection and assignment to an experimental group, students were assigned to instructor pilots trained by AFHRL/FT in the experimental design and data collection. The three groups were trained concurrently; where possible, each test group completed its particular procedure on consecutive days. In several instances, continuity was interrupted by nonflying days due to weather, but on the whole the desired schedule was maintained. Data collection flights were not flown by the same IP's who trained the Ss.

e. Performance Measurement

The standard ATC four-point subjective grading scale (unable, fair, good, excellent) was expanded into a 12-point scale that expanded the individual categories. Instructor pilots were trained to use the expanded scale for the data collection ride.

6. RESULTS

Standard nonparametric statistical treatment of the data gave results that supported the original hypothesis. There was no significant difference ($P<0.01$) between Group A and Group C, the two groups that had received training in the FFT or the aircraft. However, there was a significant difference ($P<0.05$) for Group B data when compared with each of the other two groups (see Figure 4).



DATA RIDE

A VS B	$P<0.05$
A VS C	$P<0.025$
B VS C	$P<0.5$

TWO-SHIP CHECK

A VS B	$P<0.001$
A VS C	$P<0.1$
B VS C	$P<0.2$

Figure 4 - Test Results

In summary, the data indicate that performance by the FFT-trained group is equal to the performance of the aircraft-trained group and in some respects better. For instance, the Group A performance in a straight-ahead rejoin maneuver was better than Group C performance on the same maneuver; however, on the crossunder maneuver, Group C performance was better.

In conclusion, data from this first experiment indicate that the FFT can be effectively used in the early acquisition of formation flying skills. The degree to which this part-task trainer can be used to supplement or replace formation flight hours will be the subject of further experimentation by the Human Resources Laboratory at Williams Air Force Base.

ABOUT THE AUTHORS

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